CO_2 Ice-Making: A High-Pressure, High-Efficiency Path to Clean Refrigeration

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How a closed-loop CO_2 cycle can make ice efficiently. We explain the thermodynamics, design choices, risks, and when pump-driven subcritical operation makes sense.

This webpage QR code

PDF Version of the webpage (maximum 10 pages)

Technical Assessment

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Concept recap:
A closed-loop CO_2 circuit is heated and pressurized, then expanded to a lower pressure to create a cold stream. Liquid water is exposed to this cold stream to form ice. The CO_2 is then cooled and condensed to liquid, pumped back up in pressure, passed through a heat exchanger, and the cycle repeats. Ice is harvested for use.

1) Thermodynamic feasibility

Working fluid: CO_2 (R-744) is a proven refrigerant. Its critical point is 31.1 °C and 73.8 bar. Below the critical temperature (e.g., with a cool heat sink), the cycle can condense to liquid and use a liquid pump for pressurization. Above it, the system operates transcritically and needs a compressor instead of a pump.
Cold production: Cooling is produced during expansion (throttling/Joule–Thomson or via an expander) followed by evaporation at low pressure. This can readily reach the temperature margin to freeze water, provided the evaporator is at or below \~−5 to −15 °C.
Avoiding dry ice: CO_2's triple point is −56.6 °C at \~5.2 bar. The design must keep the low side above the triple-point pressure to avoid dry-ice formation and blockage.

2) Cycle architecture options

Subcritical, pump-driven (your description):
If the heat sink (ambient, groundwater, or cooling tower) can cool the high side below 31 °C, CO_2 can be fully condensed. Then a liquid pump raises pressure efficiently. Important: add heat after pressurization mainly to reject it again at the condenser/gas cooler; you do not want to intentionally heat before expansion, since that reduces net refrigeration. The liquid should be cooled as much as possible before expansion to maximize the refrigeration effect.
Transcritical, compressor-driven:
If ambient is warm (common), the system runs transcritical with a gas cooler (not a condenser) and a compressor. This is common in CO_2 refrigeration, and ice making is practical, but you lose the "liquid pump" efficiency benefit.

3) Ice formation method

Indirect freezing (recommended): Use a scraped-surface or plate evaporator. Water flows on one side; CO_2 evaporates on the other. Ice forms on metal surfaces and is harvested (flaked or released). This avoids CO_2–water contact, contamination, and blockage risk.
Direct-contact spray into cold CO_2 (not recommended): Spraying water directly into the low-pressure CO_2 stream risks entraining moisture, forming slush/ice inside the CO_2 side, fouling valves, and complicating oil management. It also complicates dehydration of the refrigerant loop.

4) Efficiency (COP) considerations

Liquid pump advantage: When subcritical, using a pump instead of a compressor to raise pressure can improve COP because pumping a liquid requires far less work than compressing a gas.
Expected COP: For ice-making temperatures, a practical CO_2 system may achieve COP ≈ 1.5–3.0, depending on ambient temperature, heat exchanger approach, and whether you recover expansion work (expander/ejector).

Ballpark energy: Freezing 1 kg of 25 °C water requires ~~418 kJ of cooling (to chill to 0 °C and freeze). With COP = 2.5, input energy ≈ 0.046 kWh/kg (~~42 kWh per metric ton of ice), excluding auxiliaries.
Upgrades:

Can carbon dioxide be the heart of an efficient ice-making system? Yes—if you manage pressures, temperatures, and ice formation wisely. Here's how.

Introduction

As demand for efficient, climate-friendly refrigeration grows, carbon dioxide (CO_2, R-744) has reemerged as a compelling working fluid. Its favorable thermophysical properties, non-flammability, and negligible GWP compared with legacy refrigerants make it attractive for ice production—provided the cycle is engineered correctly.

How the CO_2 Ice Cycle Works

A CO_2 ice system circulates the refrigerant in a sealed loop. On the high side, heat is rejected in a condenser or gas cooler. If the heat sink is cool enough to condense below the 31.1 °C critical temperature, the refrigerant becomes a liquid. A liquid pump can then raise pressure with minimal work input. The liquid is subcooled as much as possible and expanded across a valve—or, better, an expander. The low-pressure stream becomes cold, feeding an evaporator that freezes water into ice. The CO_2 vapor returns to the high side, and the cycle repeats.

In warmer climates, the same concept runs transcritically using a compressor and a gas cooler. Control of gas cooler outlet temperature and high-side pressure is central to performance.

Making Ice Without Fouling the Refrigerant

The most reliable approach is indirect: water flows across a cold evaporator surface while CO_2 boils inside the tubes. Ice forms as flakes or releases from plates during a harvest cycle. This avoids direct contact between water and refrigerant, keeps the CO_2 loop dry, and eliminates slush blockages.

Efficiency Considerations

When subcritical, pumping liquid CO_2 instead of compressing gas can significantly improve efficiency. With good heat exchanger design and smart controls, practical systems can reach COP values in the 1.5–3.0 range for ice-making temperatures. Adding an expander or ejector reduces throttling losses and can provide a meaningful boost in capacity and COP.

Design Notes and Safety

Keep the suction pressure safely above the CO_2 triple point to avoid dry-ice formation.
Use vessels, piping, and valves rated for high pressures, and install pressure relief and gas detection.
Treat water to limit scale on ice-contact surfaces, and select an ice-harvest strategy (scraped surface, plate release, or slurry) that matches your product form and capacity.

When CO_2 Makes Sense

CO_2 is particularly attractive where a cool heat sink is available for subcritical operation or where regulatory drivers favor natural refrigerants. For large, industrial ice production with waste-heat recovery and careful controls, CO_2 provides a modern, sustainable alternative to legacy fluids.

Conclusion

A closed-loop CO_2 cycle can produce ice efficiently and safely when engineered around its unique

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Conclusion

A closed-loop CO_2 cycle can produce ice efficiently and safely when engineered around its unique pressure-temperature map. Choose the right architecture (subcritical with a pump or transcritical with a compressor), isolate the water from the refrigerant, and control the expansion process. Do that well, and CO_2 delivers clean, scalable ice production.