NATURAL WORKING FLUIDS IN ARTIFICIAL SKATING RINKS

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ABSTRACT

CO_2 technology now also used in skating rinks. In a growing number of countries it is not allowed anymore to use big amounts ammonia in areas occupied by many people. So new skating halls with direct ammonia systems are not built anymore although those systems are the best solutions concerning ice quality and energy consumption! An indirect NH_3 brine-glycol system uses 25 % more energy and by using (H)CFC's instead NH_3 it might even be more!
During the last years CO_2 has proven to be an excellent secondary refrigerant also in skating rinks!

1. INTRODUCTION

Already in the 5th century people discovered that sliding on ice made more fun and went faster than walking. For long time they skated on animal bones on the frozen natural refrigerant - water.
Around 1400 the bones changed in steel blades, but frozen water kept frozen water!
On the most Dutch winter landscapes of famous painters there are people "playing" on the ice!
Ice skating is a famous sport in Northern Europe, and in particular in the Netherlands. Most skaters prefer natural ice to make long trips over the lakes and canals. However with the nowadays winters and the changing climate this happens not as often as they like!
A good replacement of course is skating on **artificial ice -** in fact a **w**rong name - for the ice is very natural but the way how it is produced is artificial (with mechanical cooling machines).

2. THE EARLY STAGE OF SKATING RINKS

In this short overview a history is given of the first mechanical refrigerated ice skating rinks. These rinks provide examples of the achievements of cooling and freezing technology, in particular the way natural refrigerants are used in large cooling systems with excellent results.
We have to go back to the middle of the 19 th century, skating was very popular and figure skating became almost art. Specialists crossed the Ocean (from America to Europe and the other way) to give demonstrations.
Because also in those days not every winter resulted in frozen lakes there were rinks with real "artificial" ice. In 1840 there was a covered rink the *London Ice Floor*, 1868 New York got her *Covered Rink*. The "ice" surface was made of chemical mixtures : mostly salt, alum or sulphur solutions. According old books it smelled awful, there was always fog and you should not fall!

In 1851 the American physician *John Gorrie* got a patent for his ice-machine, which made use of vapour compression. It operated with air and he could make ice in a basin at –7° C. In memory of his great achievements a statue of Dr. Gorrie was erected on Capitol Hill in Washington. Soon after this invention, interest was attracted by British scientists. *Rankine* describes an open cold air machine in 1852 to cool down the air in tropical houses.
On the European continent were developed vapour compression machines for other refrigerants:

- The famous German scientist *Carl von Linde* used smelling ammonia (NH_3)
- while the Swiss professor *Raoul Pictet* designed a machine with the poisonous sulphur dioxide (SO_2)
- the Swiss company Escher Wyss had compressors working on carbon dioxide (CO_2)

In 1876 the British *Dr. John Gamgee* pumped glycerine through a network of elliptic copper tubes. The glycerine was cooled down by a machine of *Raoul Pictet*. Pumps and compressor were driven by steam. This small indoor rink (12 x 7 m!), called ***Glaciarium,*** was located in Chelsea (a quarter of London) and is mentioned in the literature as the first artificial ice skating rink in the world. Note: the world had to wait another 10 years on the invention of the automobile!

The Illustrated London News of May 13, 1876 had an illustration which showed men and women dressed in high fashion of the period skating to an orchestra situated in a balcony over one end of the rink. An article in the same journal described the process involved in creating the ice surface: The floor of the rink, working from the base up, consisted of six inches of concrete on which was laid four inches of loose dry earth. A six inch layer of cow hair was on top of the earth and on this was laid two inch thick timber planks covered with half an inch of tarred hair. A series of copper pipes were laid on the tarred hair. These pipes were immersed in the water which froze to form the skating surface. In a machine room, separate from the rink, a steam engine drove an air pump and kept sulphuric acid in constant circulation which condensed to a liquid under pressure of 1.5 atmospheres. It expanded in a vacuum which produced intense cold by the change from liquid to gas. It then passed into the refrigerator consisting of a copper casing about five feet square with a number of vertical tubes passing through it. This was submerged in a solution of glycerine in water, contained in a wooden tank placed about ten feet above the rink floor. The glycerine flowed by gravity through the pipes in the rink floor and was pumped back into the refrigerator.

This principle of pumping cold liquids through a network of tubes, was copied by others soon. Everywhere in Europe small ice skating halls were built, in Paris, London and Berlin, mostly with beautiful names like *Eispalast*, *Palais de Glace* etc.

In the United States the first ice hall of this kind opened its doors in New York, 1879. It measured 864 m^2. Shopping centers and hotels also had small ice floors for figure skating, ice dancing, ice shows etc.
In Frankfurt, Germany the first skating rink was built in 1881, the system of *Von Linde* was used. It consisted of a water basin with on the bottom a piping system of 5.3 km total length. Brine was cooled by ammonia compressors. Total surface: 532 m^2.

Berlin got its first *Eispalast* in 1908 with Borsig machines (1900 m^2). In 1910 followed by the *Sportpalast* with 2500 m^2 and Quiri machines. In 1911 the *Admiralspalast* opened with CO_2 compressors of Escher Wyss. Even for Berlin three ice palaces were too much and soon they had to close doors.

2.1 The first outdoor artificial skating rinks

All mentioned tracks had a roof on top, but after some time the public didn't like it so much to skate indoor and more and more rinks had to close down because of financial problems.
In Vienna (Austria), *Eduard Engelmann*, the European champion figure skating (1892-94), already had plans in 1896 for outside tracks. They laughed at him, even the famous *Carl von Linde* said that it was impossible to make artificial outdoor rinks, it should cost far too much energy!
It took until 1909 before the Engelmann-rink opened with 1100 m^2, later extended to 1900 m^2. The largest track must have had an area of about 4000 m^2. NH_3 compressors (814 kW in total) cooled the liquid which was pumped through 33 km of tubes.

At the same moment in Melbourne (1906) and Sydney (1907) there were tracks of 1300 m^2 with *direct evaporation* of refrigerant in the pipes.

In the Netherlands it lasted until 1934 before the first artificial ice skating track was used. On the bottom of a swimming pool in Amsterdam pipes were installed. The area of 60 x 40 m was slightly larger than a standard ice hockey track. The first training of the Dutch speed skaters took place on this track.

2.2 The first 400 m artificial ice skating rinks

In the fifties there were no 400 m artificial ice skating rinks anywhere in the world. Nevertheless European and World championships speed skating were organized every year. This took place on outdoor skating tracks with natural ice, so obviously the winters were more severe in those days. Oslo, Davos, Moscow, Helsinki, Hamar, Trondheim, Stockholm and Östersund are mentioned in newspaper reports of these events.
Many European- and World championships (and also the Olympics 1952) took place in the famous *Bislett* stadium in Oslo (on natural ice) until the mid eighties. In recent years this would have been impossible because of the higher outside temperatures.

In 1958 the World Championships soccer took place in Gotenburg, Sweden. The beautiful stadium Nya Ullevi was not built only for this purpose, also for athletics, motor speedway and skating. In 1959 the first European championships took place here on artificial ice and the famous Norwegian Knut Johanessen became champion. There were 55.000 enthusiast spectators during 2 days!
Under the speed skating rink the galvanized steel pipes (90 km in total!) were positioned on top of the runway for the athletes and partly on the soccer field. During the summer the pipes were removed. The radius of a 400 m skating track is different from the runway for athletes. That is the reason why the piping cannot be installed under the gravel of the athletic tracks. Besides that the gravel will be damaged too much during freezing and defrost.
The cooling system in Nya Ullevi consisted of HCFC-22 compressors (*STAL*) and an indirect brine pumping system (- 10° C). Since 1985 there is no skating possible anymore in Ullevi, pipes and machinery have been sold to a skating club in the North of Sweden.

The second artificial 400 m track was built for the Winter Olympics 1960 in Squaw Valley (California) : an indirect R22 system again. In reports of those days the very good and fast ice is mentioned also because it was situated at a height of 1890 m!
The Squaw Valley freezing system was moved to West Allis in 1966 to become there the first US artificial 400 m oval.

The third 400 m rink was built in Amsterdam (1961), designed and constructed by the Dutch company *Grasso*. The construction was unique in the world for it was a direct NH_3 pump system. As advantage was mentioned 20 – 25 % energy saving comparing the two existing indirect / R22 rinks.
This *Jaap Eden* rink in Amsterdam was also a "removable" rink, the complete steel piping system (ca 50 km in total) had to be stored during summer time.

42 tons NH_3 were circulating through the pipes from October until March and stored in a large suction drum during the summer. A specially designed forklift-truck would take the 269 pipe elements in a few days for storage until next winter. However in reality the work took a lot longer and the track was removed only once!
After 30 years of good service (no big leaks!) the system was renovated in 1990. The track became wider: from 11 to 13 m, new steel tubes in concrete now. Because of a much smaller pipe size (21.3 mm instead of 33.7 mm) the total ammonia charge was reduced **from 42 to 11 tons**!

The fourth 400 m oval of the world was built in **Deventer** in 1962. Because of the good results in Amsterdam here also direct ammonia evaporation. Now a permanent rink with 70 km galvanized pipe (21.3 mm) and therefore only 10 tons NH_3, you see technicians learn fast!
After 30 years in use, the rink was closed down in 1992, during this period they had about 8 million visitors (skaters and spectators). Replaced by a new built half covered skating rink, now with an indirect NH_3/glycol system (NH_3 charge 1250 kg).

The third Dutch 400 m rink became the most famous one. It is the **Thialf Stadium** at **Heerenveen**. It was built in 1966 (as usual now with NH_3 direct expansion), with the Olympic Ice Stadium of Innsbrück (1964) as example. It was the first rink in the Netherlands with a concrete floor.
A roof was constructed on top of this oval in 1986, just a bit earlier than the Olympic Oval in Calgary. Because of safety considerations direct ammonia systems are not allowed anymore in skating halls Thialf renovated their system during the summer of 2001. All the steel pipes and concrete were removed and a new floor had to be constructed, now brine is pumped through PE (poly ethylene) pipes, cooled down by four R 507 DX chillers placed on the roof, not such a nice and environment friendly solution alas!

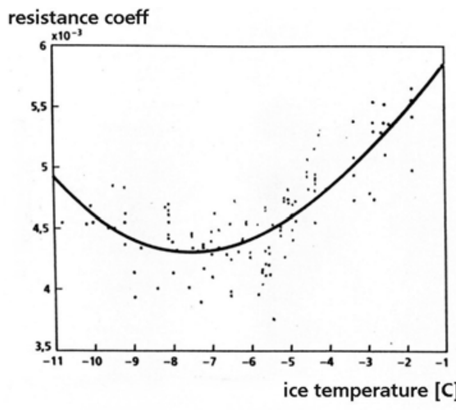
3. ADVANTAGES DIRECT EVAPORATING

In the years after all over the world small and big skating rinks were installed with direct ammonia evaporation, still the best solution as well for the energy consumption as the ice quality and temperature!
In the Netherlands we have now (2006) 14 speed skating ovals :
11 with NH_3 (7 with direct expansion), the others are operating with R22/glycol, R507/brine, R410a/brine

Besides the lower energy consumption comparing the indirect systems there is another big advantage using evaporating ammonia in the tubes!
By using a restriction (see Figure 1) at the beginning of each rink tube (length 100 – 120 m) the evaporating pressure and so the temperature will be even in every tube. If the concrete and the ice layer above the rink tubes have the same thickness everywhere also the ice surface will have an even temperature.
Especially at speed skating, where every 0.1 seconds counts, this is very important, a speed skater has to overcome the ice resistance (20 – 25 %) and air resistance (75 – 80 %). The ideal ice surface temperature is about -7 ˚C, as showed in Figure 2.

Figure 1 : Restriction and liquid headers

Figure 2: Ice resistance –temperature



Just as in more countries it is in The Netherlands not allowed anymore (according our CPR 13- 2) to use direct ammonia systems in indoor skating rinks! Also the semi covered and open 400 m rinks (charges of 7 – 10 tons NH_3) situated in living areas are under discussion now.
So we are forced to use indirect systems for new or rebuilt ice rinks.
Because we want low energy consumption and a good and equal ice quality we had to look to the best alternative for the NH_3 direct systems.
The ideal secondary refrigerant should have a high heat transfer at a small temperature difference and a small flow. Further: not corrosive, environment friendly, ecological harmful, cheap, high specific heat, low viscosity etc. All these demands are not so easy to combine!

CaCl brine is used a lot in skating rinks, comparing with glycol it is cheap and has a low viscosity at low temperatures. Disadvantage: it is quite corrosive, but nowadays there are more modern brines for sale as: *Temper, Freezium, Hycool, Tyfoxit, Pekasol etc*. These are all salt solutions of potassium formate and acetate. Every brand has added its own corrosion inhibitors but though air has always to be removed carefully from the system!
All the above mentioned agents are so called **one phase** secondary refrigerants
By using them there always will be a temperature difference of 2 – 3 K between inlet and outlet of the rink tube. This results in an unevenness temperature of the ice surface. The bigger the flow > the smaller the delta T > more flow resistance > more pump energy.

4. CO_2 AS SECONDARY REFRIGERANTS IN SKATING RINKS

At using evaporating ammonia we didn't have this ΔT so a two phase secondary refrigerant was wanted and that seemed to be CO_2. First mentioned as secondary refrigerant in 1970, the first real tests to compare glycol with CO_2 as refrigerant in a rice rink are done around 1998 by *Sulzer Escher Wyss GmbH.* They made two similar outdoor ice surfaces of 30 m² - one with glycol in the tubes and the other with CO_2 and they did a lot of interesting measurements.
To maintain the same ice surface temperature there could be said next about energy consumption:

NH_3 direct	100 %
NH_3 / CO_2	108 – 112 %
NH_3 /glycol	125 – 140 %

The Dutch research institute TNO-MEP also made a study (TNO rapport R2001/618) and their conclusion was that NH_3 direct always has the lowest energy consumption and NH_3 / CO_2 is far the best alternative:

NH_3 direct	100 %	R 507 direct	117 %
NH_3 / CO_2	105 %	R 507/glycol	132 %
NH_3 /glycol	116 %	R 507/ CO_2	121 %

A big difference at using CO_2 (R744) instead of NH_3 (R717) or glycol/brine in the tubes is the working pressure! At the needed -10 ˚C this will be around 25 bar, that is 10 times more than at the former existing systems!

The first ice rink with NH_3 / CO_2 was built in Dornbirn (Austria) in 1999, an indoor 60 x 30 m rink. Cooling capacity 600 kW at a CO_2 temperature of -7 ˚C, built by *Sulzer - EW.*
In the same year the same company converted in Wil (Switzerland) a 60 x 30 m rink from NH_3 direct to NH_3 / CO_2 by using the existing steel rink tubes (after a pressure test at 52 bar).
Then more companies started to build en rebuilt NH_3 /CO_2 rinks, most in Switzerland. In some years 14 CO_2 rinks were built (only 3 new ones) most by *Walter Wettstein AG*. There is still a lot of work

to do for there are over 140 small skating and curling rinks in Switzerland. Germany got the first CO_2 rink in 2003 and the second one (with 3 ice hockey fields) opened end 2005 in Mannheim.

5. FIRST 400 M OVAL WITH CO_2 IN THE NETHERLANDS

As mentioned already world's first 400 oval with direct evaporating NH_3 was designed and built in 1961 in The Netherlands by *Grasso*.
It took 43 years before daughter company *GEA Grenco BV* installed world's first 400 oval with CO_2 in the rink tubes!
It was the 400 x 12 m oval *Kennemerland* in Haarlem, built in 1977, already after 2 years the rink was closed (1979 – 1983) because of the risk of ammonia leakage due to a weak foundation.
It got new rinks tubes (21.3*2.0 mm) in concrete and was opened again in 1983.
Because they wanted an extra 60 x 30 m ice field and had plans to build a roof over the rink, it was a good occasion for changing the system according the new safety and environment laws.
Before starting the job a pressure calculation for the existing rink pipes (in concrete) and headers was made and as soon the ice was melted in March 2004 we did a successful pressure test at 45 bar!
This was an important day, the existing rink tubes and headers of the oval could be reused this saves a lot of work and money!
Of course the existing LP drum with NH_3 pumps, evaporative condensers and the 3 Grasso RC 911 reciprocating compressors were reused.
New installed: the NH_3 /CO_2 cascade condenser (2400 kW) with receiver and CO_2 pumps (variable speed), stainless steel pump - and wet return lines (DN 100) to the headers of the ice rinks, one Grasso RC 912E compressor (with variable speed)
We also had to install a CO_2 summer storage drum (17 m³) because the receiver of the cascade condenser was too small. The NH_3 charge was reduced from 7000 to 1800 kg, now we reused the existing low pressure drum. At a total new build 400 m oval we should install a much smaller one so the NH_3 reduction will be more.

The existing piping of the 400 m oval was divided in 4 sections of 100 m (2 curves, 2 straight ends) Rink tubes parallel with skating direction, restrictions at the begin of every rink tube (21.3 *2.0, pitch 100 mm), see Figure 1. Every section got now a motorized valve at the beginning and the end to have the possibility to operate with different ice temperatures.
At the new built 60 x 30 m field we used after each restriction 240 m pipe length (21. *2, pitch 100 mm), much longer as standard NH_3 rinks with 120 m pipe length, this because of the minor pressure drop with using CO_2 (see Figure 3). Also here a motorized valve in central liquid supply and return line, see Figure 4.

Figure 3: Temperature drop different fluids at 1 bar

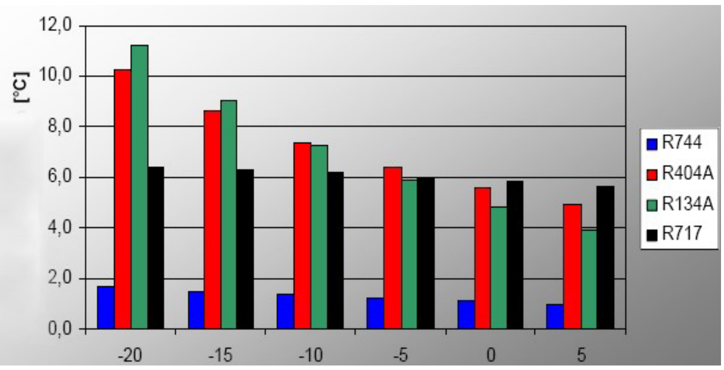


Figure 4: Liquid - /return lines ice field

5.1 Plant dates:

Total ice surface area : ca 7000 m²
Total capacity : 2400 kW at -10 ˚C CO_2 / -13 ˚C NH_3
Design pressure : CO_2 side 40 bar / NH_3 side 16 bar
Charges : 16500 kg CO_2/ 1800 kg NH_3
Rink tubes : steel 35.8 / 21,3 *2.0
Compressors: 3 existing reciprocating *Grasso* RC 911 at 860 rev/min plus the new installed *Grasso* RC 912E (600 – 1500 rev/min)
NH_3/CO_2 cascade condenser : 2 x *Vahterus* Shell & Plate
NH_3 evaporative condenser : 2 *Balitimore*
Heat recovery : shell & tube condenser
Plant Controll : *Siemens* S7 PLC

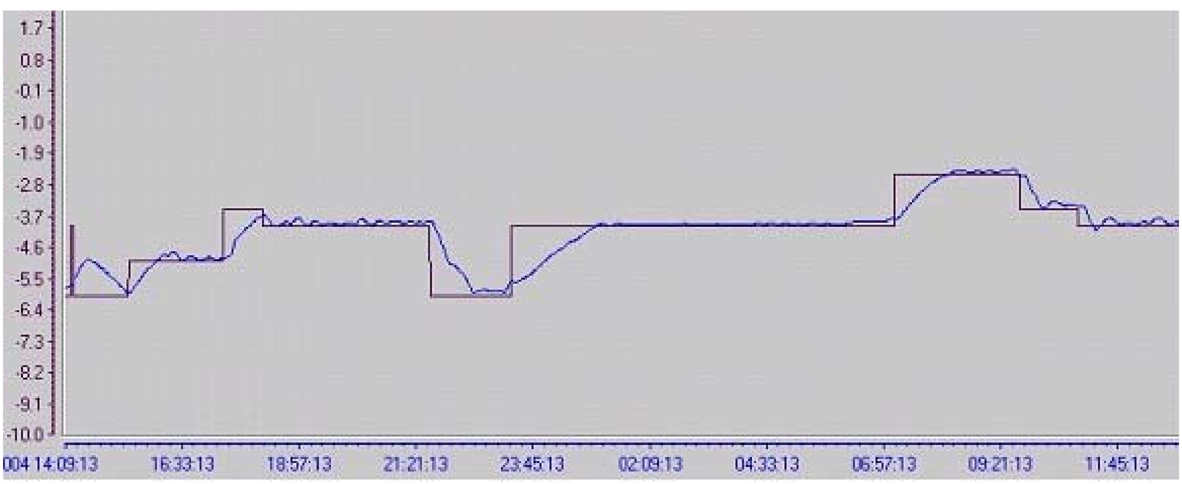
5.2 Experiences during the first season

Because we used now CO_2 in the existing rink tubes we were afraid that there should come back a lot of oil. For these rink tubes (ca 50 kilometers with an internal surface of 2800 m²) had been in use for over 20 years with. By smaller transformed rinks they had this experience. The total amount of oil depends of course of the oil separator efficiency, drain and maintenance discipline etc. So we placed : extra filters in the central CO_2 return line and a temporary oil recovery unit under the CO_2 receiver. Nevertheless we had in the beginning some problems with blocked (by oil) internal suction filters of the CO_2 pumps. Now the system seems to be clean.

Good experience with the independent operating sections at different pressure (ice temperature). Also when (next year) the oval is semi covered there can be sunshine at one part and shadow at another part of the ice during the same time. During speed skating competition they want colder ice and it is even possible to make other ice temperatures in the curves.
Also the response time was much better than we thought, even better than before with NH_3 in the tubes. In Figure 5 you can see the rapid temperature reaction of the 400 m oval after changing the set point. It is an average of the 8 temperature probes placed direct on the concrete (just under the ice layer of 25 – 30 mm)

During the first season (2004/2005) the average energy consumption / ice area [W/m²] was even about 8 % less than during season 2003-2004, then operating as NH_3 direct system!

Figure 5 : Temperature response after changing set point



At an open rink with big influence of outside temperature, wind, rain, sunshine etc. this is difficult to compare. But there was not so much difference in weather conditions during these 2 seasons,we must not forget here that also we optimized the plant control. In the past they operated at a fixed NH_3 suction temperature, now we have capacity control depending of the wanted (= adjusted) ice temperature!
Note: Now we measure the concrete temperature, to improve it we will install may be in the future infrared sensors to measure the real ice surface temperature.

6. THE CIRCLE IS ROUND AGAIN!

The first indoor ice rink had no cooling at all! Just the windows were open in the "Skating Club House" in Canada in 1854. The first mechanical refrigerated ice rinks all used indirect systems and were indoors. After a century of outdoor artificial rinks with direct evaporating systems, we see that nowadays ice rinks are built indoors with indirect systems. The same goes for the refrigerants: starting with natural refrigerants like CO_2 and NH_3 followed by on the ozone depleting chemicals like CFC-114 and HCFC-22 .
Nowadays most of the rinks are cooled by ammonia but the number of in direct systems is rising because ammonia is not allowed anymore in closed skating halls. The first rinks with CO_2 as a secondary fluid are successfully in operation now, so the circle is round, the same with the scientific interest in ice skating.
In the beginning we saw the great influence and interest of the scientists.
Nowadays (after almost 130 years) skating is high-tech again with klap-skates, aerodynamic outfits tested in wind tunnels, using treated water, adding special liquids to the water to lower the ice resistance and so on!

7. CONCLUSIONS

In the coming years CO_2 in good combination with NH_3 will certainly be used more and more in new and converted ice rinks. It has proven to be far the best alternative for an indirect system. There can still be improved a lot to lower the energy consumption by using natural working fluids.

Some advantages:

- **Less energy consumption comparing other indirect systems with brine and glycol.**
- **Better ice quality and more even ice temperatures.**
- **Rapid reaction time after changing set point.**
- **Much smaller pumps and transport lines to/from rink comparing brine and glycol.**
- **Ecologially harmless.**
- **Favourably priced and easily available.**

Note: In completed closed skating halls with CO_2 there should be placed detection sensors, so in case of leakage people can be warned. CO_2 is 1.5 times heavier than air so it is flooded and our breathing will be influenced.