

# Design Analysis of CO<sub>2</sub> Refrigeration System for Artificial Ice Rinks

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**Abstract:** With the increasingly serious environmental problems, the use of natural refrigerants has become an inevitable trend. In this paper, an artificial ice rink with a CO<sub>2</sub> refrigeration system is studied, and the ice rink site and refrigeration system process are analyzed. The structure of the ice rink site includes a surface layer, a base layer, and an antifreeze layer. The refrigeration system flow has indirect ice rink refrigeration systems and direct ice rink refrigeration systems. With the application of the CO<sub>2</sub> transcritical refrigeration cycle, the efficiency of the ice rink has been greatly improved.

**Keywords:** Artificial Ice Rink; CO<sub>2</sub>; Refrigeration; Process.

## 1. Introduction

With the 2022 Beijing Winter Olympics coming to an end, ice and snow sports have entered the public's view, leading to the development of China's ice and snow business, in which the construction of artificial ice rinks is a top priority.

From an energy point of view, artificial ice rinks need to meet the needs of refrigeration, dehumidification and heating at the same time, which consumes huge amounts of energy. According to research, artificial ice rinks in Sweden consume an average of 1000 MWh of energy per year, and artificial ice rinks in Quebec, Canada, consume an average of about 1500 MWh of energy per year, with a maximum consumption of up to 2400 MWh [1]. The refrigeration system occupies 35%-75% of the total energy consumption share of ice rinks, making energy efficiency in artificial ice rinks a key to sustainable development [2].

From an environmental point of view, most artificial ice rinks use NH<sub>3</sub> or Freon as refrigerant, which will cause damage to the ozone layer and trigger the greenhouse effect. In Europe and the United States, their artificial ice rinks used NH<sub>3</sub>/CaCl<sub>2</sub> refrigeration systems in the early days [3], and due to the toxicity of the NH<sub>3</sub> refrigerant and the risk of leakage, Freon refrigerant was gradually used later to replace NH<sub>3</sub>. In the late 1990s, the Kyoto Protocol set relevant limits on greenhouse gas emissions in developed and developing countries [4]. On September 15, 2021, the Kigali Amendment officially entered into force in our country, and hydrofluorocarbons (HFCs) refrigerants, as third-generation refrigerants, will also be gradually reduced and frozen [5]. Therefore, with the restriction of Freon refrigerants under the Montreal and Kyoto Protocols, the search for a natural refrigerant as an alternative is imminent.

The natural refrigerant CO<sub>2</sub> first originated in the 1850s and was replaced by the synthetic refrigerant CO<sub>2</sub> refrigerant due to the adoption of the synthetic refrigerant [6]. In the late 1990s, Prof. Lorentzen in Europe again proposed a transcritical cycle using CO<sub>2</sub> refrigerant [7]. It was not until 2010 that the first direct system using CO<sub>2</sub> as a refrigerant was applied to an artificial ice rink.

At present, the application of CO<sub>2</sub> refrigerant in artificial ice rinks has become an inevitable trend. The National Speed Skating Stadium in the Beijing Winter Olympics is the first

stadium in China to adopt the CO<sub>2</sub> direct system, and the first large speed skating stadium in the world to adopt this system, which promotes the development of China's artificial ice rinks using CO<sub>2</sub> refrigerant. Therefore, this paper presents a fundamental analysis of an artificial ice rink using a CO<sub>2</sub> transcritical system.

### 1.1. Structural Analysis of the Ice Rink Site

The structure of the ice rink site is shown in Figure 1. It includes a surface layer, a base layer, and an antifreeze layer. The surface construction can be divided into the reinforced concrete surface, the sandy surface, and the bare pipe surface. Due to the complete exposure of the cold pipe to the bare pipe surface layer, it is easy to damage and is rarely used at present [9]. The base layer usually consists of a protective layer, a sliding layer, a waterproofing layer, and an air barrier. To prevent the freezing of soil moisture, it is necessary to install a frost protection layer, which is made of a compacted sand layer with a built-in PE hot water pipe. Currently, the most commonly used anti-freezing measure is to arrange anti-freezing drainage pipes.

Mun [10] modeled a small ice rink for laboratory use with a sandy surface. The ice rink model is constructed as a three-layer structure: it consists of a timber floor with a thickness of 6.35 mm, a sandy surface layer with a thickness of 12.7 mm (including copper pipes), and a water layer with a thickness of 25.4 mm, with polystyrene insulation located on the lower side of the floor. The performance of the ice rink site during ice production was investigated through experimental setup analysis and numerical simulations. Haghghi et al. [11] investigated the temperature distribution of the ice field under two concrete structures by using the transient planar heat source (TPS) method to measure the properties of conventional and modified concrete. The results show that the temperature difference between the ice surface and the refrigerant carrier of the supply discharge pipe in the ice rink with improved concrete is reduced by 1-4 °C for the same heat flow density, while energy savings of 3-10% of the refrigeration system's energy consumption can be achieved. In addition, both comparison ice rink models were analyzed using reinforced concrete surfaces and assuming a constant heat source for the supply and cooling drains. Ferrantelli et al. [12] used COMSOL Multiphysics to model the ice and

concrete layers in two dimensions to perform transient simulations of the ice field temperature distribution. Selected 27mm, 35mm, and 40mm cold pipe sizes as the object of study, and from 25mm to 30mm to change the depth of the

pipeline, the study shows that the pipeline size changes in temperature by only 1°C, increasing the number of pipes to the ice surface temperature distribution is more uniform.

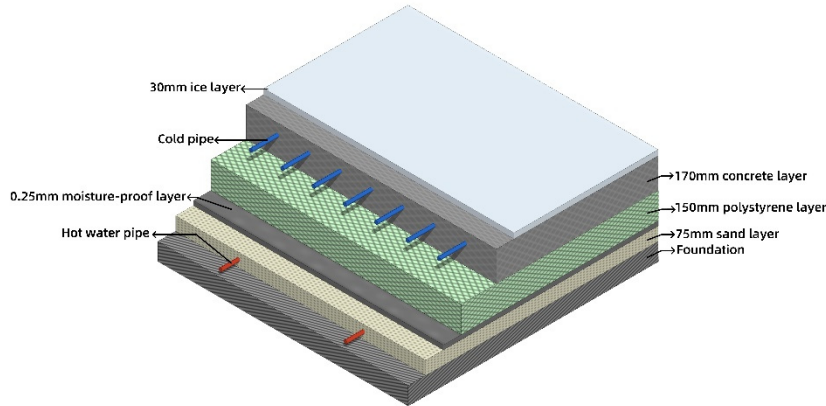


Figure 1. Ice rink structure

## 2. Refrigeration System Flow Analysis

### 2.1. Indirect Ice Rink Refrigeration Systems

Figure 2 shows a schematic diagram of a CO<sub>2</sub>/CaCl<sub>2</sub> indirect ice rink system, where the primary loop refrigerant is CO<sub>2</sub> and the carrier coolant is CaCl<sub>2</sub> brine. The brine enters the ice field through the solution pump. After the ice production is finished, the brine flows into the evaporator and CO<sub>2</sub> for direct heat exchange and then enters the ice field again to complete the circulation of the carrier cold pipeline. For the CO<sub>2</sub> line, the CO<sub>2</sub> absorbs the heat from the brine through the evaporator. And then through the compressor into a high-temperature and high-pressure gas, flow through the gas cooler to become a medium-temperature and high-pressure gas, and finally through the throttling expansion in the form of a low-temperature and low-pressure liquid with the brine for heat exchange. CO<sub>2</sub> has a high heat recovery potential when used as a refrigerant, and the recovered heat can be used extensively in ice rink support systems. However, the secondary loop is brine, with higher pumping power. When CO<sub>2</sub> is used as a primary-loop refrigerant, its COP is lower than that of the NH<sub>3</sub> indirect system.

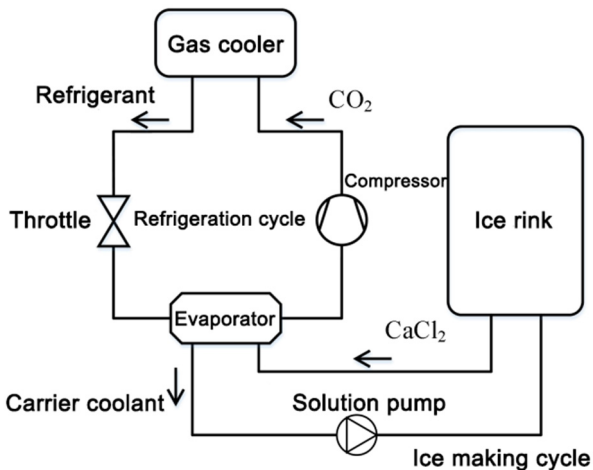


Figure 2. CO<sub>2</sub>/CaCl<sub>2</sub> indirect ice rink system.

### 2.2. Direct Ice Rink Refrigeration Systems

As shown in Figure 3, CO<sub>2</sub> liquid enters the ice rink

through a refrigerant pump and enters the CO<sub>2</sub> tank in a CO<sub>2</sub> gas-liquid two-phase flow after ice production is completed. The CO<sub>2</sub> tank acts as a gas-liquid separator. The separated CO<sub>2</sub> gas flows into the compressor and is compressed into a high-temperature and high-pressure gas; at this time, the CO<sub>2</sub> is in the supercritical state; in the gas cooler, condensing exothermically into a medium-temperature high-pressure gas; then into the throttle valve, throttling and cooling to become a CO<sub>2</sub> liquid; and then with the CO<sub>2</sub> tank separated of the liquid together with the cold pump pumped into the ice for the next cycle. Since this system does not require intermediate heat exchange, its evaporation temperature is higher than that of the NH<sub>3</sub>/CO<sub>2</sub> indirect refrigeration system. And since the work mass is CO<sub>2</sub>, the pump power is significantly reduced, saving costs. It has the highest heat recovery potential.

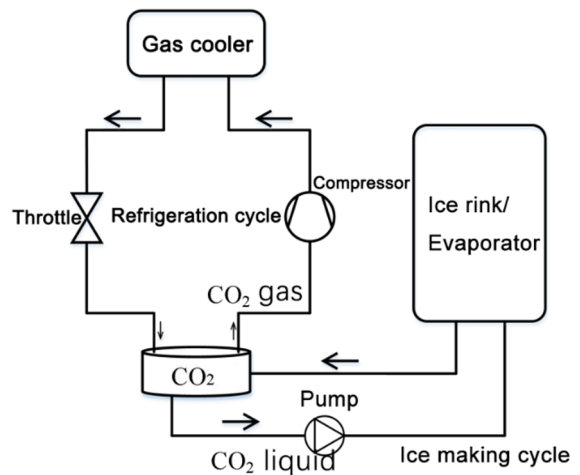


Figure 3. CO<sub>2</sub> direct evaporative ice rink system.

## 3. Conclusion

CO<sub>2</sub> as a refrigerant has important environmental significance and practical value and has outstanding environmental advantages compared with traditional refrigerants. With the application of the CO<sub>2</sub> transcritical refrigeration cycle system, the efficiency of the ice rink refrigeration system has been greatly improved.

Due to the international and domestic promotion and advancement of environmental protection and cleanliness,

and based on the good energy-saving and environmental protection of CO<sub>2</sub> refrigeration systems in ice rinks, China will use the CO<sub>2</sub> transcritical refrigeration cycle system for ice rinks for the first time in the speed skating stadium of the 2022 Winter Olympics, which not only responds to the concept of "Green Olympics, Scientific, and Technological Olympics," but also promotes the engineering and technical application of CO<sub>2</sub> refrigeration systems in ice and snow rinks and their development. It is of great significance for the popularization of natural mass refrigeration technology, which is conducive to the promotion of energy conservation, emission reduction, and environmental protection throughout society.

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