New Copper-based Heat Exchangers for R744 Refrigerant: Technologies for Tubes and Coils

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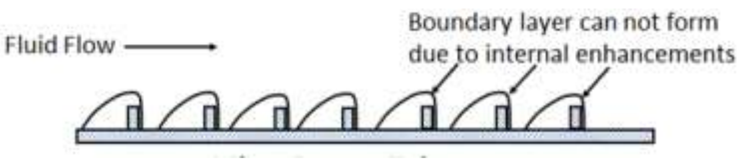
Introduction

- This paper presents critical information about how heat exchangers based on round inner-grooved small-diameter copper tube and newly-developed flat copper microchannel tubes can be applied in air conditioning and refrigeration equipment using new alternative refrigerants with special emphasis on R744
- Heat exchangers based on inner-grooved copper tubes with 5mm or 4mm outer diameters provide effective and lower cost solutions for R744 refrigerant systems
- These heat exchangers have:
  - high strength needed to sustain R744 operating pressures and conditions, and
  - antimicrobial performance to eliminate mold growth.

Small diameter copper tube technology

Heat Transfer Technologies

- Copper tube + aluminum fin modified for greatly enhanced heat transfer:
  - Smaller diameter tube (7 to 4mm)
  - Inner grooving patterns
  - Thinner walls
  - Smaller refrigerant charge
  - Better refrigerant mixing
  - More flexible circuiting to eliminate refrigerant mal-distribution



Tubes of 7mm to 4mm diameter

Herringbone pattern grooving

Benefits of small diameter copper tube

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Extruded and Drawn Products Division

Wieland

Miniaturization: Decreased outside diameter

Example: Optimization of 5.7 ton condenser implementing microgroove technology

Description	Outside diameter	Bottom wall [inch]	Unit weight decrease	Required tube length	Material ratio	Refrigerant charge
Base line	3/8"	0,0118	100%	280 ft	100%	100%
microgroove	5 mm	0,0083	36%	420 ft	54%	44%

Cuts metal costs nearly into half
Improves energy efficiency
Significantly **reduces** heat exchanger **weight**
Maintains all **advantages of copper** tube based heat exchangers
Reduces refrigerant charge by >50%

Small diameter tube performance effects

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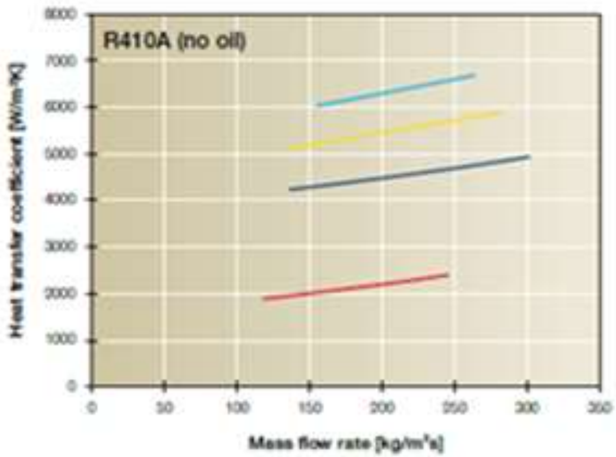
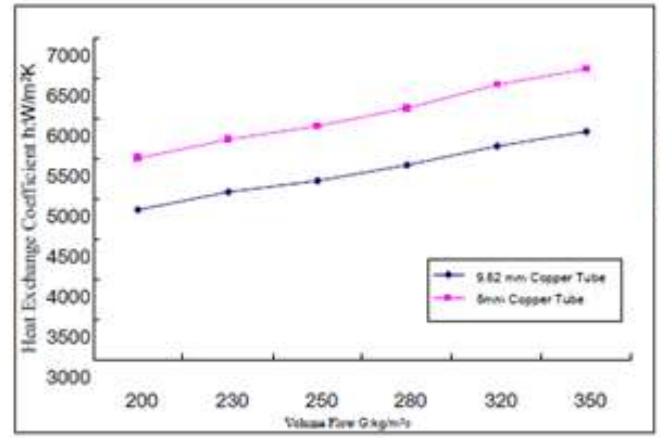
+50% HTC with 2nd generation tube; +100% vs smooth tube using R410A





+20% HTC with 5mm Cu vs 9.53mm tube using HFC refrig.

Test conditions

Condensation – 9.52 mm tubes
t_c = 35 °C
subcooling ~2 K, inlet superheat ~5 K
tube length 2 m

- 2nd generation condensation tube
- Optimized condensation tube
- Standard inner-grooved tube
- Smooth tube

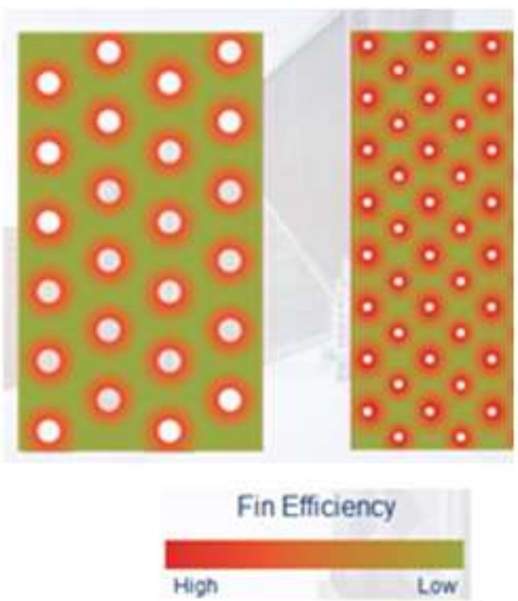
5mm vs 9.53mm tube heat exchanger:

- Up to 50% tube and fin weight reduction
- 50+% reduction in internal volume
- 50% wall thickness reduction
- 50+% HTC enhancement
- 40% reduction in heat exchanger cost

Effects of fin hole patterns on HTC

Compounding benefit of small diameter tubes:

- Greater effective primary fin heat transfer area
- Higher inside (tube) and outside (Fin) HTC
- Fins can be downsized for more compact heat exchanger

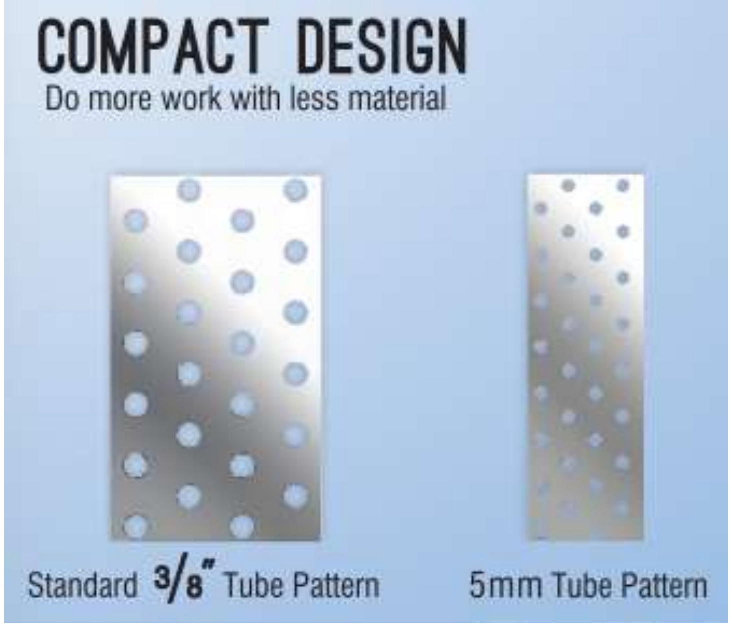


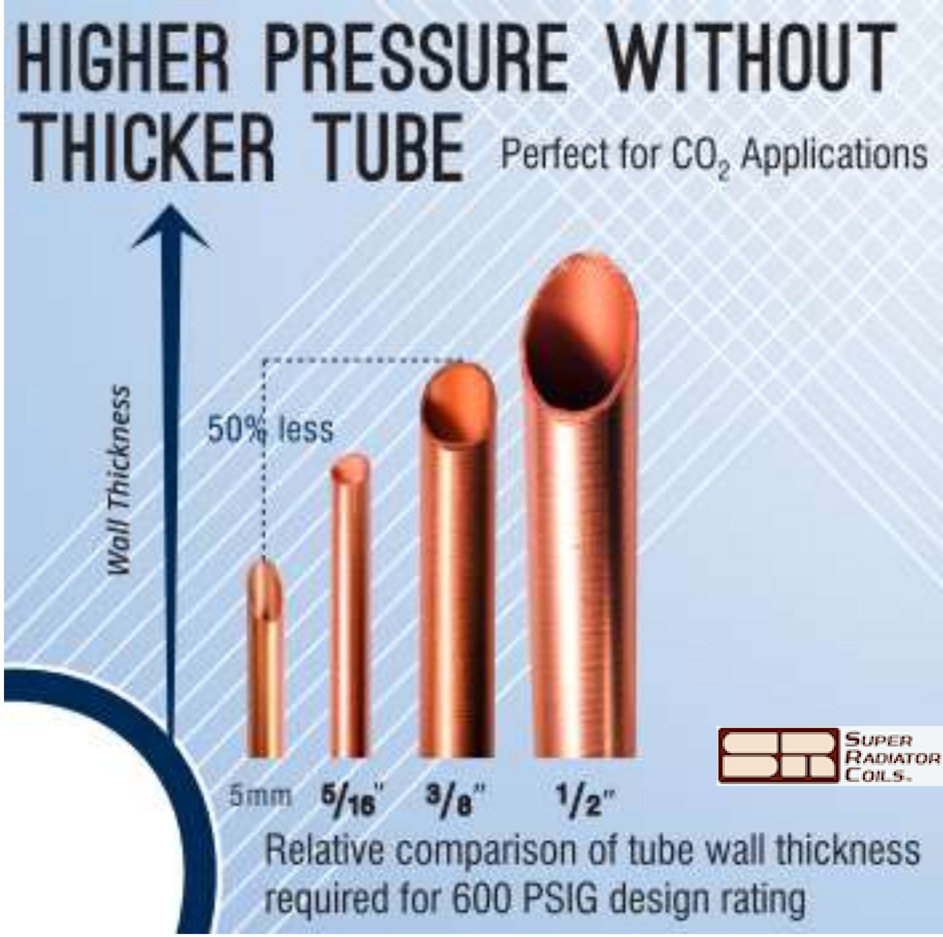
$Q = \underline{U}\,\underline{A} \times \Delta T$

- A → Less metal required for same effective area (A)
- U → Better inside and outside heat transfer coefficients

For R32, R290 and R744 – Smaller diameter copper tube an advantage:

- Higher pressure capable
- Lower refrigerant charge
- Compact design





Example

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For R32, R290 and R744 – Smaller diameter copper tube an advantage:

Tube O.D.	3/8"	5mm	5mm	5mm
Height	36"	36"	36"	36"
Length	60"	60"	42"	60"
Rows	4R	4R	6R	6R
Cu, lbs.	50	23 ↓↓↓	25 ↓↓↓	35 ↓
Al, lbs.	50	30 ↓↓	32 ↓↓	42 ↓
Internal Volume, l	14.9	6.0 ↓↓↓	6.3 ↓↓↓	8.5 ↓↓
Capacity, BTUH, 000's	196	196	196	240 ↑↑↑
Air Friction, in. H_2O	0.65	0.48 ↓	1.08 ↑	0.64

Copper alloy tube for high pressures

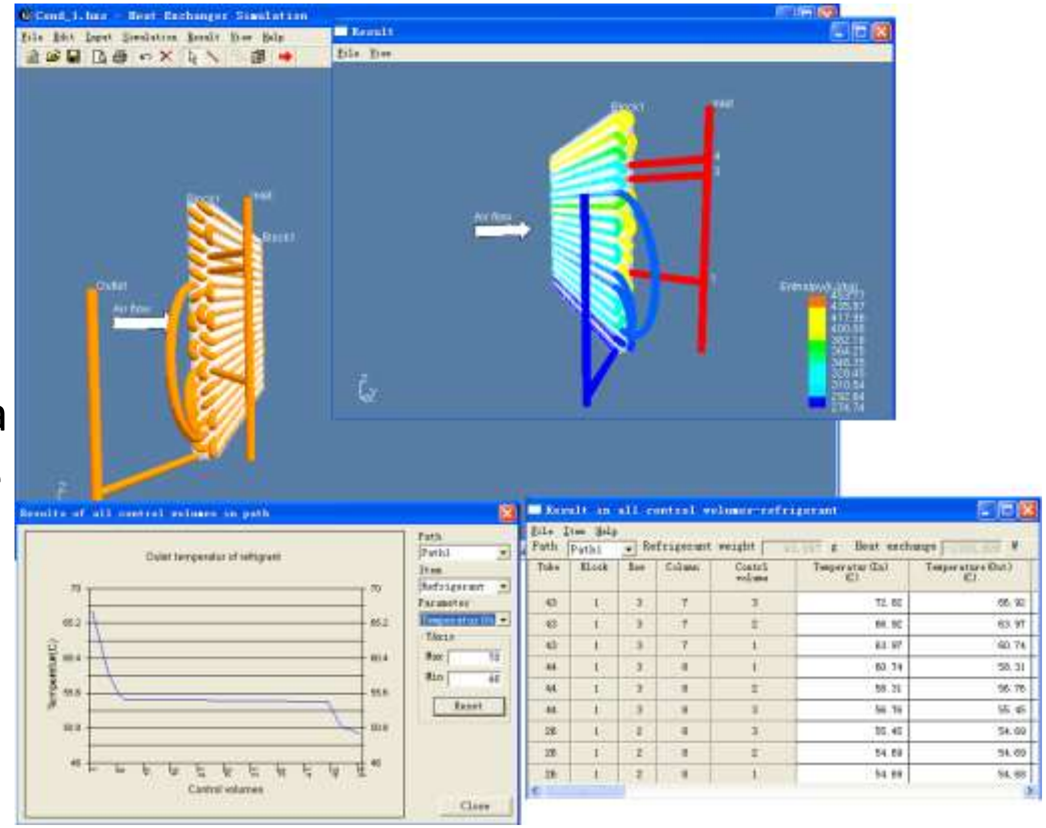
- In addition to std. copper material, smooth or inner-grooved tubes made of a high-strength copper alloy (CuFe2P) are suitable for high pressure applications using R744
- CuFe2P alloy consists of copper alloyed with Fe (2.1 to 2.6 wt. %), Zn (0.05 to 0.20 wt. %), P (0.015 to 0.15 wt. %) and Mg (0.10 max. wt. %)
- Wall diameters as low as 0.25mm
- Brazeable and weldable
- Withstands 2X the pressure of standard copper ACR tube

Plain and inner-grooved tubes for CO_2 applications

System design software for small tube HX

Heat Transfer Technologies

- Heat exchanger and system design software is available for small diameter copper tube HX in Refrigeration systems
- CFD modeling package with interactive graphical interface
- Gives user the option to choose a tube diameter, inner groove tube geometry, fin design and refrigerant type
- Optimizes entire system of compressor, evaporator, and condenser with a cost analysis
- Simulates all key technical parameters needed to optimize the performance and cost of small diameter copper tube heat exchangers and total system



Simulation results in 2D and 3D views with parameter charting

Copper microchannel tube heat exchangers

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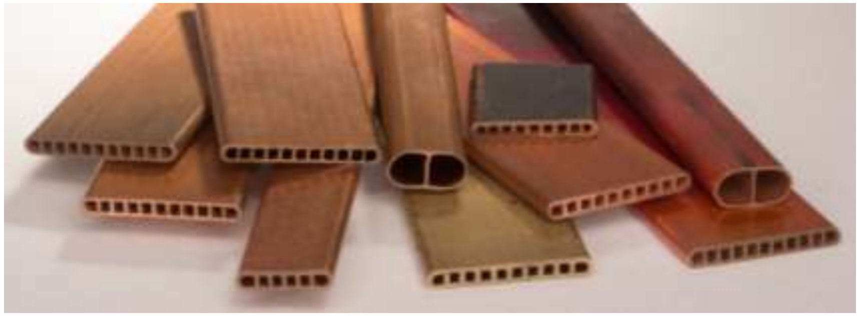
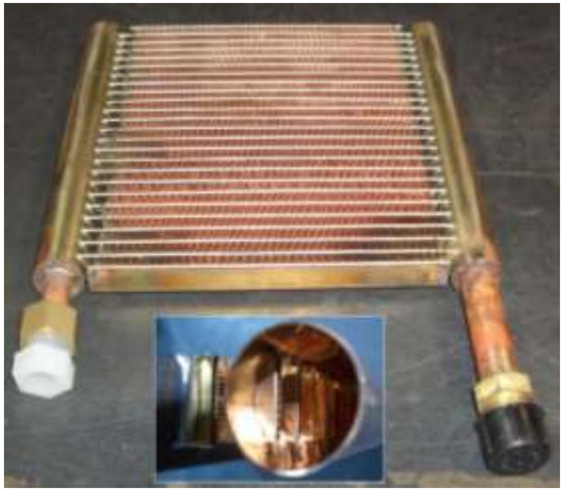
- Produced by hot extrusion or roll-bonded
- Precision, thin-wall, 0.2-0.3mm
- Multichannel copper profile, 1.0-1.3mm channel width
- Up to 62 MPa burst pressure with 0.4mm wall and 1mm channels
- Especially attractive for high pressure (17 MPa) and temperatures (180C) of CO_2
- Burst pressures predicted for tubes of 1mm channel width and 0.3mm wall:
- **UNS C12200 copper: 47.6 MPa**
  AA 3102 aluminum: 18.6 MPa
  AA 3003 aluminum: 26.9 Mpa
- 2x27mm Roll formed tube burst at 12MPa



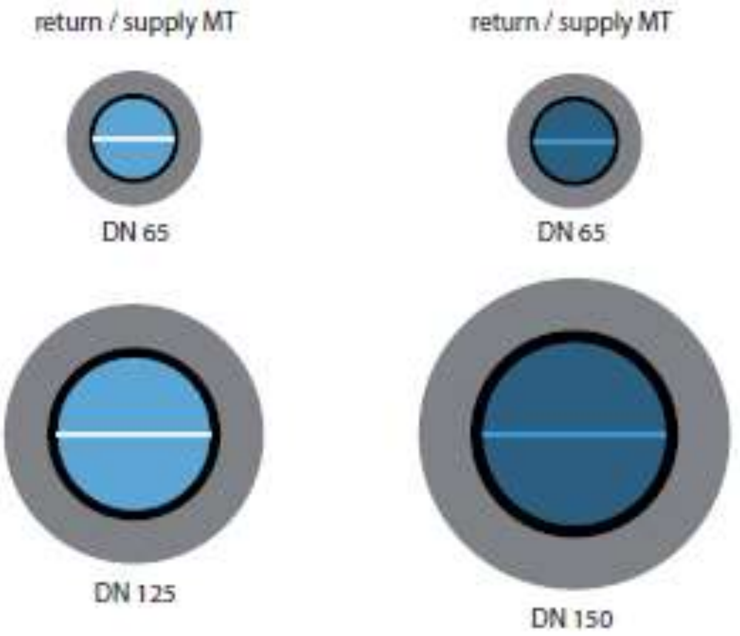


CO_2 refrigeration systems

- Volume of CO_2 required to achieve the same cooling effect is much lower than for HFCs used in refrigeration, so components and tubing can be smaller than in conventional installations
- In CO_2 Cascade system with NH_3, compared to a water-based brine/glycol system, the piping and component size on a CO_2 system is considerably smaller for the same capacity

CO_2 pipes, Copper or steel

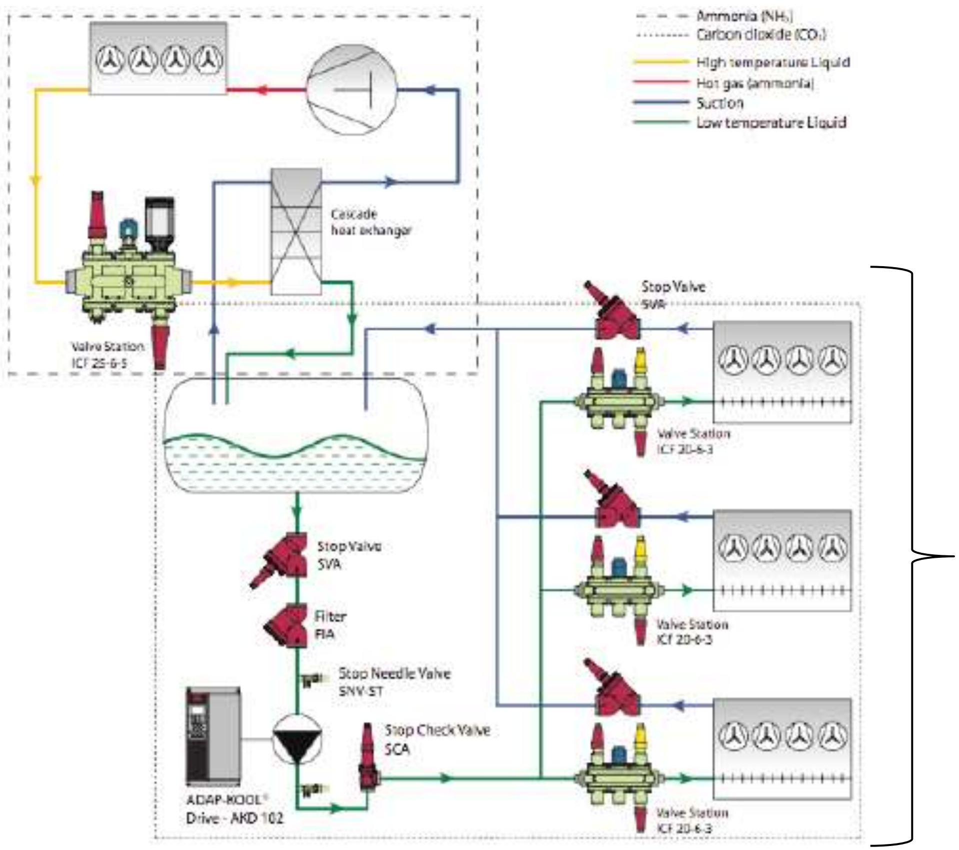
Brine pipes, Steel or plastic



Source: "Examples of NH_3/CO_2 secondary systems for cold store operators", Shecco, 2011

NH_3/CO_2 Cascade system

- In Cascade systems, discharge pressure at 3-3.5 MPa with CO_2 is still within normal design limits for refrigeration pipe work and components
- Potential application for high strength copper alloy CuFe2P tubing in CO_2 lines

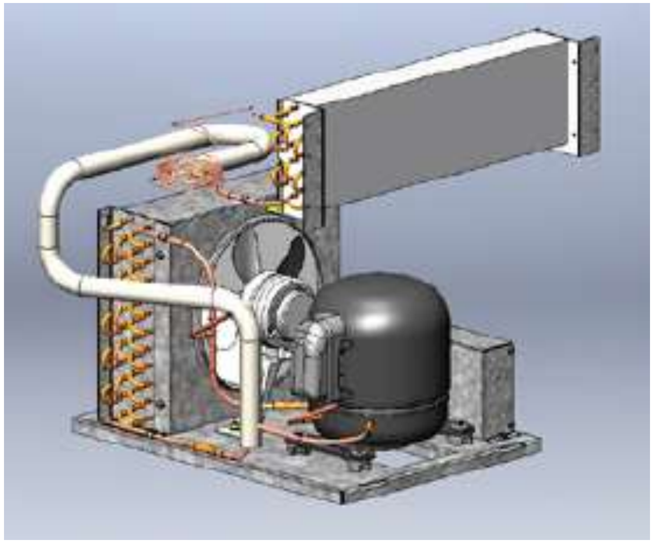


Potential for thin wall CuFe2P copper alloy piping for liquid and vapor CO_2

Source: "Examples of NH_3/CO_2 secondary systems for cold store operators", Shecco, 2011

CO_2 Vending refrigeration system

- Vending refrigeration machines using liquid CO_2 refrigerant
- 10 MPa operating pressure
- Evaporator and condenser both use 5mm inner-grooved copper tube



CO_2 refrigeration cassette with both evaporator and condenser using 5mm inner-grooved copper tube.

(SandenVendo America)

CO_2 Secondary loop refrigeration systems

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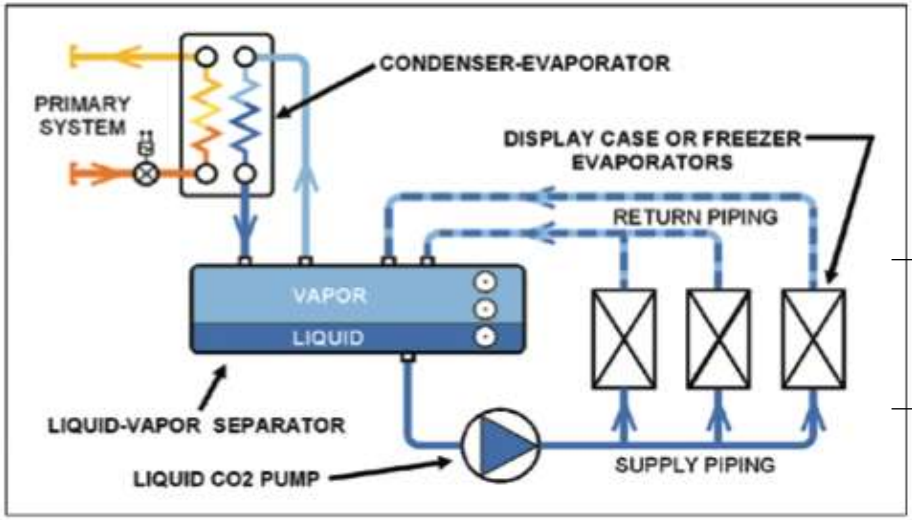
- Pumps circulate liquid CO_2 through a smaller refrigeration device (like a display case) at the required case temperature

- Ideal for thinner-wall CuFe2P high-strength alloy copper piping that is significantly smaller than in traditional Direct Expansion systems, at lower cost



Low Temp secondary loop system using liquid CO_2

Potential for thin-wall CuFe2P copper piping for liquid CO_2

Source: Hill Phoenix

Copper tubing reduces costs for piping and insulation:

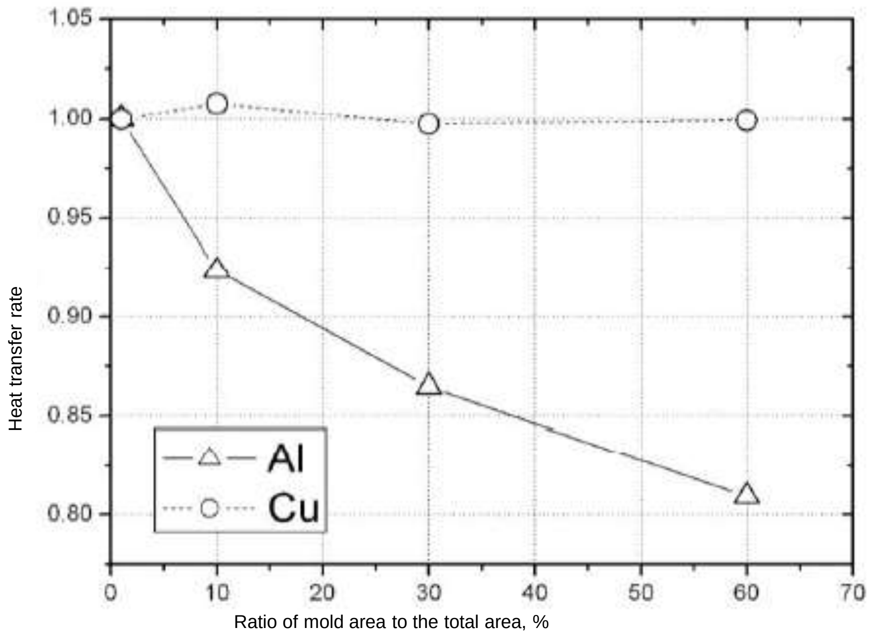
- 42% cost reduction in CO_2 Cascade systems vs DX
- 83% cost reduction in CO_2 Secondary loop systems vs DX
- Additional 67% cost reduction vs plastic tube in Secondary Refrigerant Systems

System	Length	Diameter	Insulation	Costs
Direct Expansion (copper tubing)	100m 100m	32mm 10mm	10mm -	100%
Secondary Refrigerant System (plastic tubing)	200m	32mm 10mm	30mm	167%
CO_2 Secondary Refrigerant System (copper tubing)	100m 100m	18mm 6mm	30mm 10mm	83%
CO_2 Cascade System (copper tubing)	100m 100m	18mm 6mm	10mm 5mm	42%
Additional costs not included: fittings, insulation Additional costs for CO_2 : extended pressure range or 2nd defrost system				

Source: U. Hesse, "Secondary Refrigerant Systems for Supermarket Application with Brine or Carbon Dioxide," International Refrigeration and Air Conditioning Conference at Purdue University, 1996, p.372, 374

Copper improves operating efficiency

- Mold buildup cuts efficiency
- **No change in efficiency with all-copper** vs 19% decline with aluminum fin as mold growth reaches 60% of total heat exchanger area
- Important to maintain efficiency throughout system operational lifetime



Source: Ding, G.(2007). Comparative Study of the Long-term Performance of Copper and Aluminum Fin-and-Tube Heat Exchangers. Report V to ICA

Very small diameter finless copper tube HX

Heat Transfer Technologies

- Finless HX cores become practical with very small (0.8mm) diameter tubes
- Experimental performance matches expectations from simulation

Conclusions

- Transition to CO_2 in commercial refrigeration in Cascade, Transcritical R744 booster, and Secondary loop systems is already occurring at a quickening pace in Europe and North America and eventually will expand to rest of world.
- These high-pressure systems will require the use of available smaller-diameter, high-strength alloy, copper tubing, avoiding increased wall thickness and material usage and cost control
- Significant degradation in efficiency from mold buildup and corrosion can be addressed by the use of all-copper heat exchangers
- High-strength copper-alloy tube as well as unalloyed copper tube in smaller diameters, and copper microchannel tube integrated with advanced compact heat-exchanger design match the needs of higher pressure CO_2 refrigeration systems

Thank You