VENUE

2003 A.S.H.R.A.E. WINTER MEETING
CHICAGO, USA

TITLE

SECONDARY REFRIGERATION EUROPEAN EXPERIENCES

AUTHOR

Zafer URE M.Sc., MCIBSE, MASHRAE, M.Inst.R
Environmental Process Systems Limited
Unit 32, Mere View Industrial Estate,
Yaxley, Cambridgeshire, PE7 3HS, UNITED KINGDOM
Tel: +44-(0)-1733 243400, Fax: +44-(0)-1733 243344,
e-mail: z.ure@epsltd.co.uk, www.epsltd.co.uk

Environmental concerns over Ozone Depletion and Global Warming have prompted the search for alternative refrigeration technologies in order to minimise refrigerant usage. Secondary Refrigeration can be considered as one of the options available to designers to overcome this global problem.

In many cooling applications, heat is transferred to a Secondary Refrigerant, which can be any fluid cooled by a primary refrigerant and used to transfer heat without a phase change. These liquids are also called Brines, Secondary Coolants and Heat Transfer Fluids.

Secondary refrigerants generally consist of Anti-freeze Solution, Corrosion Inhibitor(s) and Biocides where applicable to satisfy the temperature and application range.

A wide range of Glycol, Potassium Acetate and Potassium Formate based energy efficient secondary refrigerants has been applied for both chilled and frozen food as well as air conditioning applications.

This paper aims to convey the experiences gained from European installations and operational problems from these installations from design to commissioning stages and lessons learnt from these applications. The important design lessons and behaviour of Secondary Refrigerants for the real applications will be presented in a form that will help practising engineers, contractors and consultants to develop an effective and efficient Secondary Refrigeration cooling system.

1.0) BACKGROUND

The recent environmental concerns (1) over CFCs, HCFCs and, most recently, over HFC refrigerants, have forced designers to explore alternatives, among them indirect solutions.

In many refrigeration applications, heat is transferred to a secondary fluid, which can be any liquid cooled by the primary refrigerant and then used to transfer heat without changing state.

These fluids are also known as heat transfer fluids, brines, or secondary refrigerants (2). They are also found in many new applications and in low temperature refrigeration, enabling the use of environmentally friendly primary refrigerants such as ammonia and hydrocarbons.

Indirect refrigeration systems can have some significant potential advantages over direct refrigeration systems. In an indirect system, for example, it is possible to design and manufacture factory-built compact refrigeration units with an extremely small primary refrigerant charge.

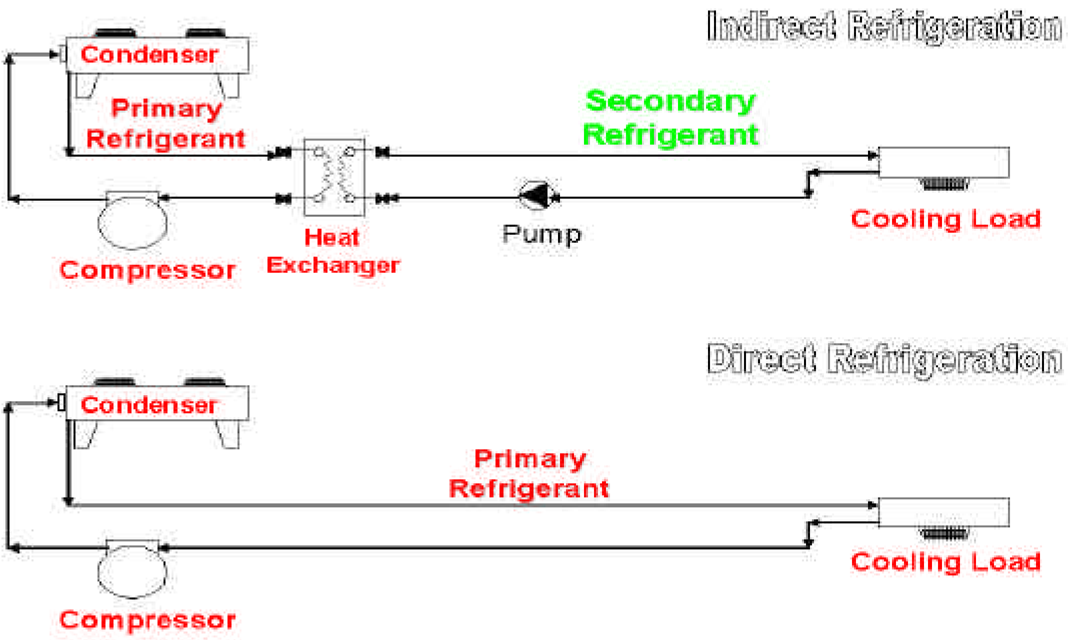

Figure 1.1- Direct Vs Indirect Refrigeration System

However, an indirect system with a secondary refrigerant circuit means an extra cost for the pump and heat exchanger with an added temperature difference. If a secondary refrigeration system is not designed correctly, this may lead to higher total energy consumption in comparison with a direct system.

Therefore, it is vital to choose the right secondary refrigerant for the application in order to provide an economical and energy efficient system.

In principle, water is an excellent secondary refrigerant for mainly air conditioning and many other applications for temperatures down to around +3°C (37.4 °F). The main problem, however, is to find suitable fluids for chilling and freezing applications below the water freezing point of 0°C (32 °F).

2.0- SECONDARY REFRIGERANT OPTIONS

There are several fundamental requirements (3) that any secondary refrigeration must satisfy:

- Low Viscosity
- High Specific Heat
- Good Thermal Conductivity
- Good Chemical Corrosion Inhibitor
- Chemically Stable, No Separation or Degrading
- Non-Toxic
- Non-Flammable
- Food Grade for Food Refrigeration

Furthermore, any secondary refrigerant must be compatible with commonly used materials in terms of corrosion and long-term stability. It is also vital to satisfy health and safety and environmental requirements.
The freezing point can be considered as the starting point to choose a secondary refrigerant, and it should be below the operating temperature of the system with a comfortable safety margin.

The physical properties of secondary refrigerants are also very important. It is essential to find the right or balance between the viscosity, specific heat and thermal conductivity for optimum design efficiency.

Some of the most important parameters are corrosivity, environmental pollution, toxicity, and flammability, handling security and cost levels.

2.1- Secondary Refrigerant Options

The commercially available secondary refrigerants can be divided into two categories, namely aqueous (i.e. water based) and non-aqueous solutions (4).

Aqueous solutions are mixtures of various salts and water. The mixtures of such compounds as magnesium and calcium chloride have been used extensively since the early days of refrigeration.

More recently, mixtures of potassium acetate and potassium formate have been introduced to the market to overcome some of the corrosion and physical property problems of the old mixtures, in particular for low temperature applications.

Non-aqueous liquids are marketed under many different brand names and they have comparatively poor heat transfer ability and transport capability. They are also quite expensive and have practical application problems in terms of cross contamination, corrosion and operating pressures.

2.2- Properties

Freezing point can be described as the crystal formation point whereby the liquid turns from fluid to solid. It is common practice to choose a fluid with the freezing point at least 5 -10 C below the system operating temperature When comparing different secondary refrigerants it is vital to evaluate the combination of freezing point, viscosity, specific heat and thermal conductivity as a whole. Other thermal properties are the boiling point, thermal volume expansion and the surface tension.

A low boiling point can be a problem for applications where the operating temperature of the liquid may exceed the boiling point even at relatively low temperatures when exposed to atmospheric air, as in the case of open systems.

Surface tension can be described as the force per unit length that strives to keep the surface as small as possible. A low surface tension may increase the tendency of the solution to leak out; it may also increase the risk of foaming within the system and result in pump cavitation.

Density is based on the concentration levels and is considered one of the easiest and main ways of checking the concentration level and effectively keeping an eye on the condition of the fluid.

Viscosity is a very important factor for sizing the pipes and pumps. Hence, viscosity should be acceptable at the operating temperature of the secondary refrigerant for an economical installation both for the initial installation and day to day running cost point of views.

Specific heat capacity should be as high as possible in order to reduce the flow rate needed for a given cooling load. The lower flow rate leads to smaller volume flow requirement and consequently, smaller pipes and pumps.

Thermal conductivity should be as high as possible in order to provide a good heat transfer efficiency and there by decreasing the temperature difference between the liquid and tube wall.

Thermal volume expansion is also an important element for the application. It dictates the size of the expansion vessel for the system.

Most commonly used secondary refrigerants (5) are listed in tables 2.2.1 and 2.2.2.

Description	Concentration Freezing Temperature		
	-15ºC	-30ºC	-40ºC
	5 ºF	-22ºF	-40ºF
Ethylene Glycol / Water	30.5	45.4	52.8
Propylene Glycol / Water	33.0	48.0	54.0
Ethyl Alcohol / Water	24.5	40.9	53.1
Methyl Alcohol / Water	20.0	33.6	41.0
Glycerol / Water	39.5	56.0	63.0
Ammonia / Water	10.8	17.7	21.1
Potassium Carbonate / Water	27.0	36.6	-
Calcium Chloride / Water	17.9	25.4	28.3
Magnesium Chloride / Water	14.0	20.5	-
Sodium Chloride / Water	18.8	-	-
Potassium Acetate / Water	24.0	34.0	39.0
Potassium Formate / Water	24.0	36.0	41.0

Table 2.2.1- Aqueous Secondary Refrigerant Solutions

The majority of aqueous solutions are based on salt mixtures and they are relatively corrosive by nature. Therefore, it is vital to stabilise these solutions by means of corrosion inhibitor packages and chemical stabilisers for a long-term use.
Some low concentration solutions as in the case of ice slurry and anti-freeze applications will also require the addition of biocides to prevent microbiological fouling. It is important to choose a secondary refrigerant with a long track record for the intended temperature range.

Description	Concentration Freezing Temperature ºC	Concentration Freezing Temperature ºF
Diethylbenzene Mixtures	-73.0	-99.4
Synthetic Hydrocarbon Mixture	-85.0	-121
Hydrofluoroether	-43.0	-45.4
Polydimethylsiloxane 1	-100.0	-148
Polydimethylsiloxane 2	-93.0	-135.4
Citrus Oil Solution	-96.0	-140.8
Carbon Dioxide	-56.7	-70.06
Alkylated Benzene	-148.0	-234.4
Alkyl Substituted Aromatic	-103.5	-154.3
Ester Based Solutions	-62.0	-79.6
Aliphatic Hydrocarbon	-85.0	-121

Table 2.2.2 - Non-aqueous secondary refrigerant options

3.0- Secondary Refrigeration System Design Issues

There are two common techniques applied to utilise secondary heat transfer fluids, namely open and sealed systems, as illustrated in Figure 3.1.

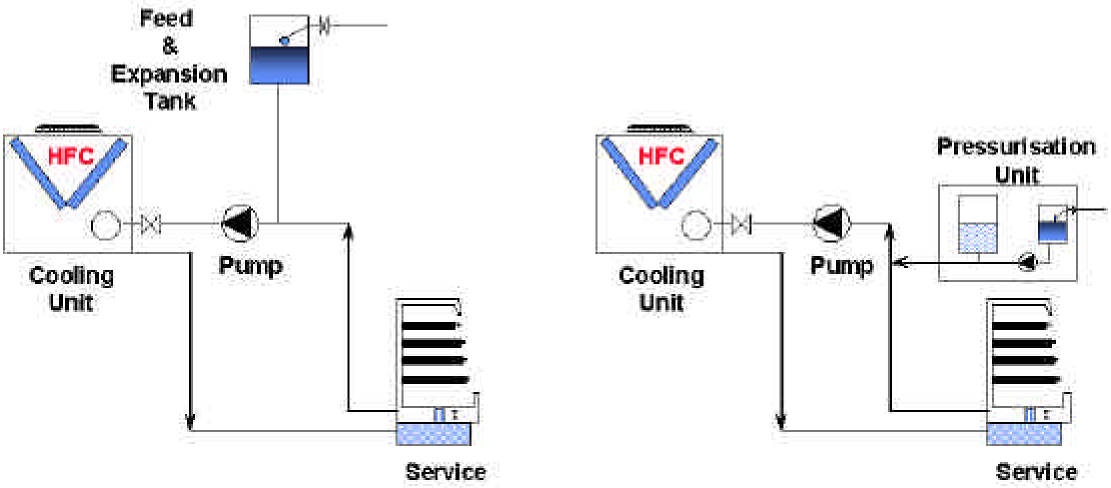

Figure 3.1- Circulation system types

Both systems are widely applied throughout the world. Some of the advantages and disadvantages are summarised in table 3.1.

	OPEN SYSTEM	SEALED SYSTEM
ADVANTAGES		
	Simple Cost Effective Design No Power Supply	Freedom of Location Air Free Operation Positive Pump Suction Protection
DISADVANTAGES		
	Air Contamination Solid Contamination Health & Safety Concerns Tank must be installed above the pump suction to match NPSH	Installation Cost Annual Maintenance Small Power Consumption

Table 3.1- Open Vs Close System Comparison

Some of the design issues related to the fluid selection and applications are as follows;

Viscosity and Specific Heat Capacity: Viscosity strongly influences the type of flow that occurs inside the heat exchanger. It also has a significant impact on the pipework pressure drop.

However, higher specific heat capacity reduces the mass flow requirement for a given cooling load with identical system circulation temperature differences. System volume flow requirement can be obtained by dividing the mass flow rate by the density.

Considering very close density values for the majority of the salt based solutions, higher specific heat capacity solution leads to smaller volume flow rates.

Low viscosity may not necessarily offer smaller pipes and less pressure drop for the system as a whole if it has a very poor specific heat capacity.

Therefore, it is vital to strike a balance between the specific heat capacity and viscosity of the fluid for the intended operating temperature range, in order to achieve optimum pipe velocities.

Heat Transfer: The Reynolds number dictates the type of flow for the pipework and in return the heat transfer rate is calculated based on the flow regime.

Materials Compatibility: It is vital to check all system components' compatibility with the intended secondary refrigerants. The majority of the chloride based solutions attack metal, and both potassium acetate and potassium formate attack zinc. Hence, any material containing zinc and zinc alloys, such as galvanised surfaces, should be avoided.

Maintenance: A full maintenance programme must be incorporated as part of the design in order to ensure that the concentration level as well as the fluid corrosion protection ability is maintained throughout the useful life of the fluid.

Health and safety issues: For applications where human contact is a possibility, or for food applications, it is best to consider non-toxic fluids such as organic salts, propylene glycol and glycerol.

4.0- Applications

In many European countries designers are gradually moving towards minimum primary charge systems due to concerns over the long-term availability of HFC refrigerants which is under threat from environmental groups and some European Governments.

The risk associated with Ammonia in commercial applications is far higher than the benefits due to lack of qualified work force and therefore it still remains within the industrial environments.

Fluids like calcium chloride, ethylene and propylene glycol solutions are still the driving force for the industrial sector for mainly chilled temperature range applications but frozen temperature applications generally utilise pump circulation direct refrigeration system as a standard option.

Initially, the small scale low temperature secondary refrigeration applications started from the supermarket refrigeration application in order to minimise the expensive HFC refrigerants and partly due to pressure from Environmental groups.

Many installations have been successfully applied in many supermarket chains both in the UK and many other European countries. However, partly due to additional up front investment and partly reduction in primary HFC refrigerant cost pushed the market back to the conventional direct expansion systems with the exception of Scandinavian countries, Denmark, Germany and Switzerland.

Many large scale application found their way to mainly distribution cold stores and food factories and some of these distribution centres and food factories contain as much as 80m3 (2,825 ft3) Potassium Acetate system charge for both chilled and frozen food applications.

There is also genuine move towards replacing Propylene Glycol solutions with new Potassium Acetate and Potassium Formate based solutions for food applications. This is partly due to superior heat transfer and pressure drop characteristic and partly the reduced running costs due to lower pump power.

The benefit of new high performance Potassium Acetate based solution in comparison with Propylene Glycol applications is illustrated in Figure 4.1 for 100 kW (28.4 TR) refrigeration capacity at -8 ºC (46.4 ºF) operation.

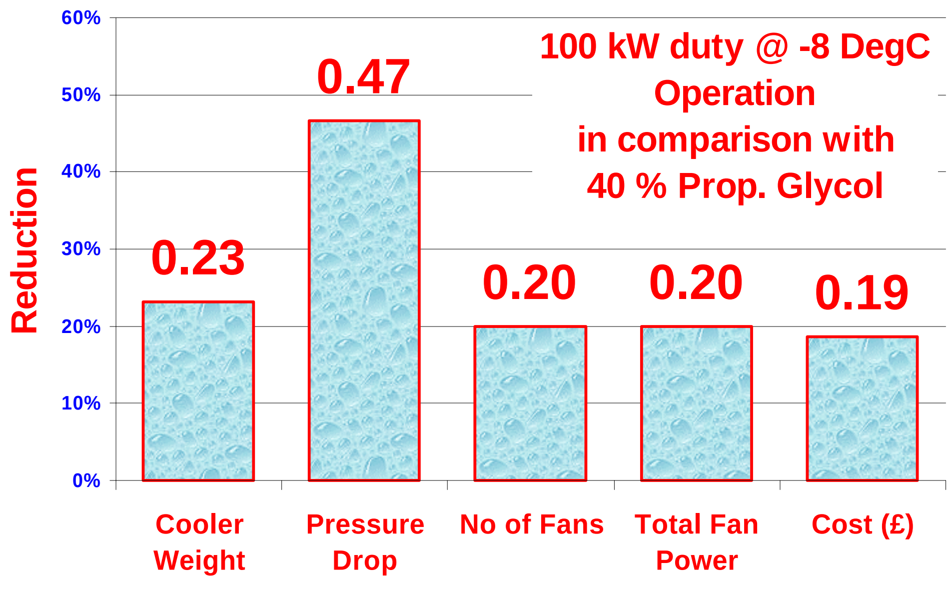

Figure 4.1- Potassium Acetate Vs Propylene Glycol Operation

Ethylene Glycol still remains the dominant secondary refrigerant due to its very good thermodynamic properties and its relative low cost for large-scale industrial applications. However, the toxicity as well as high disposal cost aspects somewhat limits its use for the larger market.

Non-aqueous solutions like Silicon Oils have been also successfully applied to supermarket refrigeration like Sainsbury, Horsham Store and many industrial applications for both high and low temperature systems. The cost to purchase and difficulty of handling any contamination restricted their use for large-scale applications.

Phase change secondary refrigeration applications like ice slurry (6) and carbon dioxide have been successfully applied for both commercial and industrial applications but they are excluded from this paper which remained to cover only heat transfer system without any change of phase i.e. solid-liquid or liquid-gas.

Despite the fact that many large scale and variety of secondary refrigeration applications it was not an easy ride in particular with the new high performance refrigerants like Potassium Formate.

4.1) - Component Failures;

The most common problem is the control valves, which are generally designed for water services in the commercial field, and they were not necessarily suitable for the sub-zero operations. In particular, the actuator failures and excessive pressure drops due to solenoid valve design created not only frequent failures but also excessive daily running cost due to excessive pump power. A number of custom-made secondary refrigeration valves complete with heated actuators and pre-moulded insulation boxes with full-bore ball valves solved this problem.

4.2) – Air;

It is vital to minimise the air contamination for a safe and reliable operation. Some sites in Europe suffered fatal failures due to excessive air, which contains moisture, and gradually this turns to ice crystals within the circuit and eventually blocking the narrow passages such as filters, valves and low velocity section of the circuits. Once the moisture turns into ice crystal form it is very difficult to get rid of it due to permanent sub-zero conditions.

Hence, many refrigeration companies started treating secondary refrigeration similar to conventional direct expansion installations and applying vacuum before the charge in order to overcome this problem. However, it is still vital to provide adequate air venting points throughout the system to eliminate the micro-bubbles which naturally comes from the water based solutions.

Any air in the system does not necessarily cause blockages but also it causes excessive corrosion problems.

4.3) - Corrosion;

The most critical components of any of heat transfer fluid are the corrosion inhibitors. If uninhibited solutions are used, a system can develop fatal corrosion problems in a surprisingly short period of time (as low as months rather than years).

The lack of inhibitor results in excessive corrosion and premature failure. This problem becomes catastrophic in the case of galvanic corrosion, which occurs when two dissimilar metals are in contact with each other in the presence of moisture and air. The higher the operating temperature the higher the corrosion rates and therefore Heat Recovery and Solar Systems must be properly protected.

Even if a glycol solution is fully inhibited against corrosion, some commercially available inhibited glycol solutions are not compatible with hard water, and so specify that demineralised or deionised water must be used to dilute the glycol to the required concentration. This not only increases the cost and future top up practicality problems, but also has the potential to reduce the effectiveness of the corrosion protection program.

This is because, surprisingly as it may seem, ultra pure demineralised or deionised water is far more corrosive than main water. Therefore one must add more corrosion inhibitor to stabilise the solution.

Some of the commercially available Potassium Acetate and Formate solutions caused extensive corrosion problems within as little as two months after first charge such that it resulted in major shut-down due to leakage. Both Potassium Formate and Potassium Acetate attacks Zinc and therefore if the circuit contains any zinc surfaces these fluids will eat away the zinc as a matter of hours. Galvanised surfaces such as cold store floors, steel structures such as cable trays and main galvanised steel supports must be carefully designed to avoid any direct contact with these fluids.

Some of the early supermarket installations, the cabinet fan baffles generally made of Galvanised panels disappeared with in days even during the commissioning stage of the project.

If the spill is not quickly diluted even the normal service drains / vents within the cold store coolers resulted in excessive corrosion problems as a matter of days for the cold store floor and the same experienced for the cable trays and main building steel structure.

4.4) - Bacterial Activities;

Both Potassium Formate & Acetate based solutions are relatively safe against any Biological contamination BUT Propylene and Ethylene Glycol Solutions are susceptible to bacterial contamination, in particularly for low concentrations and high operating temperature. Any bacterial activity is significantly reduced below 14 DegC but temperature above this limit which is generally the heat recovery, heat rejection and warm defrost circuits, are the most vulnerable part of any refrigeration system.

A major UK distribution centre had a severe biological contamination which resulted in addition of as much as 10% of the system volume on a daily basis by fresh neat Propylene Glycol in order to keep the concentration level above freezing limit. Once the type of Bacteria is identified, a custom-made concentrated Biocide Solution is added and after two days all bacterial activities ceased. This problem is especially relevant if the glycol is being used in SlurryICE and anti-freeze protection systems whereby the glycol concentration may be as low as 7-8%. Therefore on all glycol solutions must be labelled to advice on whether the product may be diluted, and if so, to what degree. This ensures that, if used correctly, optimum corrosion and bacterial protection are always maintained.

5.0- Conclusion

It is clear that no single secondary refrigerant is ideal for every type of application, and therefore designers must find the best solution for the application on a job by job basis based on temperature range and application.

Aqueous solutions generally require less volume flow rates in comparison with non-aqueous solutions, in order to transport the identical cooling capacity. However, they are relatively difficult to eliminate corrosion risks in particular with salt-based solutions. It is vital to achieve an air-free installation in order to avoid any potential corrosive problem.

Designers must compare the corrosivity, environmental pollution, toxicity, and flammability, site handling and cost issues along side the thermophysical properties of the intended secondary refrigerants.

Practical applications in the field indicated that the new high performance salt based such as Potassium Acetate and Potassium Formate based solutions require very careful handling and the corrosion issues must be addressed very carefully. It is observed that some of the sites in particular with warm solution defrost systems suffered excessive and rapid corrosion problems less that a few months.

It is essential to keep a site record regarding standard concentration and fluid quality reports as part of the regular maintenance checks and take the necessary modification works for major problems before they become a major problem.

Finally, it is vital to establish a reliable supply chain for any new type of secondary refrigerants and some of the sites in Europe used imported fluids but suffered badly when there was a major leakage, hence, it is vital that both consultants and end-user ensure that a full charge of the system either kept on site or alternatively kept by the supplier at all times for any critical refrigeration applications

6.0- REFERENCES

1) Heap R.D., “European Developments Relating to Refrigerants “, Institute of Refrigeration Presentation, 2nd November 2000, London.

2) ASHRAE Book, “Fundamentals.

3) Ure, Z. “Benefits that flow from secondary systems “RAC Journal, UK, July 2000 Issues, p. 32 – 37.

4) Sassi Ubaldo, “ Caracteristiche dei fluidi secondari per basse temperature“ , ZERO SETTO ZERO Magazine, October 1998, ITALY.

5) 2002 Malinker, Ake “ Thermophysical Properties of Liquid Secondary Refrigerants “, International Institute of Refrigeration, 1997, France.

6) Paul, J., “Innovative Applications of Pumpable Ice Slurry”, Institute of Refrigeration Presentation, 7th February 2002, London.