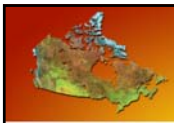
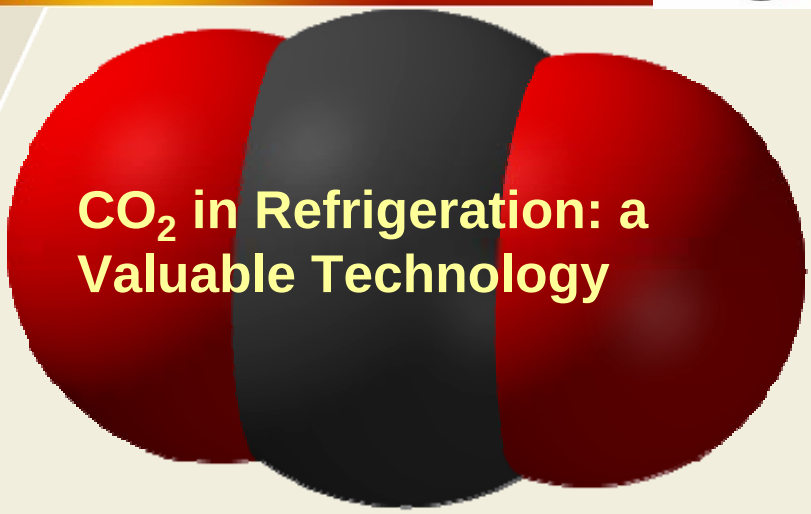


R744



CO_2 in Refrigeration: a Valuable Technology

Daniel Giguère, CETC-Varennes, AQME Trois-Rivières, April 11, 2008

Presentation

R744

For several years, carbon dioxide (**CO_2**) has been making a comeback in the refrigeration industry.
The goal of this presentation is to provide information on the current status of the technologies and applications that use **CO_2** as a refrigerant or coolant. The following points will be presented: a brief **history** of CO_2 in refrigeration, its **thermodynamic properties**, **safety measures**, **industrial**, commercial and residential applications, and finally, some **products available on the market**.

History of CO_2

CO_2 transcritical cycle

Golden age of CO_2

J&E Hall: first two-stage CO_2 refrigeration system

CFCs invented, 1928

History of CO_2 (G. Lorentzen) of Norway

Initial concept of CO_2 as a refrigerant (Alexander Twining, British patent)

Montreal protocol Jan. 1, 1989

1850

1920 ----------1930

1960

1993

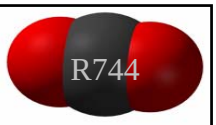
First CO_2 refrigeration system: Carle Linde

*Danfoss, **Niels P Vestergaard Niels P Vestergaard** Ver 2004-04-SI+US*

The Thermodynamic Properties of CO_2

Natural Resources Canada Ressources naturelles Canada

Canada



- CO_2 is now present in the atmosphere in a proportion approximately equal to 0.0375% in volume or **375 ppmv** (parts per million in volume). However, this concentration is increasing rapidly by about **2 ppmv/year** as a result of human activities involving the consumption of fossil fuels: coal, oil, gas.
- CO_2 used in refrigeration is a by-product of ammonia and hydrogen production processes (Wikipedia).

Properties

Refrigerant		R404A	NH_3	CO_2
Natural refrigerant		NO	YES	YES
Ozone Depletion Potential	ODP	0	0	0
Global Warming Potential	GWP	3260	-	1
Critical condition [psi/°F]		541/162	1640/270	1067/88
Boiling point at 15 psig [°F]		-51	-28	-69
Boiling point at 400 psig [°F]		137	144	16
BTU/cubic foot	at -40 [°F]	36	24	226
Saturated ΔT / ΔP = 1 psi at -40 [°F]		2.1	3.4	0.3
Flammability		NO	(slight)	NO
Toxicity		NO	YES	NO

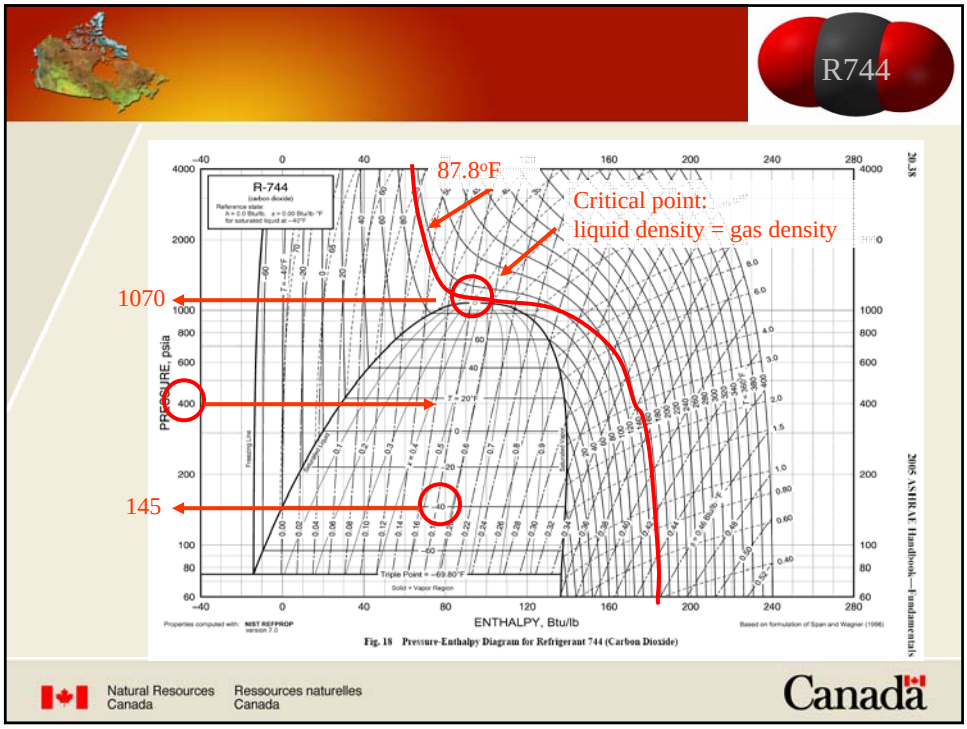


Fig. 18 Pressure-Enthalpy Diagram for Refrigerant 744 (Carbon Dioxide)

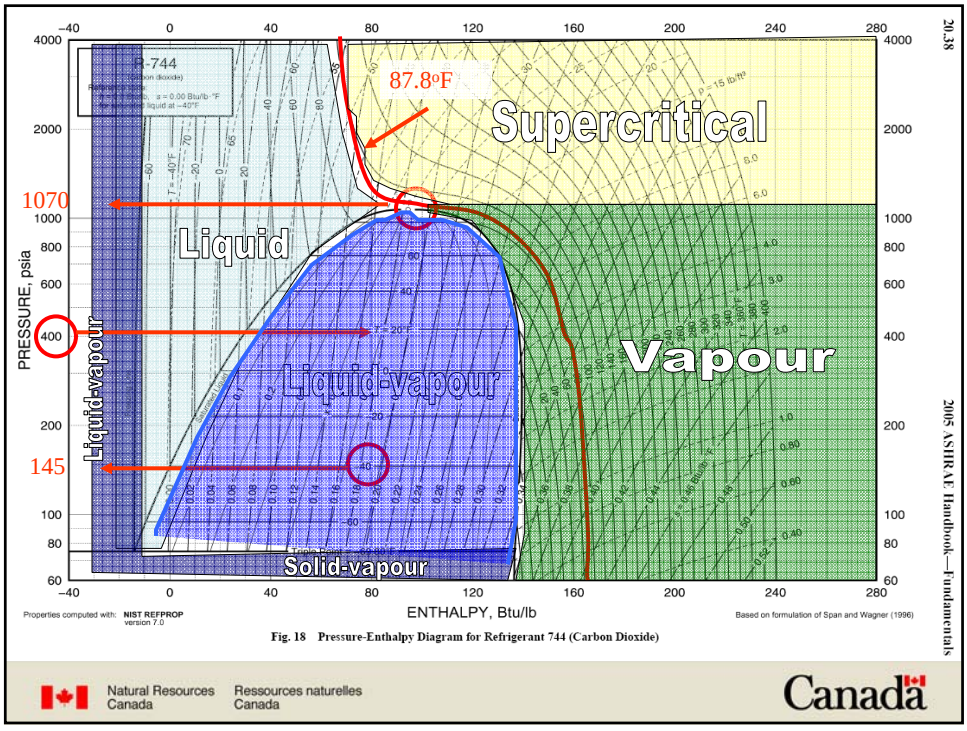
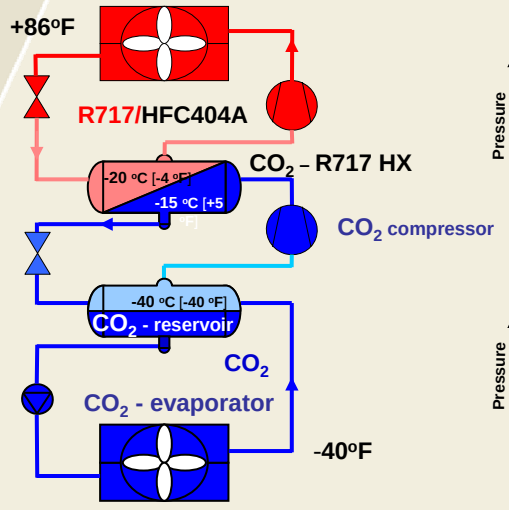


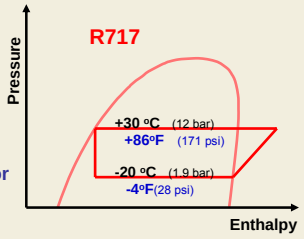
Fig. 18 Pressure-Enthalpy Diagram for Refrigerant 744 (Carbon Dioxide)

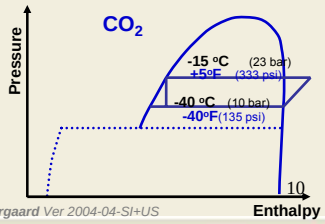
Refrigeration cycles under critical conditions

- Cascade systems
- DX systems
- Secondary fluids

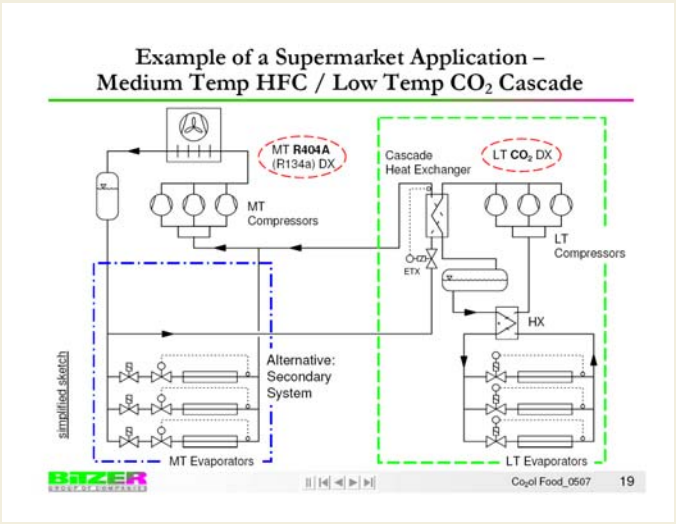
717-CO_2 Cascade System







DX 404A-CO_2 Cascade System



11

Natural Resources Canada | Ressources naturelles Canada

Canada

R744

BENEFITS

- Lower operating temperatures with higher production yields
- Up to 33% better efficiency on the low side
- Lower equipment cost
- Lower installation cost
- CO_2 is classified as nontoxic and nonflammable
- No ammonia in working/process/storage areas

M&M REFRIGERATION

412 Railroad Avenue · PO Box 449
Federalsburg, Maryland 21632
Tel: 410.754.8005 · Fax: 410.754.5813
www.mmrefrigeration.com

EQUIPMENT · ENGINEERING · PARTS · SERVICE

12

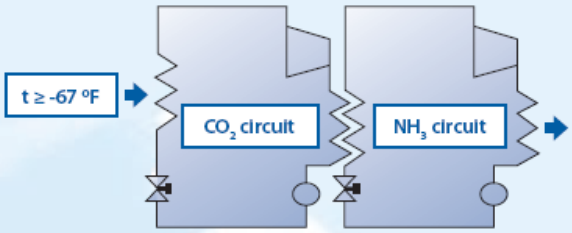
Natural Resources Canada | Ressources naturelles Canada

Canada

R744

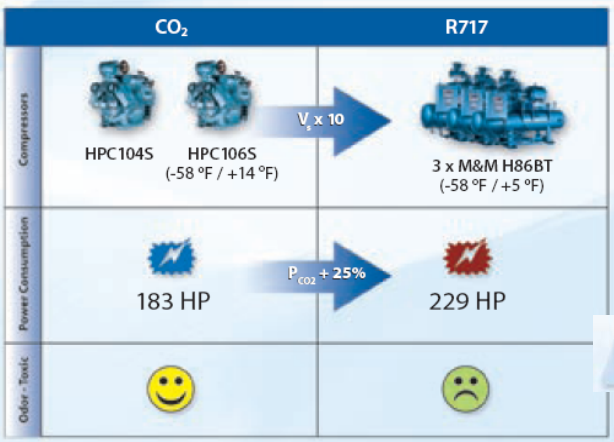
CO_2 - Ammonia Cascade Systems

The innovative M&M Refrigeration CO_2/Ammonia concept is based on a cascade system that combines the advantages of CO_2 on the low-temperature side and ammonia on the high-temperature side. Ammonia is limited to the engine room. Only CO_2 will be present in working/storage area.



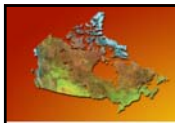
R744

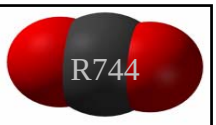
Differences CO_2 versus R717 on the low temperature side at -58 °F, 134TR:



M&M REFRIGERATION

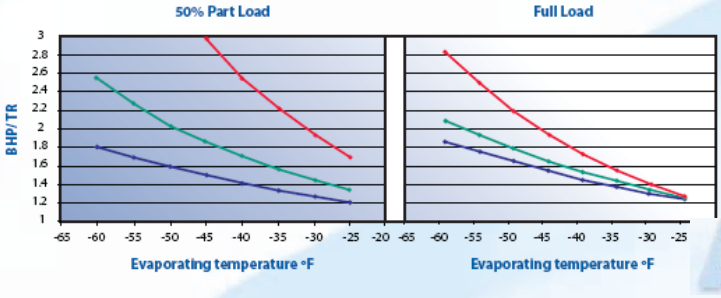
Natural Resources Canada Ressources naturelles Canada
Canada





Low operating costs at low temperatures. Compared with conventional two-stage or single-stage systems with economizer, a CO_2 /Ammonia Cascade System uses significantly less power in the temperature range from -30 °F to -60 °F.

BHP/TR comparison of CO_2/Ammonia with conventional Ammonia Systems

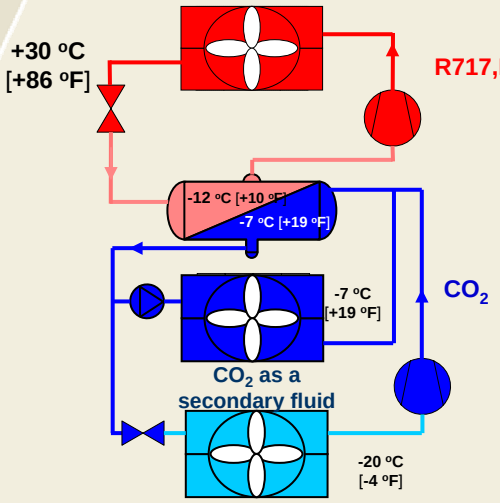


15

Natural Resources Canada Ressources naturelles Canada

Canada

CO_2 Cascade System with Two Temperature Levels (Used in Supermarkets)



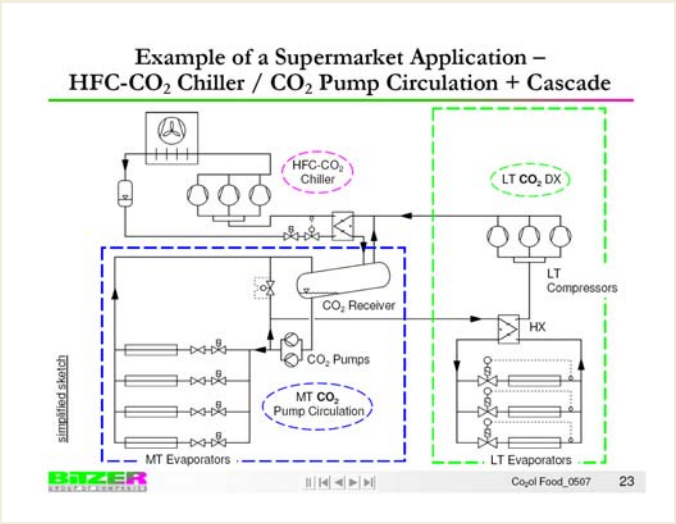
16

Danfoss ,**Niels P Vestergaard Niels P Vestergaard** Ver 2004-04-SI+US

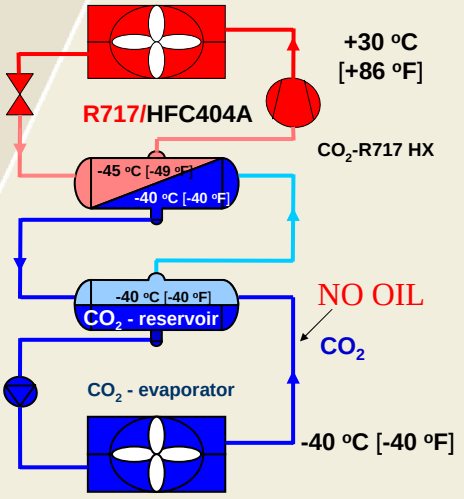
Natural Resources Canada Ressources naturelles Canada

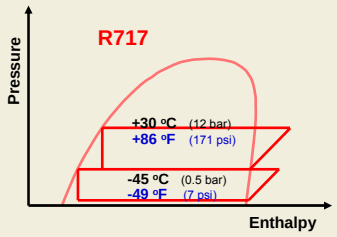
Canada

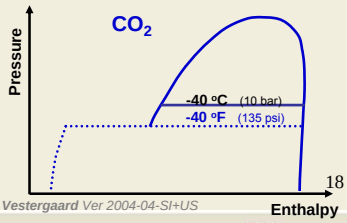
DX-404A secondary fluid-CO_2 Cascade System



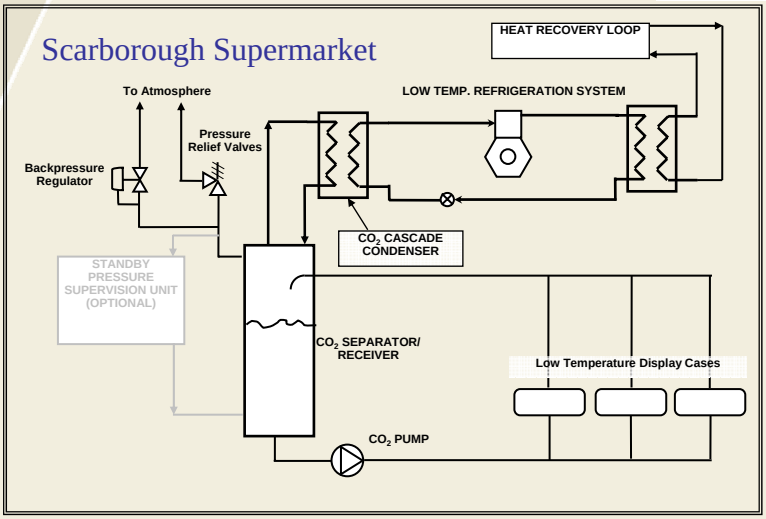
R717 or HFC-CO_2 as a Secondary Fluid





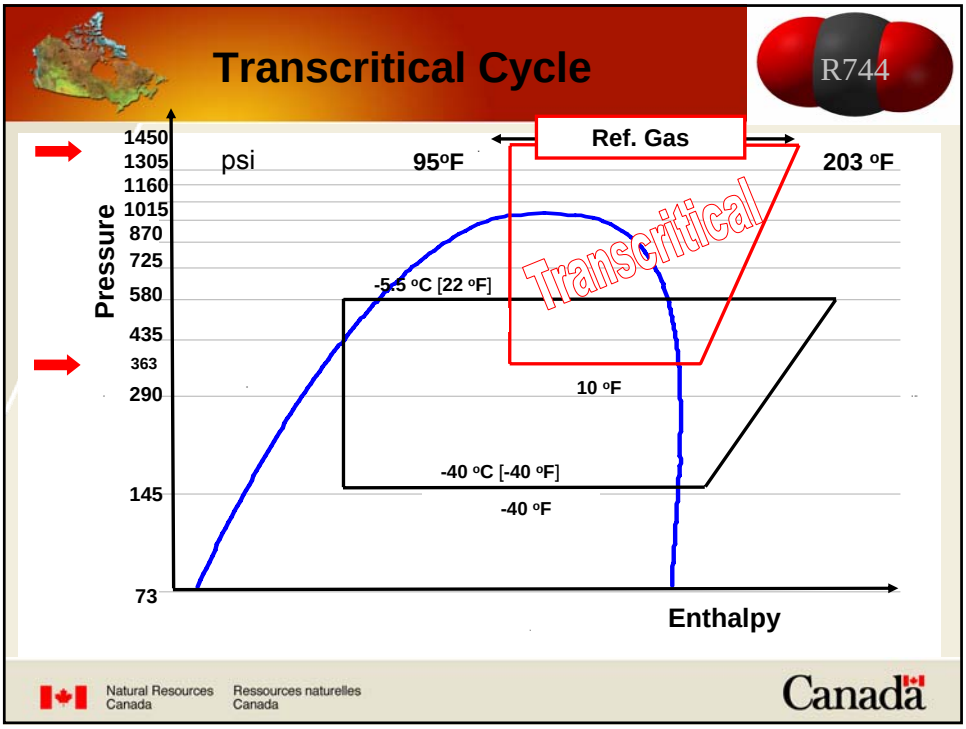


CO_2 as a Secondary Fluid Only

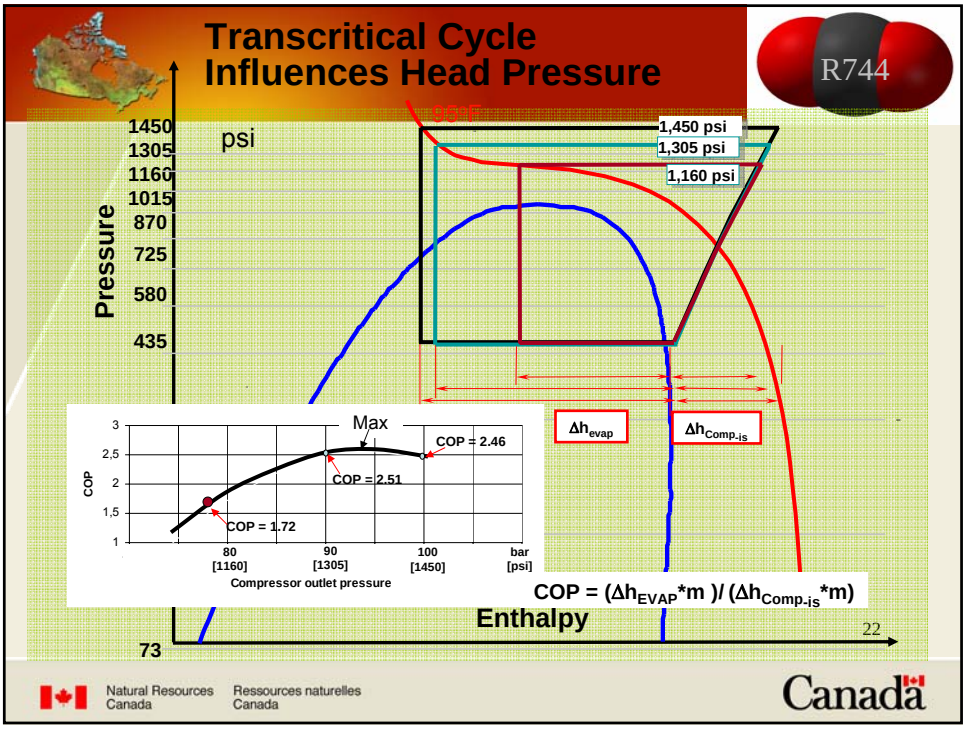


Transcritical refrigeration cycles

Transcritical Cycle



Transcritical Cycle Influences Head Pressure



CO_2 Transcritical Systems with Heat Recovery for Supermarkets

R744

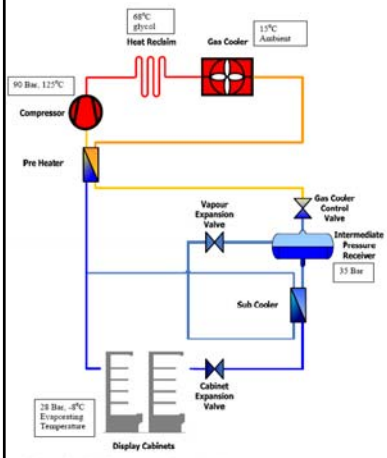


Figure 4. Simplified System Layout (Transcritcal Mode)

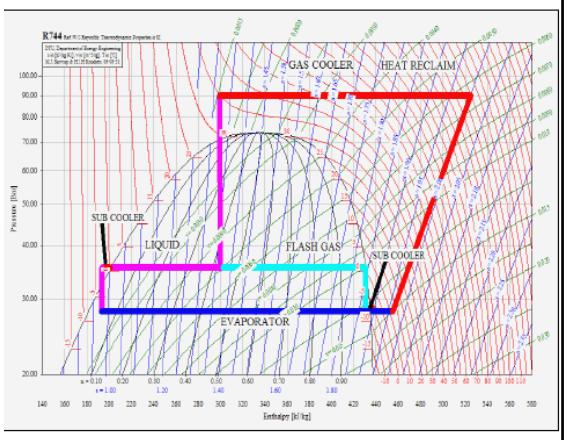
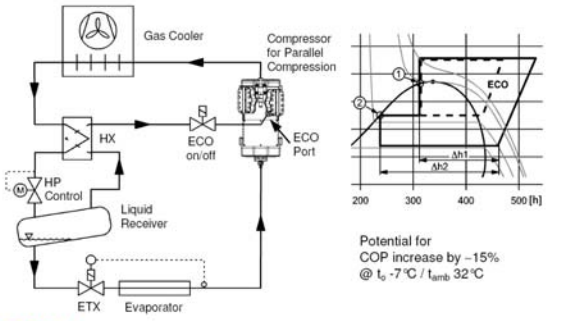


Figure 5. System Cycle Pressure Enthalpy Diagram

R744

The Application of Parallel Compression

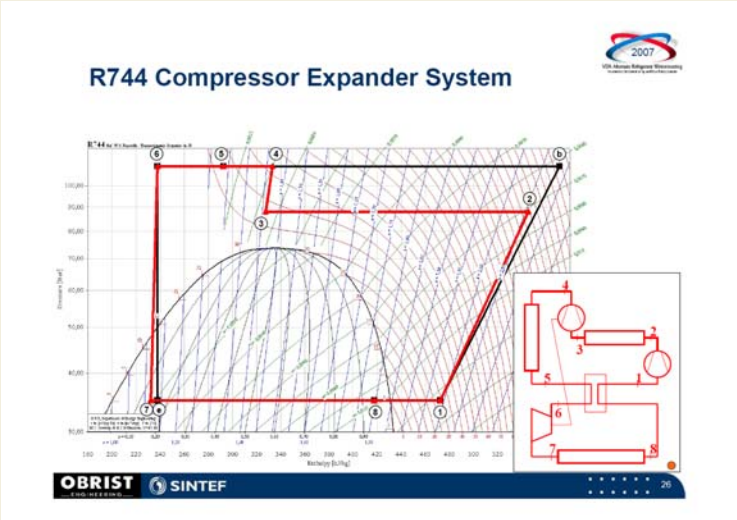
Economiser Circuit "ECO"



Potential for COP increase by –15% @ t_0 -7 °C / t_{amb} 32 °C

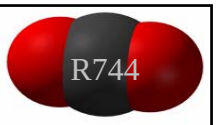
BITZER Co2ol Food_0507 21

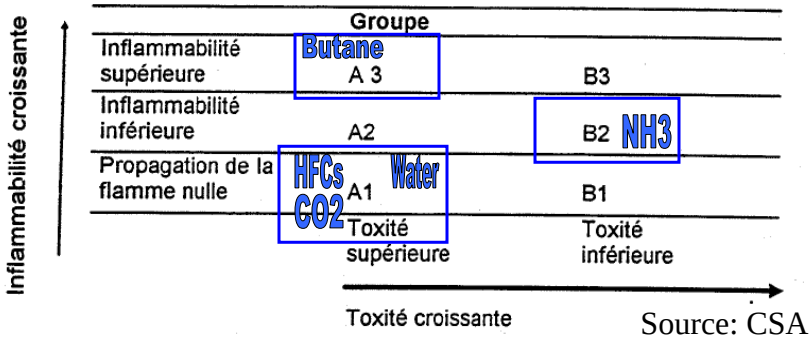
Another Transcritical Cycle



CO_2 Safety Measures

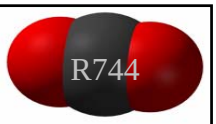
Classification of CO_2 Refrigerant





Source: CSA

Health/Toxicity



- Air contains between 0.03% (**300 ppm**) and 0.06% (600 ppm) carbon dioxide depending on location. Carbon dioxide concentration increases by 2 ppm per year because of human activities.
- A person exhales about 4.5% (45,000 ppm) of carbon dioxide (in volume).
- The CSA B52 refrigeration code determines the maximum refrigerant concentration in percentage by volume so that people can leave the premises without immediate danger to life and health (IDLH). For carbon dioxide, this value is 5%, or **50,000 ppm** (5.7 lbs/1,000 cu. ft.) For example, a 50,000-square-foot supermarket that is 25 feet high can accept a quantity of 50,000*25*5.7/1,000 = 7.125 pounds of carbon dioxide.
- For refrigeration engineers or people exposed to refrigerants for eight hours a day, the threshold limit value (TLV) they can withstand without adversely affecting their health is 0.5% or **5,000 ppm**.
- Regarding air quality, **1,000 ppm** causes discomfort in 20% of people. At **2,000 ppm**, discomfort is generalized and may cause headaches or nausea.
- Given that carbon dioxide is odourless, a detector should be installed in a ventilated mechanical room.

Design Pressure

R744

Design pressure depends on:

- Operating pressure
- System shutdown pressure
- CSA Code B52 - Refrigeration
- CSA Code B51 - Pressure vessels and pressure piping

CSA Minimum Design Pressure Requirements

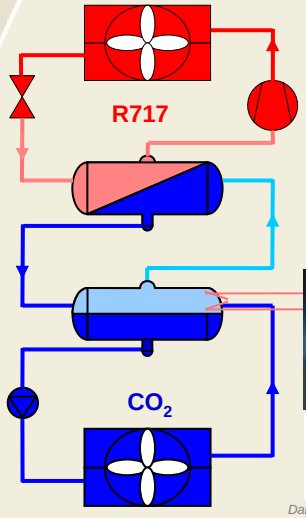
R744

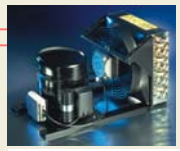
Tableau 6.1
Pressions minimales* de calcul
(Voir les articles 6.2.1 et 8.1.2)

		Pressions minimales de calcul (manomètre)					
		Côté basse pression		Côté haute pression			
				Refroidi à l'eau ou par évaporation		Refroidi à l'air	
Frigorigène	Nom	kPa	(lb/po²)	kPa	(lb/po²),	kPa	(lb/po²),
R-11	Trichlorofluorométhane	103	15	103	15	145	21
R-12	Dichlorodifluorométhane	579	84	875	127	1165	169
R-13	Chlorotrifluorométhane	3591	521	3770	547	3770	547
R-13B1	Bromotrifluorométhane	1585	230	2213	321	2826	410
R-14	Tétrafluorométhane	375	544	3750	544	3750	544
R-22	Chlorodifluorométhane	993	144	1454	211	1916	278
R-40	Chlorure de méthyle	496	72	772	112	1041	151
R-113	Trichlorotrifluoroéthane	103	15	103	15	103	15
R-114	Dichlorotétrafluoroéthane	124	18	241	35	365	53
R-115	Chloropentafluoroéthane	1048	152	1337	194	1737	252
R-123	Dichloro-2,2trifluoro-1,1,1 éthane	103	15	103	15	125	18
R-134a	Tétrafluoroéthane 1,1,1,2	593	86	937	136	1282	186
R-170	Ethane	4246	616	4887	709	4887	709
R-290	Propane	889	129	1296	188	1682	244
R-C318	cfafluorocyclobutane	234	34	407	59	586	85
R-500	Dichlorodifluorométhane, 73,8 % et fluorure d'éthylidène, 26,2 %	703	102	1055	153	1399	203
R-502	Chlorodifluorométhane, 48,8 % et Chloropentafluoroéthane, 51,2 %	1110	161	1599	232	2075	301
R-503	Trifluorométhane, 40,1 % et Chlorotrifluorométhane, 59,9 %	4253	617	4253	617	4253	617
R-600	N-Butane	159	23	290	42	420	61
R-600a)	Isobutane	269	39	434	63	607	88
R-611	Formiate de méthyle	103	15	103	15	103	15
R-717	Ammoniac	951	138	1475	214	2020	293
R-744	Dioxide de carbone	6583	955	7293	1058	7293	1058
R-764	Dioxide de sulphure	310	45	538	78	793	115
R-1150	Ethylène	5046	732	5046	732	5046	732

* Les conditions d'expédition, de fonctionnement et de mise en attente peuvent nécessiter le choix d'une pression de calcul supérieure.
† Les pressions de saturation correspondent à une température du côté basse pression de 27 °C (80 °F) et à une température du côté haute pression de 40 °C (105 °F), dans un système refroidi à l'eau ou par évaporation, et de 52 °C (125 °F), dans un système refroidi à l'air.

Maintaining Shutdown Pressure





Pressure regulation unit

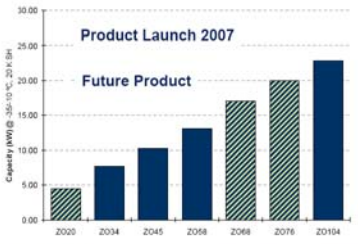
CO_2 pressure regulator that flushes out to atmosphere

Applications: Products Available on the Market

Copeland CO_2 Subcritical Scroll Product Overview & Outlook

Model	Motor Size	Cooling Capacity @ 100%	Displacement	Net Weight
	Hp	kW (1)	m³/h	kg
ZO 34 K3E	1.9	8	4.1	31
ZO 45 K3E	2.6	11	5.4	32
ZO 58 K3E	3.4	13	6.9	34
ZO 104 KCE	6.0	23	11.7	40

(1) Evaporating -35°C, Condensing -10°C, Suction Superheat 20 K, Subcooling 0K



Just like scroll

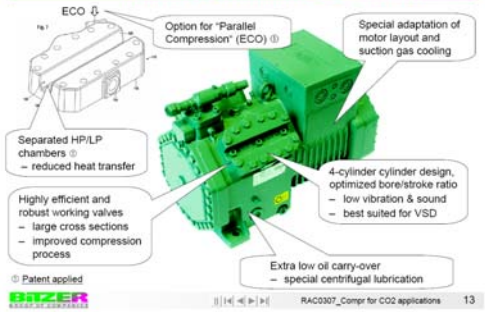
Copeland

Cooling with Carbon Dioxide, 26 th March 2007, Page 6

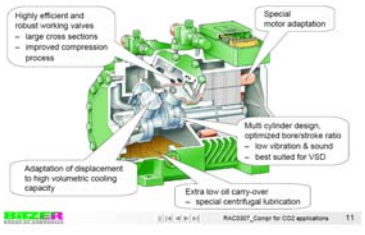
EMERSON Climate Technologies

R744

CO_2 Compressors for Trans-critical Applications – Measures for Improved Performance & Efficiency



CO_2 Compressors for Sub-critical Applications – Measures for Improved Performance & Efficiency

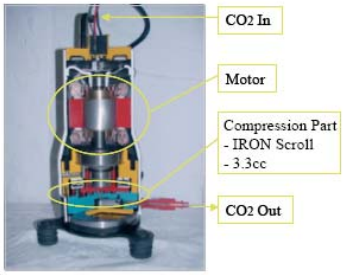


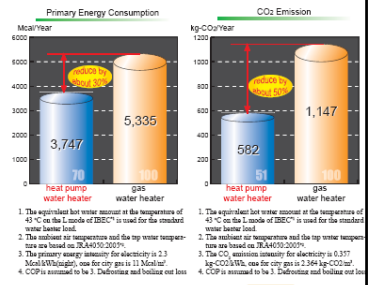
Natural Resources Canada Ressources naturelles Canada

Canada

Eco-Cute
CO_2 Water Heater

R744





- Five million of these will be installed in Japan by 2010.

R744

	Winter (Dec.-Mar.)	Intermediary (Others)	Summer (Jun.-Sep.)	Yearly
Ambient air temperature (°C)*1	4.6	13.8	22.5	-
Tap water temperature (°C)	8.3	15.9	23.2	-
Hot tap water temperature (°C)*2	65	65	65	-
Estimated system COP (-)*3	3.1	3.5	3.9	-
Hot tap water demand (MJ)	7369	5828	4291	17488
Energy consumption (MJ)	2378	1679	1115	5172
Estimated yearly average COP				3.4

*1 Temperatures are the average for each season.
*2 Heating capacity / power input to inverter of compressor motor
*3 Heating capacity / power input to heat pump unit (including input to air fan and water pump)

Table 1: Estimation of yearly average COP of the final prototype for a family living in Tokyo

IEA Heat Pump CENTRE NEWSLETTER Volume 24 No. 3/2006

Natural Resources Canada Ressources naturelles Canada

Canada

Figure 3 – Carrier 60kW CO2 Heat Pump installed on restaurant roof in Oregon

IEA Heat Pump CENTRE NEWSLETTER Volume 24 No. 3/2006

Nestlé

In 2000, no commercial freezers with scraped-surface CO_2 heat exchangers were available on the market. **In 2001, Nestlé installed the largest CO_2-NH_3 cascade system ever built in the past 50 years at the Nescafé plant** in Hayes, UK. Nestlé engineers and the R&D department, in collaboration with key suppliers such as Star Refrigeration (www.star-ref.co.uk), took on the challenge of the in-house development of a first CO_2 freezer to freeze coffee liqueur.

R744

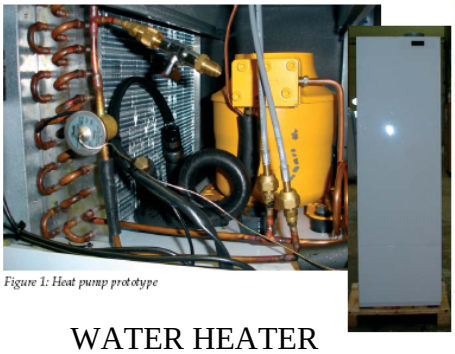


Figure 1: Heat pump prototype

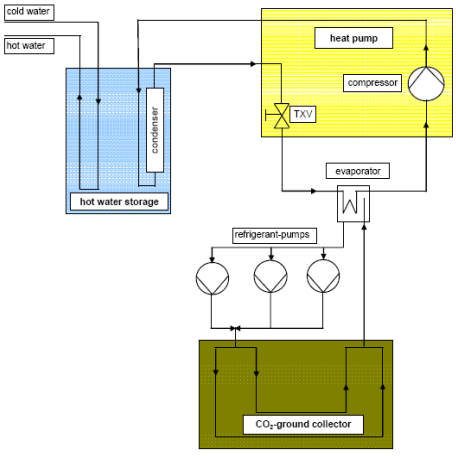
WATER HEATER

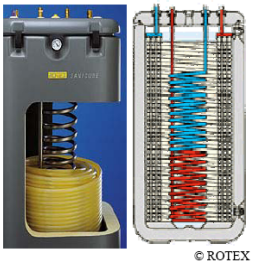
Figure 4: Heat pump in commercial clothes drier (front and back)

DRYER

CO_2 Horizontal Ground Loops

R744





© ROTEX

Figure 1. Scheme of the installed heat pump system (left), hot water storage (right)

R744

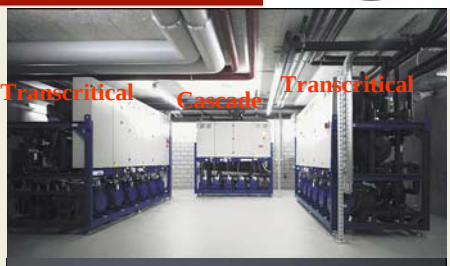
Target Applications

R744

Natural Resources Canada Ressources naturelles Canada
Canada

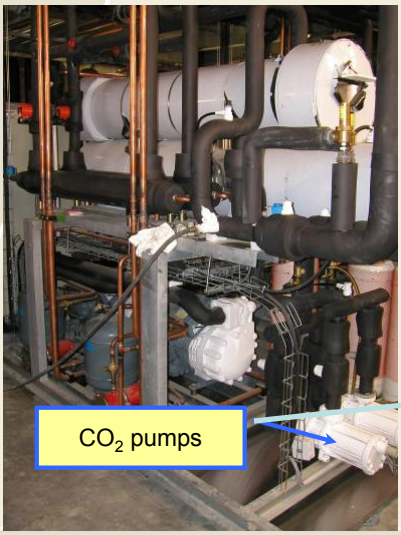
CO_2 Commercial Refrigeration Equipment

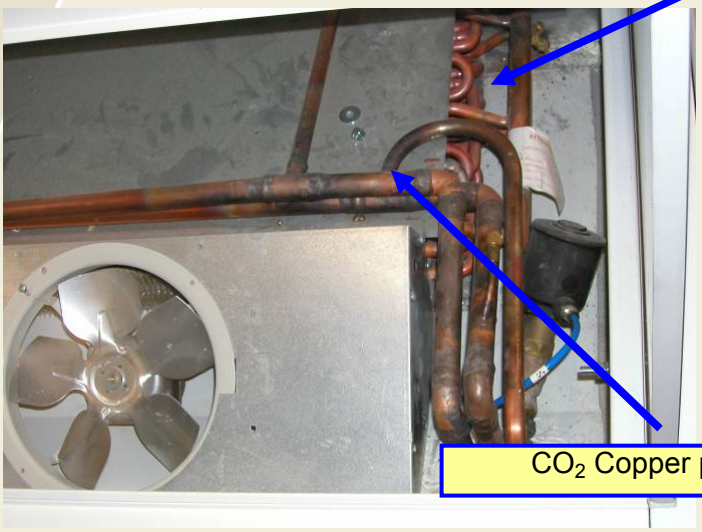
R744



CO_2 as a Secondary Fluid

R744





45

Natural Resources Canada Ressources naturelles Canada

Canada

Conclusions

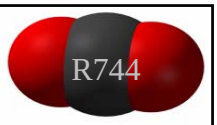
- The development of products and applications that use CO_2 has accelerated in the last 10 years.
- These applications cover all sectors.
- Low-temperature refrigeration and heat pumps are especially promising .
- Operating pressures can be high, but the equipment is more compact and often more efficient.
- CO_2 is a natural refrigerant that is **safe** and inexpensive.

46

Natural Resources Canada Ressources naturelles Canada

Canada

Conclusions



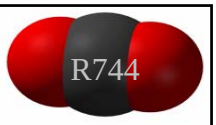
- It is a refrigerant that can be used as an efficient and safe secondary fluid for cold applications.
- Subcritical equipment is available on the market at competitive prices.
- Transcritical equipment is being developed.
- Every refrigeration equipment manufacturer around the world is interested in CO_2 as a refrigerant.

47

Why CO_2?

Strong arguments	Commercial/ Supermarkets	Industrial refrigeration
Environment Gradual elimination of substances that deplete the ozone layer, such as CFCs and HCFCs: (ODP (Ozone Depletion Potential), GWP (Global Warming Potential))	☐	
Safety Toxicity and inflammability for systems using large ammonia loads		☐
Costs • Lower operating costs because of • energy efficiency of compressors and • improved heat transfer • Lower refrigerant costs • Lower component volume	☐	☐

48



CO_2 is a HOT refrigerant.

Thank you.

Any questions?

c-dig, the carbon dioxide interest group

www.R744.com

http://www.heatpumpcentre.org