Introducing a New Ammonia/CO$_2$ Cascade Concept for Large Fishing Vessels

Per Skærbæk Nielsen
Thomas Lund
YORK Refrigeration, Marine & Controls

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What fishermen want....

Essentially – Frozen fish, right here - right now

- Rapid freezing is extremely important for product quality
- Available space on board is severely limited
- System must be able to withstand harsh environment on board
- Hazards from refrigerant leaks must be acceptable
- Long terms solution with regards to laws and regulations
- Simple system and good availability of parts and service
MS Kvannøy

• 75m (250 ft) trawler / purse seiner.
• Freezes 210 tons (463,000 pounds) of fish per day.
• Complete filleting & packaging system
• 2 ammonia Refrigerated Sea Water units
• CO$_2$ / ammonia cascade freezing system with hot gas defrosting.
The CO$_2$ / ammonia cascade

- 6 reciprocating CO$_2$ compressors, 3 available for defrosting
- 2 screw ammonia compressors
- 11 CO$_2$ vertical plate freezers, 39 stations each
- 1 CO$_2$ vertical flake ice machine
- Natural air convection CO$_2$ coils in 3 cargo holds
- Shell and tube interstage heat exchanger

Total capacity 1350 kW (4,606 MBH) at $-48^\circ$C ($-54.4^\circ$F)
Concept diagram

CO2 / NH3 Cascade System

Air Cooler
VPF
Standstill Cooling Unit

CO2 Hot Gas Defrost Compressor

Reciprocating

Screw

CO2 Cooling Compressors

Desuperheater

Oil Rectifier

Cascade Cooler/Condenser

Pilot Receiver & Expansion Valve

Filter Dryer & Sightglass

Patent pending

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Hot gas defrosting

- Defrost system only pressurized when in operation (50 bar, 725 psi)
- Minimum gas volume under defrost pressure
- High defrost capacity available, 800 to 1000 kW (2.729-3.412 MBH)
- Overall power consumption saving while defrosting
- Compressor can be used both for freezing and defrost

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Evaporator (VPF) design

- Evaporators need to be specially designed for CO₂.
- High vapour density yields low velocity and bad flow pattern (1-2).
- Smaller channels and longer circuits result in better flow pattern (3-6, 6 best).
- CO₂’s behaviour keeps pressure loss within acceptable limits.

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Stand still unit and safety

- Stand still unit keeps low-pressure receiver at max –25°C (-13°F)
- During black-out, evaporators return liquid and not vapour.
- Stand still unit can handle complete shut-down
- Safety valves fitted at appropriate locations
- Solenoid valve can blow charge under controlled conditions

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Lubrication

• Fully miscible Polyol Ester oil (POE) used
• Piping system built like a traditional R22 system.
• Miscible oil an advantage for lubrication of system components
• No negative effects seen with regards to heat transfer efficiency

Be aware:
• Oil is hygroscopic and very miscible.
• No POE oil into the ammonia system.

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Special CO$_2$ issues

- Elastomer compatibility problems reported above 50 bar (725 psi)
- Below 50 bar (725 psi) some elastomers (PTFE) cause product problems (capacitative rods, ball valves)
- Cavitation is apparently no problem. Implosion energy is approximately 3% of water at 1 bar.
- CO$_2$ create acid with water. Drying filters is a necessity
- Strong cleaning effect. Careful cleaning during construction.
- Isolated sections with CO$_2$ present an high pressure hazard
- Evacuation to ambient pressure does not necessarily mean that the system is empty (dry ice)
Controlling the system

• Fast responding control system necessary
• A defrost introduce rapid changes in both the CO$_2$ & NH$_3$ system
• Defrost compressor must be kept within it’s operating limits

• Low capacity situation demands fine regulation (dry ice)
• Small recips offer low minimum capacity
• Some recips can run fully unloaded
Expected concept benefits

• Lowering TE from –40°C to –50°C (-40°F to –58°F) theoretically means a reduction of the freezing time by 20%. Production up 25% (1/0.8 = 1.25)

• Reduction in equipment size increases production per deck area

• No loss of product due to refrigerant leaks (possibly lower insurance)

• Improved quality from faster freezing and fast defrosting

• Pressure loss behaviour of CO₂ is very favourable
Experiences: Freezing

Expectations fulfilled, and:

Whole round herring, frozen to a core temperature of \(-25^\circ\text{C} (-13^\circ\text{F})\)

- Traditional R22, TE=\(-40^\circ\text{C} (-40^\circ\text{F})\) 3 to 3½ hours
- CO2 / NH3, TE=\(-48^\circ\text{C} (-54.4^\circ\text{F})\) 1 ¾ hour

Freezing time compared to traditional systems (R22, TE = -40°C, -40°F) is 40% better

Possible reasons: Smaller temperature difference between plates and low-pressure receiver results in higher gain than the 25%.
Experiences : Defrosting

• No soft spots found on fish blocks after defrost. Handling blocks with soft spots will result in damage which reduce the price. (5 to 15%)

• Uniform temperature distribution on plates during defrost

• Efficient defrost of plates, manifolds and hoses.

• Due to the low temperature, metallic contact is essential to defrost elements not heated
Service

• Evacuation very easy as refrigerant can be blown off
• CO₂ does not expand, but contract when frozen
• Liquid charge can be kept in an open system as dry ice
• Dry ice in filters etc when opened is no problem

Careful!

• Dry ice can block valves, hoses etc during evacuation. Make sure that the section is completely equalized before dismantling.
• Enclosing a dry ice charge can lead to high pressures.

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Environment

For the same freezing capacity – old concept versus new concept

“Kvannøy”
Old: 13 tons (28600 lb) R22, TE = -40°C (-40°F)
New: 5.5 tons (12100 lb) CO₂, TE=-48°C (-54.4°F), 600 kg (1300 lb) NH₃

“W. Van Der Zwan”
Old: 55 tons (121000 lb) R22, TE = -43°C (-45.4°F)
New: 12 tons (26500 lb) CO₂ and 1 tons (2200 lb) NH₃, TE=-50°C (-58°F)

“Atlantic Dawn”
Old: 5 tons (11000 lb) NH₃ + 100 tons (220000 lb) CaCl, TE=-42°C (-43.6°F)
New: 12.5 tons (27500 lb) CO₂ and 1 tons (2200 lb) NH₃, TE=-50°C (-58°F)
Conclusion

CO2 is not just the future – it’s also the present

• All features normally expected in a system can be realized with CO2
• System utilizes well known refrigeration components and technology
• Faster freezing – better product quality – higher production
• Environmental friendly – both globally and locally
• Quick reacting control system necessary
• Minimum load situation needs attention during design

The experience actually exceeded the expectations!