EVOLUTION OF CO_2 AS REFRIGERANT IN ICE RINK APPLICATIONS

12TH IIR Gustav Lorentzen Natural Working Fluids Conference

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ABSTRACT

The first ice rink system using carbon dioxide, CO_2, as secondary refrigerant was built in Austria 1999. It would take until 2010 in Canada until the next generation, using a trans-critical CO_2 solution, was realized for the first time. That eventually the ice rink business moved to trans-critical CO_2 systems was a very natural step considering the 1st generation systems using CO_2 as secondary refrigerant, and the parallel development of trans-critical CO_2 systems in supermarkets. Ice rinks and supermarkets are rather similar when it comes to cooling capacity and heat recovery requirements which implies that the system design and associated control could easily be carried over to the ice rink applications. CO_2 as refrigerant in both direct and indirect ice rinks systems where proposed several times before it eventually happened in 2010. The reason why it took so long before the ice rink industry accepted these systems is probably because there were no customers ready to take the risk and the somewhat higher cost for installing them. The most recent CO_2 ice rink systems have demonstrated that essentially any ice rink can be self-sufficient with heat and that the overall energy efficiency is taken to a new level due to the unique properties of CO_2. Today we see a rapid growth in the number of CO_2 ice rink systems in Canada, the U.S. and Sweden, which is most likely just the beginning.

Keywords: Ice rink, Carbon dioxide, Trans-critical, Refrigeration, Heat recovery, Controls

1. INTRODUCTION

We are most likely experiencing the beginning of a paradigm shift in the way ice rinks are refrigerated. After the first ice rink system using carbon dioxide, CO_2, as secondary refrigerant was built in 1999, it took until 2010 before the first ice rink using a trans-critical CO_2 system was realized. In this paper the rationales behind using CO_2 in ice rinks are demonstrated together with the most important steps of the evolution of the technology. The latest generations CO_2 ice rink systems have demonstrated that with proper design essentially any ice rink can be self-sufficient with heat, Rogstam and Bolteau (2015). In general the overall energy efficiency is taken to a new level due to the unique properties of CO_2.

1.1 History of ice rinks

The history and evolution of ice rinks is well documented by Martin (1997) where it is concluded that the first known ice rink was the "The Glaciarium" in London from 1876. Technically it is described that "Copper pipes were laid down, and through these, a mixture of glycerine and water was circulated after having been chilled by ether." Most modern ice rinks could be described similarly, although the fluids would be different. The fast growing popularity of ice hockey in the 1880s added to the public demand for construction of ice skating rinks. The first mechanically refrigerated ice rink in the U.S. was constructed in 1879 and installed in the Old Madison Square Garden.

2. REFRIGERANTS AND SYSTEM SOLUTIONS

In the early days of refrigeration history, which starts in the 19th century, only natural fluids were used, since they were the only ones available. In the beginning of the 20th century, chemical science learned how to create substances with more "suitable properties" such as R12 and R22. Today R22 is subject to phase out according to the Montreal Protocol but is still in use in many ice rinks throughout North America. Due to the current focus on environmental issues and sustainability the refrigeration industry has to return to the natural alternatives. Among these only a few are suitable for refrigeration purposes and the following ones are normally considered; ammonia, hydrocarbons and CO_2. In the industrial refrigeration sector, to which ice rinks count, ammonia has been widely used for decades. In recent times we have seen a growing interest to use CO_2 as refrigerant in many applications, especially in the commercial sector. Since a few years back this development has begun to enter the industrial sector as well which will have considerable implications for the business.

2.1 Carbon Dioxide in the Refrigeration Industry

The history of CO_2 can be divided into two parts where the first part is very well described by Williams and Bodinus (1999) who explained how the systems evolved and developed during the 19th and 20th centuries. They concluded that for the first part the interest in CO_2 as a refrigerant virtually disappeared in the 1950s.

Figure 1. An advertisement for CO_2 systems originating from the early 20th century

It would take until the end of the 1980s when the Norwegian Professor Gustav Lorentzen brought up the idea of using CO2 again – and initiated the second part of the CO2 history. He investigated how the CO2 technology could be used in different applications and published numerous articles. Lorentzen (1993) stated that "CO2 is as close to the ideal refrigerant as it is possible to come…". He covered many aspects of using CO2 in his publications, not the least how heat may be reclaimed as well as the associated control strategies in order to optimise the process.

2.2 Properties of Carbon dioxide

Carbon dioxide is a natural, non-flammable and non-toxic substance which offers technical advantages of great interest when compared to the other natural alternatives. The challenge with CO_2 basically stems from the fact that it has a critical point at a temperature of about 31°C with a corresponding pressure of about 74 bar_a. At conditions above the critical point the difference between liquid and vapour disappears, thus no condensation occurs. With proper design however, CO_2 systems offer good efficiency and low cost in many applications.

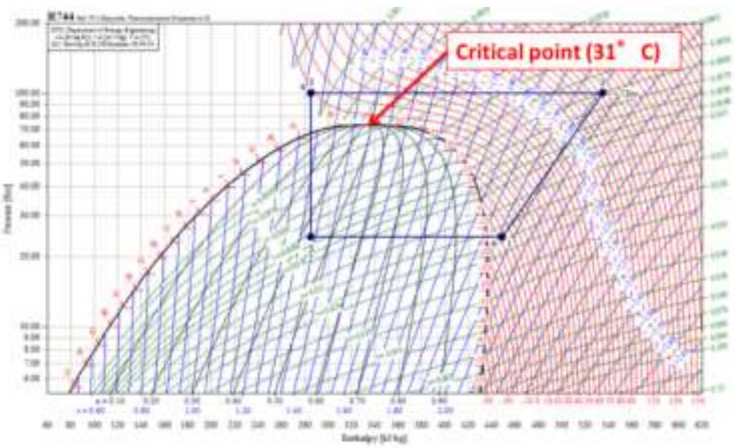

Figure 2. Schematic trans-critical CO_2 cycle in a p-h diagram.

2.3 Trans-critical solutions

This mode of operation is very relevant since most modern CO_2 systems are designed to operate this way. The term trans-critical refers to the critical point as mentioned above. When the refrigeration cycle operates above and below the critical point, which is unique for CO_2, the mode of operation is called trans-critical. This can be seen in Fig. 2.

2.4 Commercial applications

Sawalha (2008) reports that the first Scandinavian installation of a trans-critical CO_2 system took place in Denmark in 2003 and was followed by two Swedish installations in 2004. One of the pioneers in the trans-critical CO_2 supermarket area was Linde who presented the CO_2 solution illustrated in the Fig. 3 below, Haaf et al. (2005). This system comprises a trans-critical supermarket CO_2 systems including a heat reclaim function.

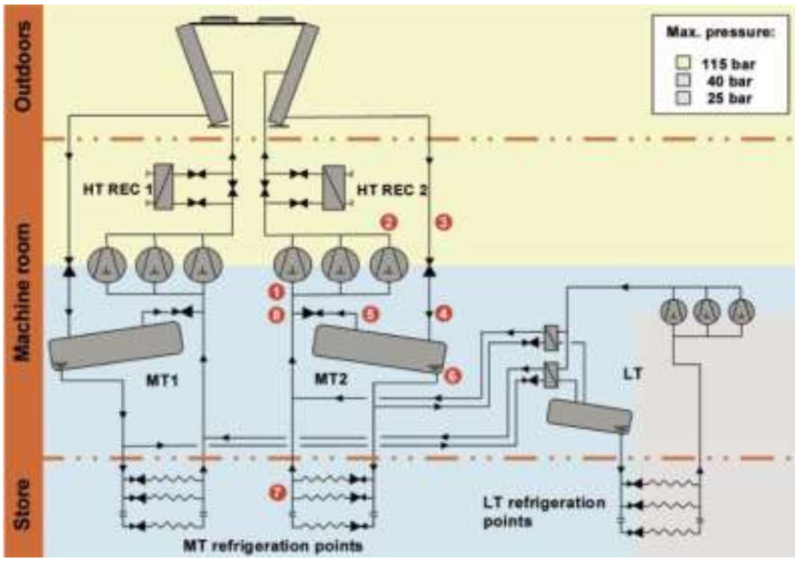

Figure 3. A schematic figure of a Linde trans-critical CO_2 system, Haaf et al. (2005).

2.5 Heat reclaim

The concept of reclaiming heat from refrigeration systems is widely known and has throughout the history been implemented either "passively" by simply using the heat available, mostly de-superheat, or "actively" by controlling the head pressure to raise the temperature level of the rejected heat. The same principle applies to CO_2 as well, with the only difference that there are some further implications as to the optimisation of the head pressure when operating above the critical point. This mode of operation and associated control was described by Lorentzen (1993) and further illustrated and applied by many others. In Fig. 4 Madsen (2010) illustrates the elevated head pressure in a winter case in order to reject the heat at a "higher" temperature.

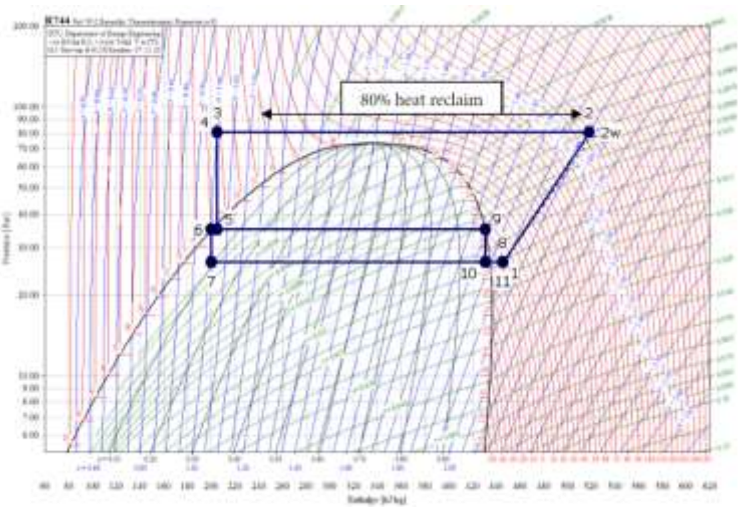

Figure 4. Illustration of the head pressure control to optimise the heat rejection based on the demand.

3. CO_2 ICE RINKS

3.1 First generation CO_2 ice rinks

Most ice rinks in the recent years have been built as indirect systems using a secondary refrigerant. There are a couple of secondary refrigerants commonly used in the industry which are listed below.

Table 1. Example of secondary refrigerants used in the ice rink refrigeration industry

Name of substance	Abbreviation	Aqueous solution	Pure
Calcium Chloride	C.C.	X	
Propylene Glycol	P.G.	X	
Ethylene Glycol	E.G.	X	
Carbon Dioxide, CO_2	R744		X

Both propylene and ethylene glycol are relatively environmentally friendly but otherwise have rather poor properties, which results in high pumping power and thereby a lower overall performance of the refrigeration system. Calcium chloride which is a salt offers better efficiency in terms of pumping power than the glycols and is therefore still the most common solution, at least in European ice rinks. Calcium chloride however has practical challenges such as corrosion and is therefore phased out in favour of CO_2 or ammonia-water. CO_2 is used pure as a secondary refrigerant and from an energy perspective it offers significant advantages due to its low pumping power. Rogstam et al. (2005) compared CO_2 to calcium chloride and concluded that CO_2 requires less than 10% of the pumping power. On the other hand the system operating pressure is high so the rink floor piping system needs to be made of metal in order to withstand the pressure.

Ice rinks where CO_2 is used as the secondary refrigerant in combination with a primary refrigerant are here referred to as "1st generation". The very first ice rink to be built with pump circulated CO_2 as a secondary refrigerant and ammonia as primary refrigerant, was the Dornbirn ice rink in Austria 1999. Sulzer (Axima) designed and built the system, Axima (2005) as presented in Fig. 5.

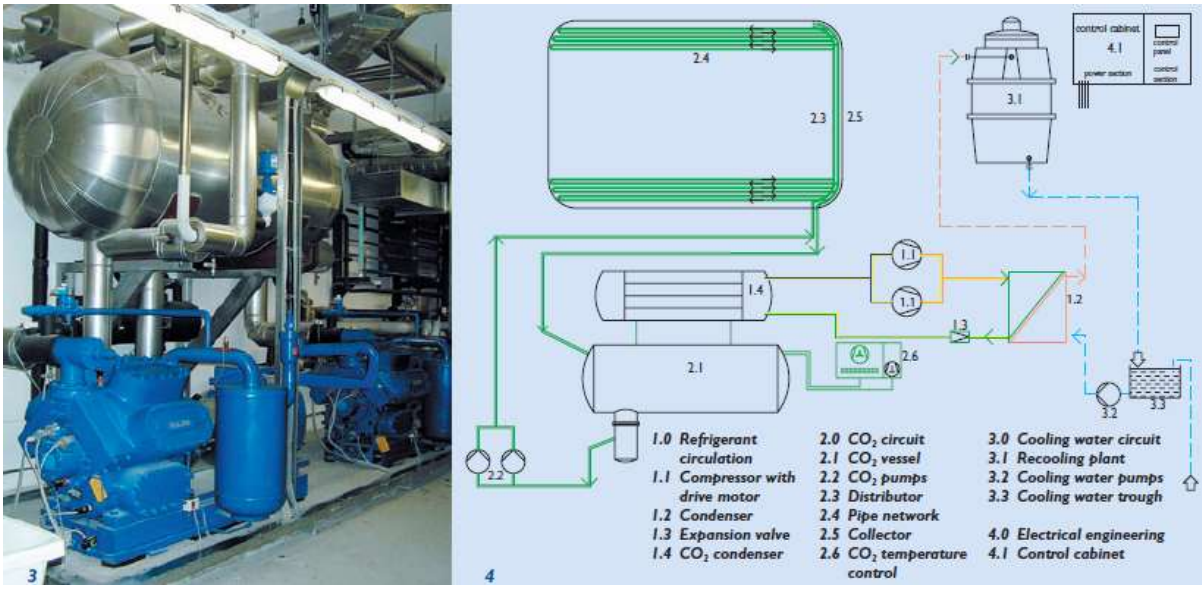

Figure 5. The ammonia- and CO_2-based system in the 1999 Dornbirn ice rink, Axima (2004).

Axima and other companies in Austria, Germany, Switzerland, the Netherlands, Japan and Scandinavia continued using CO_2 as secondary refrigerant in both new construction and retrofit after 1999. In 2015 there were 56 known ice sheets, in the world, cooled with CO_2 as secondary refrigerant. A step forward in the development which reduced the installation cost was to use copper tubing in the rink floor. Rogstam et al. (2005) investigated this solution which resulted in the construction of the Backavallen ice rink in 2006. The compressors and the pump module of the Backavallen ice rink can be seen in figure 6. Another 15 rink floors have been built with this copper tubing technology from 2006 until 2015.

Figure 6. The Backavallen ice rink in Sweden with CO_2 as secondary refrigerant in copper tubes.

3.2 Second generation CO_2 ice rinks – direct systems

In the light of what has been discussed so far, the use of CO_2 as primary refrigerant in an ice rink application seems to be a very natural consequence. We normally refer to ice rink systems using CO_2 as primary refrigerant as the "2nd generation". With the pump circulation CO_2 systems evolving from the Dornbirn ice rink in 1999 and the parallel development of trans-critical CO_2 system in the commercial sector, it became obvious to combine the two. In the early 2000s the components for trans-critical CO_2 systems were not yet at the point where they needed to be, for instance in terms of compressor cooling capacities. As a consequence a CO_2 ice rink refrigeration system would have required about 15 compressors to meet the capacity needs, where a typically ammonia system would only use 2 compressors, which made the CO_2 system seem expensive and impractical. This contributed to a relatively late introduction of the technology in ice rink applications although the potential advantages were known.

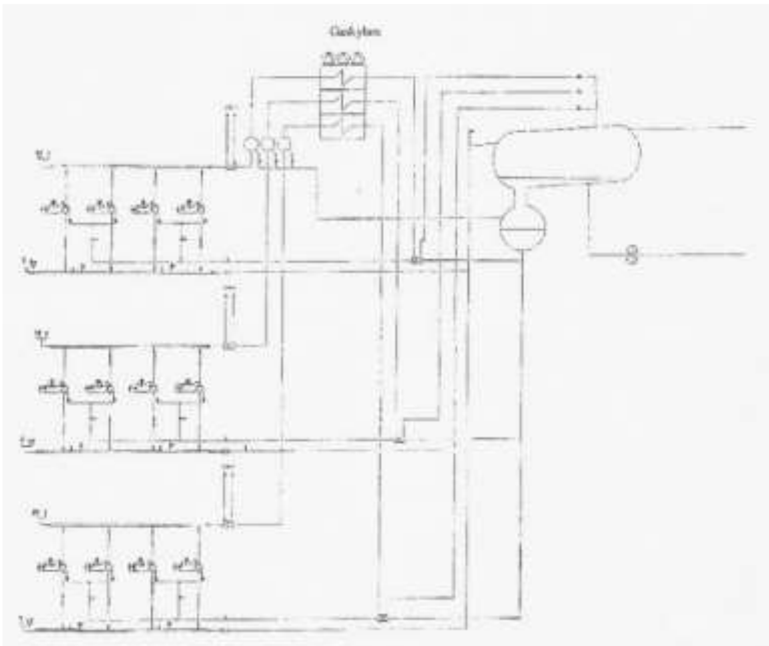

Figure 7. The proposed trans-critical CO_2 system in the Katrineholm city tender in January 2006.

The first known CO_2 trans-critical ice rink design is the one that was proposed by Larsson (2006) for the Katrineholm city ice rink tender in January 2006. The proposed design for this tender, which can be seen in Fig. 7, illustrates the difficulties at the time in terms of the number of compressors. On the left in the figure the 12 compressors designed to meet the specified cooling capacity of 300 kW can be seen. The Katrineholm city eventually chose to install the prescribed 1st generation CO_2 system which was the first in Sweden at the time, so this proposed trans-critical CO_2 system was never built.

The second known trans-critical CO_2 ice rink proposal is the 2009 Gentofte ice rink extension project in Denmark where one alternate tender consisted of a direct trans-critical CO_2 system. The ice rink extension project was however postponed and eventually a traditional indirect ammonia solution was selected.

The first known direct 2nd generation CO_2 ice rink to be realised is the Arena Marcel Dutil in St Gedeon, Quebec, Canada in 2010. Due to being the first realized 2nd generation CO_2 ice rink, it has been well documented and Simard (2012) presented the system as can be seen in Fig. 8.

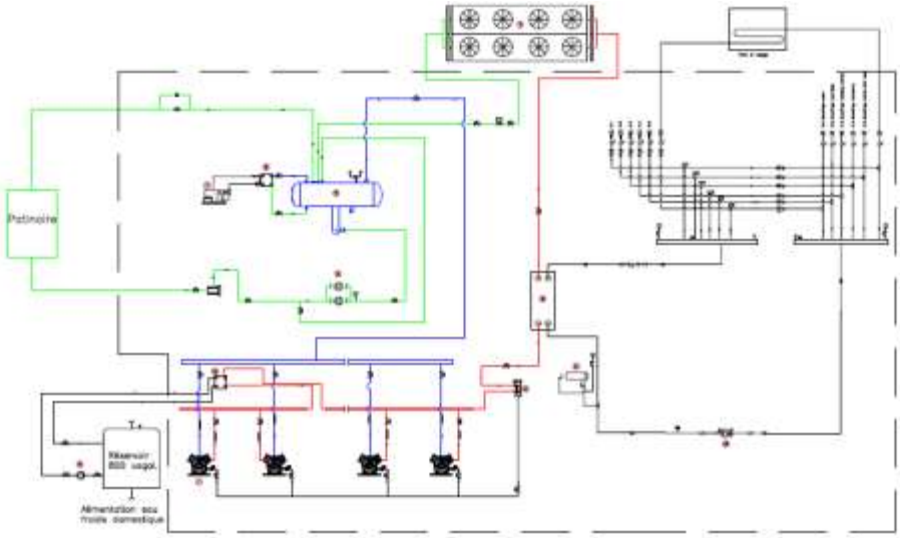

Figure 8. The trans-critical CO_2 system installed in St Gedeon 2010 (Simard 2012).

The system drawing shows the relationship and how the trans-critical CO_2 supermarket systems have been combined with the 1st generation CO_2 systems introduced in Europe. To the centre left, the liquid receiver is connected to the "green" circuit which essentially shows the pump circulation part of the system. Directly under the receiver, the liquid pumps are placed, which distribute the CO_2 to the rink floor. In the bottom left part, 4 out of 7 compressors can be seen which are connected with the blue suction line to the liquid receiver. The red lines indicate the high pressure part from the compressor via the heat reclaim exchanger to the gas cooler. As reported by Simard (2012) a significant reduction of the energy cost was recorded which to a large extent can be explained by the heat reclaim. Further, the ice quality was recognised as being very good, which is a potential advantage with direct refrigeration of rink floors since they are typically easier to control.

3.3 Second generation CO_2 ice rinks – indirect systems

CO_2 can also be used as primary refrigerant in indirect ice rink systems where it cools a secondary refrigerant such as calcium chloride, glycols, etc. This solution is slightly less favourable from an energy standpoint, but it is still interesting in the case of a refrigeration system retrofit. The use of CO_2 as primary refrigerant together with a secondary refrigerant in ice rinks has been proposed in the past, but it would take until 2012 before it was realized. First to publicly propose CO_2 as primary refrigerant in ice rinks was IIHF (2002) and the second was a patent application from Mayekawa (2007). In Fig. 9 the trans-critical CO_2 system is indicated as the box 20 and the rink floor as number 4.

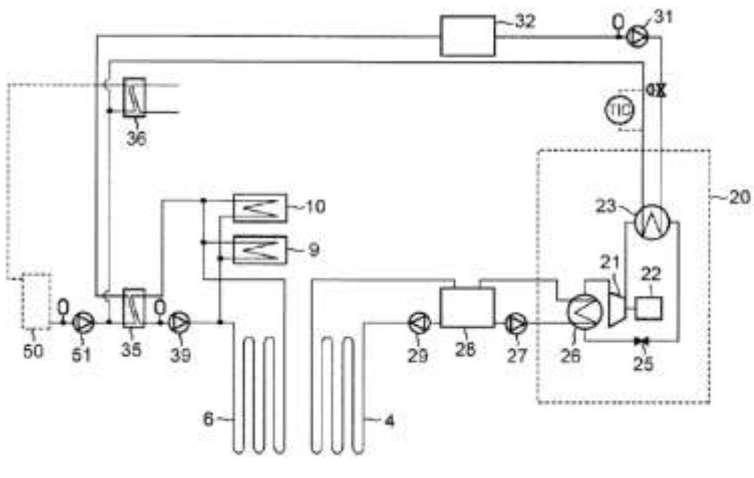

Figure 9. An indirect ice rink refrigeration system using CO_2 as primary refrigerant with heat recovery.

Still it would take until 2012 before the first indirect CO2 ice rink was built - the rewarded and well-recognised installation at Dollar des Ormeaux, Quebec, Canada. This facility is an interesting example of how the reclaimed heat from a CO2 ice rink system can be utilised to heat a swimming pool complex in addition to the ice rink itself. This installation is well described by Heon and Guerra (2015) and was awarded with the first price in the ASHRAE technology award case studies 2015.

4. DISCUSSION AND CONCLUSIONS

The basic system principle and functions of today's trans-critical CO_2 ice rinks principally work exactly like the direct refrigeration systems from the past did, the difference is just the choice of refrigerant. As a matter of fact the very same system solutions and basic components apply regardless if the refrigerant is ammonia, R22 or even CO_2. For people in the refrigeration business it should be clear that CO_2 has properties that are very suitable for ice rink applications, so we have to ask why it took so long until it was introduced, although it was identified as a potential solution several times in the history prior to 2010.

To find the answer we need to look back to the point where the natural refrigerant alternatives started their comeback. As described earlier, the revival of CO_2 started with Professor Lorentzen's work and the first applications to be developed were automotive A/C systems in the early 1990s. In the beginning of this new CO_2 era the components such as compressors etc., were developed and adapted for the rather small cooling capacities required in the automotive systems.

The next stage in the development was when the commercial sector began to adapt systems for CO_2, at the end of the 1990s. Primarily, the compressors were challenging to adapt for larger cooling capacities so the first supermarkets to be built had 10-20 compressors. The ice rink industry was however still used to normally work with 2 compressors. Using a large number of compressors would therefore inevitably affect the cost of the system in a negative way.

For CO_2 to become a generally accepted system solution in the industrial sector all components had to be adapted in order to allow for practical designs such as higher allowed pressures, but not the least in order to lower the costs. Since the designs were new and the number of components manufactured was low, the price was often high. As the systems became more popular and the designs were further optimised the price decreased.

The compressor is a very vital component in the system as far as performance and cost are concerned. It is therefore a relevant example to illustrate the development in terms of the number of compressors required in order to maintain a single sheet ice rink. In the first trans-critical ice rink proposal from Larsson (2006), 12 compressors were required to meet the 300 kW cooling capacity requirement. When the Marcel Dutil Arena was built in 2010 it used 7 compressors which corresponded to a 317 kW of cooling. A recent CO_2 ice rink project in Sweden uses 4 compressors to meet the specified cooling capacity of 250 kW, Rogstam and Bolteau (2015). These figures show the rapid development of the CO_2 technology component-wise in the recent years.

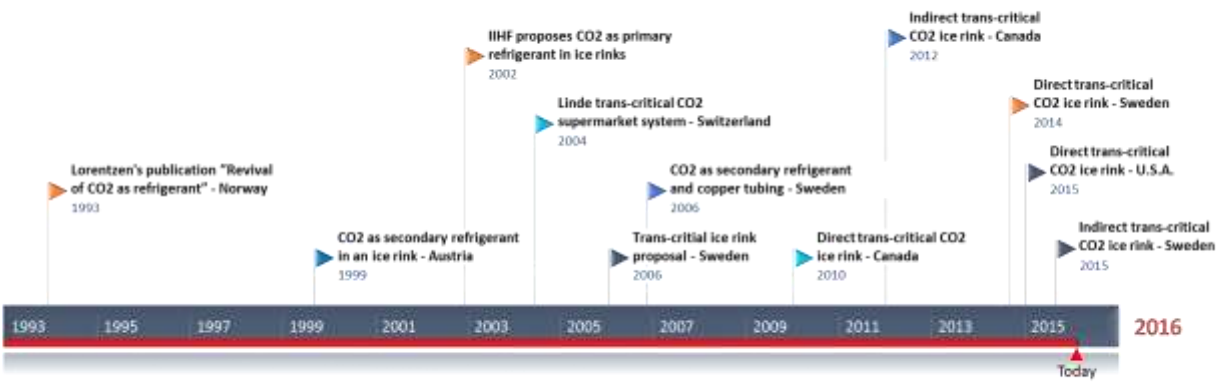

Figure 10. CO_2 ice rink technology evolution timeline.

The first ice rinks using CO_2 as secondary refrigerant in Europe all used ¾" steel pipes in the rink floor. Three out of the first seven installed systems during 1999 and 2000 were "retrofits" which used existing pipe systems that previously carried ammonia. New systems with newly installed steel pipe systems were built as well, and between the years 1999 and 2004 about 23 ice sheets were built where half of them were new and the rest were retrofitted. The challenge with the steel pipe design was the cost of installation, which indeed is the reason why the steel pipe design was abandoned in the 70ies in favour of plastic pipes. In order to use CO_2, however, there is no choice since the system pressure of CO_2 requires metal pipes. Although a couple of ice rinks were built with CO_2 from 1999 to 2004 the commercial success was not obvious.

The copper tube concept with CO_2 as secondary refrigerant that was installed in the Swedish Backavallen ice rink proved to be a good technical solution, but it was still not enough to make a commercial success. The very same concept was installed in 5-6 new ice rinks in Sweden, Norway, Russia, Japan and Finland during the years 2005 to 2010 – still with CO_2 used only as secondary refrigerant and in most cases in combination with ammonia.

In the beginning of the 2000s the so called trans-critical CO_2 systems gained popularity and the first systems in commercial use were installed in 2003. With the introduction of the technology in the commercial sector, which had a significant cost focus, the cost of the system components decreased. Furthermore, it triggered the development of new and better adapted components that would allow for higher design pressures, make systems more practical and safer to handle and ultimately lead to more energy efficient solutions.

The reason why it took until 2010 before the ice rink industry accepted the 2nd generation systems is probably because there were no customers ready to take the risk and the somewhat higher cost for installing a trans-critical CO_2 system. There was no demand for these systems but as the technology gradually became more refined in supermarkets, primarily in Europe but also in Canada, the confidence in the technology grew. The cost of components, and eventually the systems, decreased which opened the market for the 2nd generation CO_2 ice rink refrigeration systems. Today we see a rapid growth in the number of CO_2 ice rink systems in Canada, the U.S. and Sweden, which is most likely just the beginning.

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