USE OF NATURAL REFRIGERANTS

By
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CFC REFIGERANTS

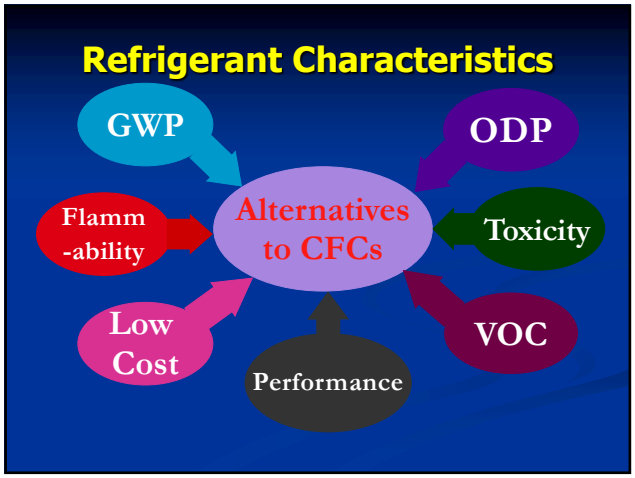
Thomas Midgley & Albert Henne & Robert McNary, working with General Motors and Frigidaire developed CFC refrigerants as safe alternatives to toxic refrigerants in the year1928

These refrigerants were Considered as man made & god sent refrigerants for long time

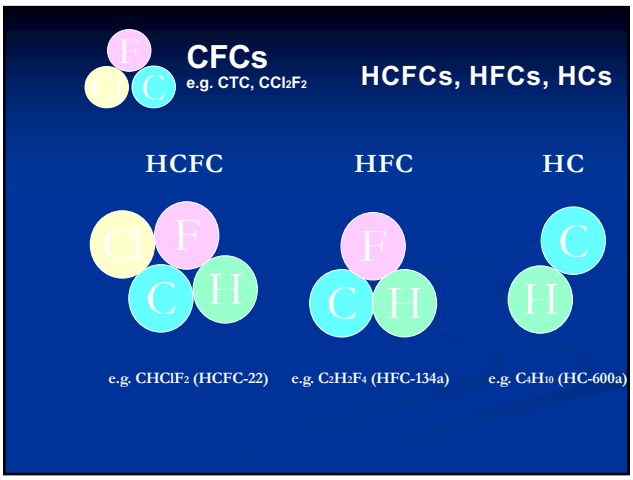
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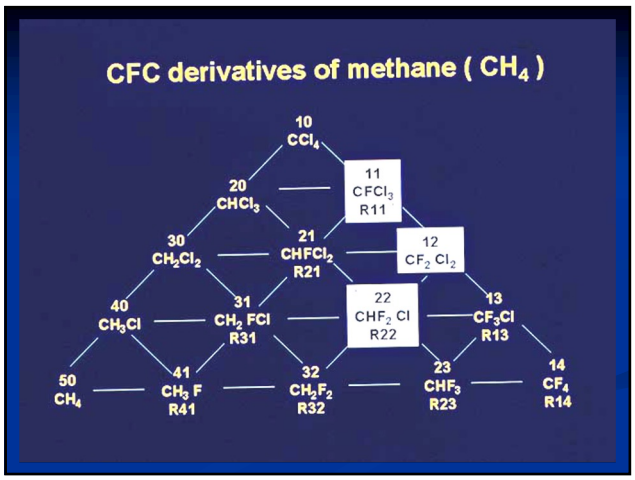
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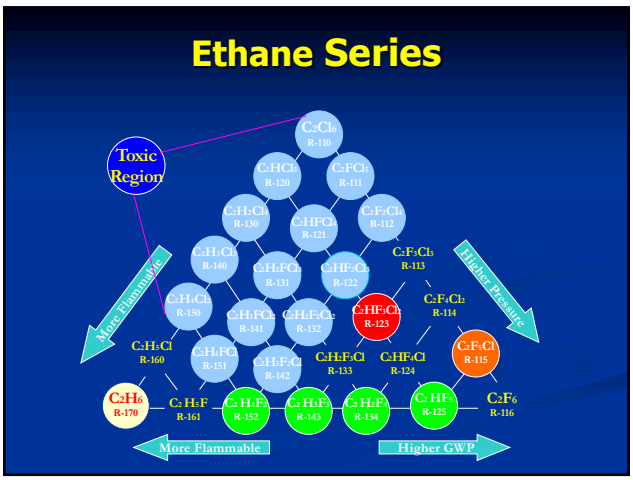
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CFCs
e.g. CTC, CCl_2F_2
HCFCs, HFCs, HCs
HCFC
HFC
HC
e.g. $CHClF_2$ (HCFC-22)
e.g. $C_2H_2F_4$ (HFC-134a)
e.g. C_4H_{10} (HC-600a)

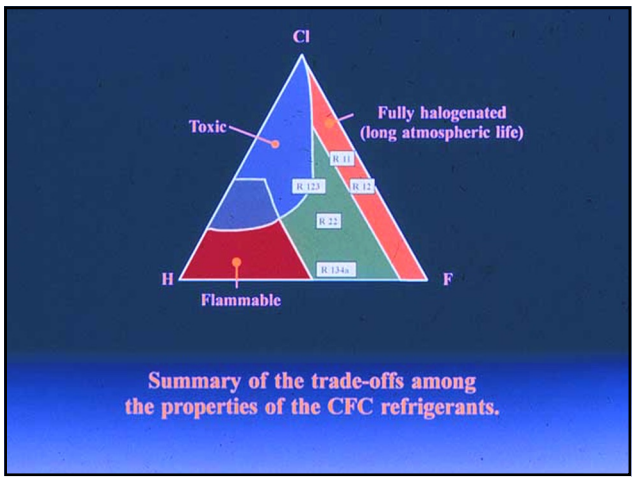
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CFC derivatives of methane (CH_4)
10 CCl_4
20 $CHCl_3$
11 $CFCl_3$ R11
30 CH_2Cl_2
21 $CHFCl_2$ R21
12 CF_2Cl_2
40 CH_3Cl
31 CH_2FCl R31
22 CHF_2Cl R22
13 CF_3Cl R13
50 CH_4
41 CH_3F R41
32 CH_2F_2 R32
23 CHF_3 R23
14 CF_4 R14

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Ethane Series
Toxic Region
More Flammable
Higher Pressure
More Flammable
Higher GWP

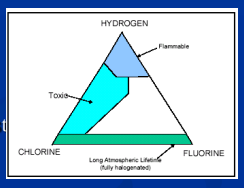
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Cl
Toxic
Fully halogenated
(long atmospheric life)
H
F
Flammable
Summary of the trade-offs among
the properties of the CFC refrigerants.

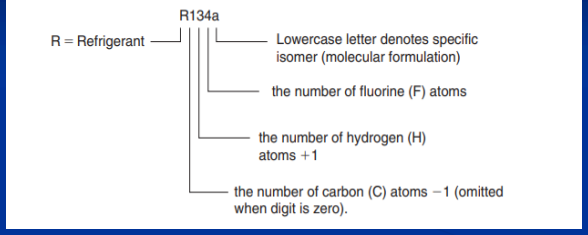
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Refrigerant Chemistry

- Chlorine :
  - Increases ODP of the substance
  - Raise the boiling point
- Fluorine :
  - Increases atmospheric Life
  - increase the GWP of the subst
  - reduce toxicity.
- Hydrogen :
  - increases flammability.
  - decrease its atmospheric lifetime



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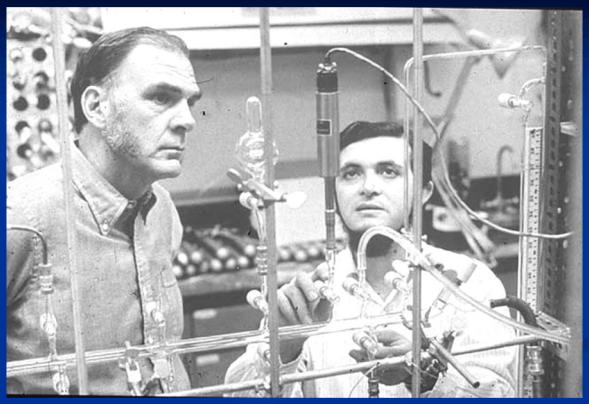


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The theory that CFC refrigerants can destroy the stratospheric ozone layer was proposed in 1974 by two scientists:
Mario J. Molina — a Mexican-born chemist.
F. Sherwood Rowland — an American chemist.
They published their research in the journal Nature on 28 June 1974, explaining how CFCs could reach the stratosphere, be broken down by ultraviolet radiation, and release chlorine atoms that destroy ozone molecules.

In 1995 they won the Nobel price

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Antarctic Ozone hole was reported in 1985, When satellite pictures showed ozone hole, Approximately after 54 years of CFC was commercially introduced in 1931

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MONTREAL AGREEMENT

Due to serious ill effects resulting from depletion of ozone, resulted in Montreal protocol-16Th September 1987 where almost all countries (186) agreed to phase out CFC's in a time bound program. This was the single first protocol when all countries unanimously agreed to phase out CFC refrigerants containing Chlorine molecule.

GLOBAL WARMING ISSUE WAS UNTOUCHED

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Environmental Effects of Refrigerants

- Depletion of the ozone layer in the stratosphere

- Global warming :

  Refrigerants directly contributing to global warming when released to the atmosphere

  Indirect contribution based on the energy consumption of among others the compressors, (CO_2 produced by power stations)

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KYOTO PROTOCOL

The Kyoto Protocol is an international treaty which extends the 1992 United Nations Framework Convention on Climate Change (UNFCCC) that commits state parties to reduce greenhouse gas emissions, based on the scientific consensus that (part one) global warming is occurring and

(part two) it is extremely likely that human-made CO_2 emissions have predominantly caused it. The Kyoto Protocol was adopted in Kyoto, Japan on 11 December 1997 and entered into force on 16 February 2005. There are currently 192 parties (Canada withdrew effective December 2012)[4] to the Protocol.

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EPA SNAP(Rule20) July 2015

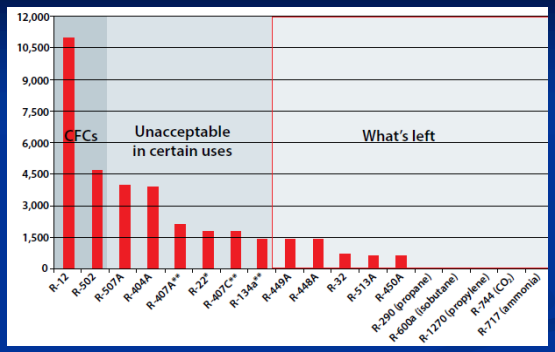
(Significant New Alternatives Policy Program) spells out phasing out of refrigerants R404A and R507

October2016-Most of the countries decided to phase out R134a, R404a, R517, R410A and look for natural refrigerants as a long term solution

Ref: Euromon document

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EPA SNAP-20 RULE



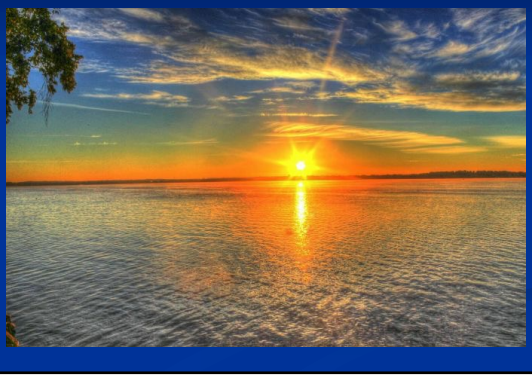
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EPA SNAP RULES

The U.S. Environmental Protection Agency (EPA) publishes Significant New Alternatives Policy (SNAP) rules continually, with recent major milestones including **SNAP Rule 25** finalized on April 19, 2023, **SNAP Rule 26** published on May 22, 2024, and **Proposed SNAP Rule 27** issued on October 24, 2025.

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The Kigali Amendment to the Montreal Protocol on phasing down HFCs will enter into force on 1 January 2017 after surpassing the required ratification threshold.



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KIGALI AGREEMENT-25th October 2016

A historic global climate deal was reached in Kigali, on 25th October 2016 Rwanda at the Twenty-Eighth Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer (MOP28). The Kigali Amendment which amends the 1987 Montreal Protocol aims to phase out Hydrofluorocarbons (HFCs), a family of potent greenhouse gases by the late 2040s. Under Kigali Amendment, in all 197 countries, including India. **The Kigali Agreement or amended Montreal Protocol for HFCs reduction will be binding on countries from 2019. It also has provisions for penalties for non-compliance**

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Various conference leading to acceptance of use of natural refrigerants

1. MONTREAL PROTOCOL -SEPTEMBER 1987-CFC PHASE SCHEDULE

2. KYOTO PROTOCOL -11TH DECEMBER 1997-REDUCE EMISSION GASES CAUSING GLOBAL WARMING

3.KIGALI AGREEMENT-25TH OCTOBER 2016-PHASE OUT HFC -HIGH GLOBAL WARMING REFRIGERANTS

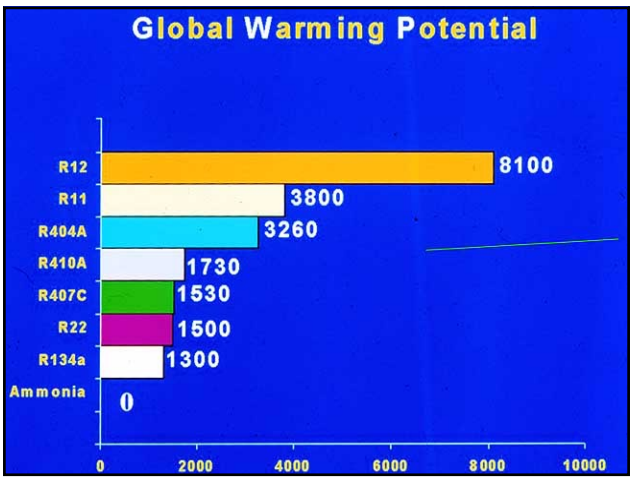
4. EPA SNAP RULE-OCTOBER 2016-PHASE OUT R134A,R404A, ETC.-HIGH GLOBAL WARMING REFRIGERANTS

5. PARIS AGREEMENT-NOVEMBER 2016-HFC PHASE DOWN IN 30 YEARS

6.KATOWISE POLAND(COP24)-DECEMBER 2018-LIMIT TEMPERATURE RISE BELOW 2^0C

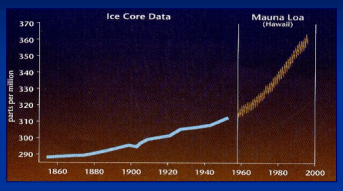
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Global Warming Potential



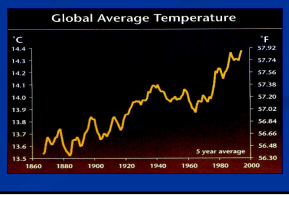
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Climate is Changing!

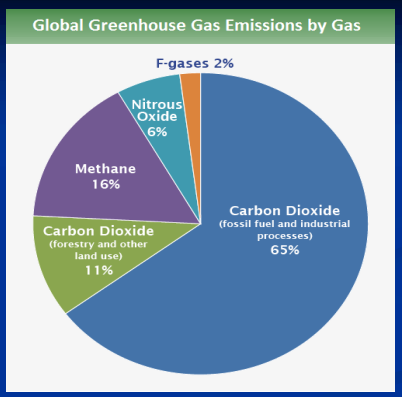


CO_2 concentration has been continuously increasing.

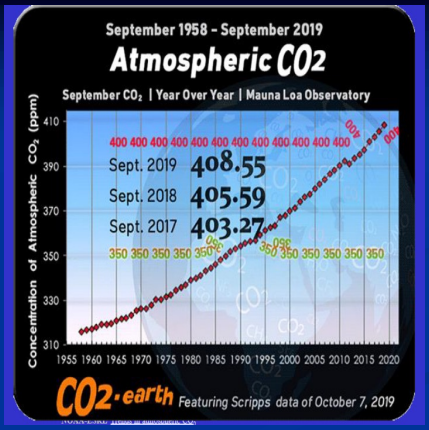
Global temperature has also been continuously increasing.



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0.1kW/Ton increase is Equivalent to

9.9 billion kg of CO_2 + 6.3 grams SO_2 + 3.5 billion gm NO_x

OR

3 MILLION CARS OFF ROAD

OR

PLANTING 600 MILLION TREES

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THE EFFECT OF 2^0C TEMPERATURE RISE

1. Severe heat waves affecting 37% population
2. Decline in marine catch by 3 Million tons
3. 16% loss of trees/Plants
4. Sea level rise-by 0.6m
5. Reduction in crop production by 7%
6. Decline in Coral life -99%

Ref: Times of India-09102018

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Figure 3.6 Effects of Global Warming

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CURRENT SITUATION-GLOBAL WARMING

1. Air conditioning and refrigeration industry consumes more than 40 % of total world production of energy.

2. 40% of Building Power consumed by comfort- Air Conditioning

Ref.: ASHRAE Journal September-2014

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TWO TYPES OF GLOBAL WARMINGS BY HVAC&R

1. .Direct Global warming due to leakage of Refrigerants- Depends on type of Refrigerant and quantity of refrigerant charge in the system

2.. Indirect GWP from equivalent CO2 emission due to energy consumption over the life time(TEWI)It is important to note that 90% GWP contribution in HVAC&R comes from energy consumption & every kWh of extra power contributes nearly 0.8kg of CO2

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Global warming leads to increase in atmospheric Carbon Dioxide & increase in temperatures

350-450PPM	**-acceptableOut door CO2 concentration**
350-1000 PPM	**Typical in occupied indoor environment and acceptable Less than 600PPM**
1000-2000PPM	**Complains of drowsiness and poor ventilation**
2000-5000PPM	**Headaches, Sleepiness, increased heart rate and Nausea etc.**

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ISSUES NEED TO BE ADDRESSED

1. Global Warming
2. Energy Efficiency
3. Environmentally Friendly Solutions
4. Alternate Technologies

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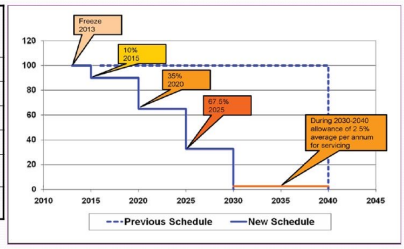
HFC PHASEOUT SCHEDULE-KIGALI AGREEMENT

Average HFC consumption levels for 2011,2012,&2013+15% of HCFC base line	
2019	-10%
2024	-40%
2029	-70%
2034	-80%
2036	-85%

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Accelerated Phase-out Schedule

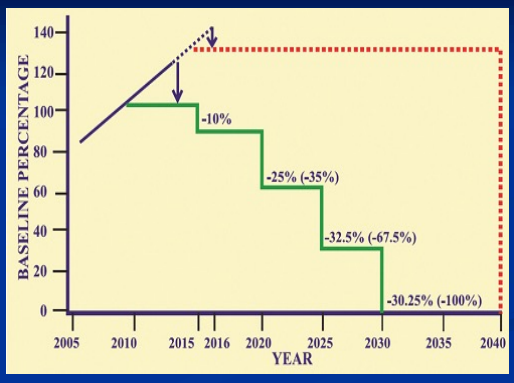
Year	% of Phaseout from Baseline (avg 2009 and 2010)
2013	Freeze
2015	10%
2020	35%
2025	67.5%
2030	Full phaseout*
2040	100% phaseout



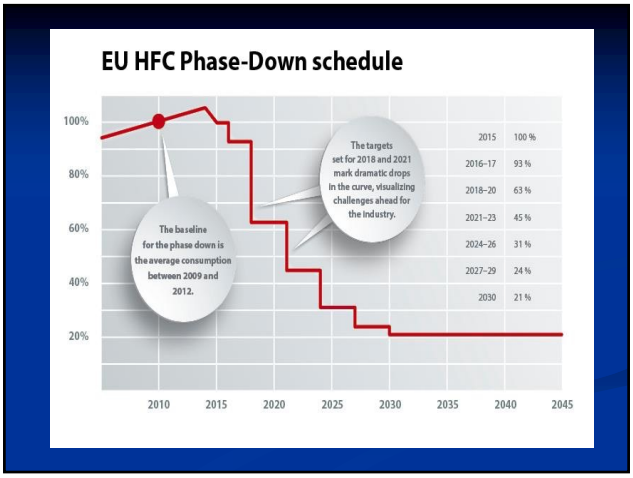
* 2.5% of the baseline allowed for servicing – to be reviewed in 2025

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PHASE OUT SCHEDULE FURTHER ADVANCED



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Important Dates in Refrigeration History

- 1834 : Jacob Perkins patented refrigeration by vapour compression which was based on the reverse Rankine cycle
- *Use of Natural Refrigerants:*
  - 1880's : NH_3, SO_2, CO_2, HC's
- Toxic and flammable refrigerants led to fatal accidents
- *Use of Synthetic Refrigerants: (Stability, Non-toxicity and efficiency)*
  - 1930 : R11, R12
  - 1936 : R22
  - 1961 : R507

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Types of Refrigerants

1. Halocarbons
2. Azeotropic Refrigerants
3. Zeotropic Refrigerants
4. Inorganic Refrigerants
5. Hydrocarbon Refrigerants

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Halocarbon Refrigerants

- Halocarbon Refrigerant are all synthetically produced and were developed as the Freon family of refrigerants.

Examples :

- CFC's : R11, R12, R113, R114, R115
- HCFC's : R22, R123
- HFC's : R134a, R404a, R407C, R410a

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Inorganic Refrigerants

- Carbon Dioxide
- Water
- Ammonia
- Air
- Sulphur dioxide

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Azeotropic Refrigerants

- **A stable mixture of two or several refrigerants whose vapour and liquid phases retain identical compositions over a wide range of temperatures.**
- **Examples : R-500 : 73.8% R12 and 26.2% R152**
  R-502 : 8.8% R22 and 51.2% R115
  R-503 : 40.1% R23 and 59.9% R13

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Zeotropic Refrigerants

- A zeotropic mixture is one whose composition in liquid phase differs to that in vapour phase. Zeotropic refrigerants therefore do not boil at constant temperatures unlike azeotropic refrigerants.
- Examples :R404a : R125/143a/134a (44%,52%,4%)
  R407c : R32/125/134a (23%, 25%, 52%)
  R410a : R32/125 (50%, 50%)
  R413a : R600a/218/134a (3%, 9%, 88%)

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The TEWI Factor

- The Total Equivalent Warming Impact (TEWI) rating measures the efficiency of a refrigerant by combining its direct and indirect global warming contribution.
- It is expressed in kg of CO_2.
- TEWI = leakage rate + Recuperation Rate + Indirect
  emissions due to energy consumption

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Leakage Rate

- Leakage rate is the amount of green house gases released into the atmosphere by the refrigeration system. It is given by the mass of refrigerant emissions in kilograms times the GWP of the refrigerant
- Leakage Rate = Mass of refrigerant leaking from system x GWP of Refrigerant
- **Typical leakage rates**:

  Hermetic compressor : 1 - 2%

  Split units : 6 - 8%

  Automotive air conditioning : 10 - 20%

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Recuperation Rate

- Recuperation rate = GWP_{ref} x $Charge_{ref}$ x (1 – recuperation factor)

Recuperation factor is the percentage of refrigerant recovered when a refrigeration or air conditioning equipment reaches the end of its useful life.

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Indirect Emissions

Indirect emissions are emissions of CO_2 which occur by generation of electricity needed to run the RAC equipment during its lifetime.

$CO_{2\ contrib}$ = *Machine life x Energy cons. Pa x Emission factor*

The emission factor is the amount of CO_2 released into the atmosphere when fuel is burned to produce one kWh of electricity. The emission factor for electricity varies from country to country and according to the primary source of energy.

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Example of TEWI Calculation

- Chiller unit running on R407c with a charge of 426 kg.
- Average leakage rate pa : 4 kg
- Lifespan of equipment : 25 years
- GWP of R407c : 1610 kg CO_2
- Average power rating of unit : 298.3 kW
- Chiller working on an average of 20 hours per day
- Recuperation factor assumed to be 50 %

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Calculation of TEWI

- Leakage Rate = 4 x 1610 x 25 = **128 800 kg CO_2**
- Recuperation rate = 1610 x 426 x (1 – 0.5) = **342 930 kg CO_2**
- Indirect contribution due to energy consumption =
  = 25 x (298.3 x 20 x 365) x 0.6 = **32 663 850 kg CO_2**
  {Emission factor is assumed to be 0.9 for Mauritius}

TEWI factor for the chiller unit calculated over its lifetime of 25 years :
128 800 + 342 930 + 32 663 850 = 33 135 580 kg CO_2
This implies that the chiller will contribute to the equivalent of **33 135 580 kg of CO_2** over its useful life of 25 years.

- ***Direct emissions = 1.4 % of the indirect emissions***

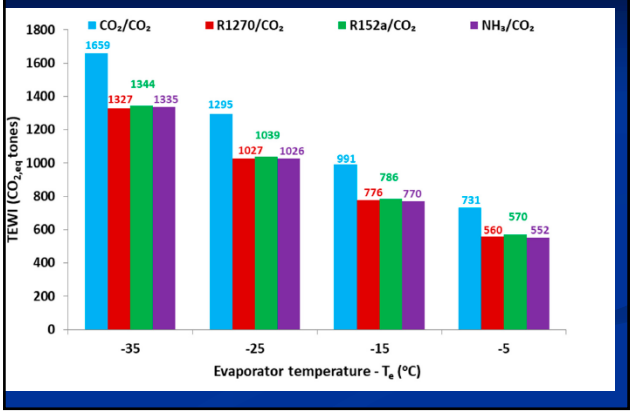
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Improving TEWI of a System

- Using refrigerant with lower GWP
- Eliminating leakages in the system
- Improving the electrical efficiency of the system

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TEWI EFFECT OF REFRIGERANTS



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ADVANCES IN REFRIGERATION TECHNOLOGY LAST 50 YEARS

Refrigerants

1. Refrigerants -Alternate Refrigerants
2. Trade Offs
3. Natural Refrigerants-Increased use of Ammonia and Carbon Dioxide as refrigerants

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What are the Alternatives ?

HFC's are definitely not a good option for the replacement of CFC's and HCFC's

The best choices from an environmental point of view are the natural refrigerants:

- Ammonia
- Hydrocarbons
- Carbon dioxide : Mainly for Vehicle AC and mobile refrigeration

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Survey Of Refrigerants

Refrigerant	Group	Atmospheric life	ODP	GWP
R11	CFC	130	1	4000
R12	CFC	130	1	8500
R22	HCFC	15	.05	1500
R134a	HFC	16	0	1300
R404a	HFC	16	0	3260
R410a	HFC	16	0	1720
R507	HFC	130	1	3300
R717	NH3	-	0	0
R744	CO_2	-	0	1
R290	HC	< 1	0	8
R600a	HC	< 1	0	8

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Natural Refrigerants
(Zero ODP & Ultra-low GWP Refrigerants)

- Ammonia (R-717)
- Carbon Dioxide (R-744)
- Air (R-729)
- Water (R-718)
- Sulphur dioxide (R764)
- Hydrocarbons (HC-290-Propane, HC-600a-Isobutane and R-1270 Propylene & others

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Petroleum-derived hydrocarbon (HC) refrigerants, all are flammable & have successfully been used as refrigerants in industrial, commercial and domestic applications.

1. Methane (CH_4) [R-50]
2. Ethane (CH_3CH_3) [R-170]
3. Propane ($CH_3CH_2CH_3$) [R-290]
4. Ethylene (CH_2CH_2) [R-1150]
5. n-butane ($CH_3(CH_2)_2CH_3$) [R-600]
6. Isobutane ($CH_3CH(CH_3)_2$) [R-600a]
7. Propylene (CH_3CHCH_2) [R-1270]
8. Pentane ($CH_3CH_2CH_2CH_2CH_3$) [R-601]
9. Isopentane ($CH(CH_3)_2CH_2CH_3$) [R-601a]
10. Cyclopentane ($(CH_2)_5$)

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Hydrocarbon Refrigerants

- Many hydrocarbon gases have successfully been used as refrigerants in industrial, commercial and domestic applications. Most popular are
- Examples: R170, Ethane, C_2H_6
  R290 , Propane C_3H_3
  R600, Butane, C_4H_{10}
  R600a, Isobutane, C_4H_{10}
  Blends of the above Gases

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What is the need for use of Natural refrigerants in AC&R ?

1. No Global warming
2. Selection of refrigerants known to mankind since the life came to earth
3. No regret solution
4. Environmentally safe solutions

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"Changing rules around the use of high global warming potential (GWP) refrigerants have been one of the hottest topics in the HVAC&R industry in the last few years.

Following the phase out of ozone-depleting refrigerants starting in the 1990s, the U.S. EPA, acting under the Significant New Alternatives Policy (SNAP) program, has recently changed the status of certain high GWP refrigerants. In the next several years, refrigerants such as R-404A, R-507A, R-134a, and others will be prohibited for use in some types of new or retrofit commercial refrigeration installations"

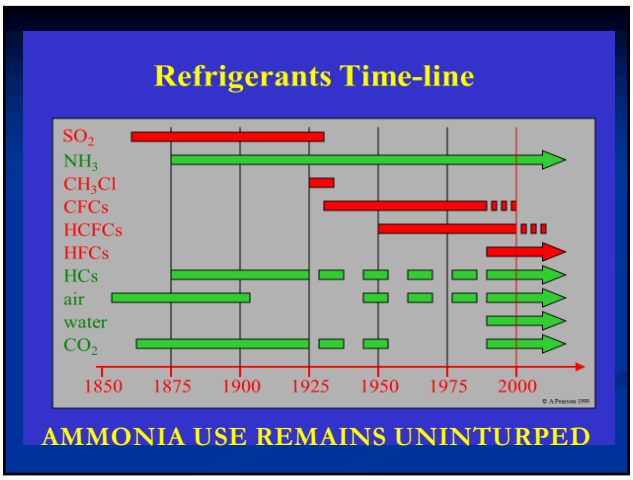
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ASHRAE POSITION DOCUMENT ON AMMONIA AS A REFRIGERANT

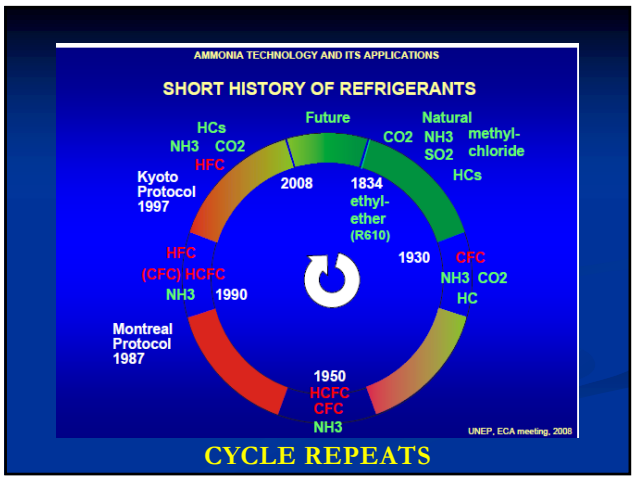
Approved by ASHRAE Board of Directors July 2, 2014

1.Ammonia has been continuously used as a refrigerant since the initial practical use of the vapor-compression refrigeration cycle was developed.
2.It has remained the main refrigerant used in industrial refrigeration systems because of its superior thermodynamic properties and low cost.
3. Restrictions on CFC, HCFC and many HFC refrigerants have re-focused attention on ammonia to emerge as one of the widely used refrigerants that, when released to the atmosphere, does not contribute to ozone depletion and global warming.
4. ASHRAE considers that the continued use of ammonia is necessary for food preservation and air conditioning.
5. ASHRAE promotes a variety of programs such as a dedicated chapter in the Refrigeration Handbook and several current and former research projects to preserve the economic benefits of ammonia refrigeration while providing for the management of risks.

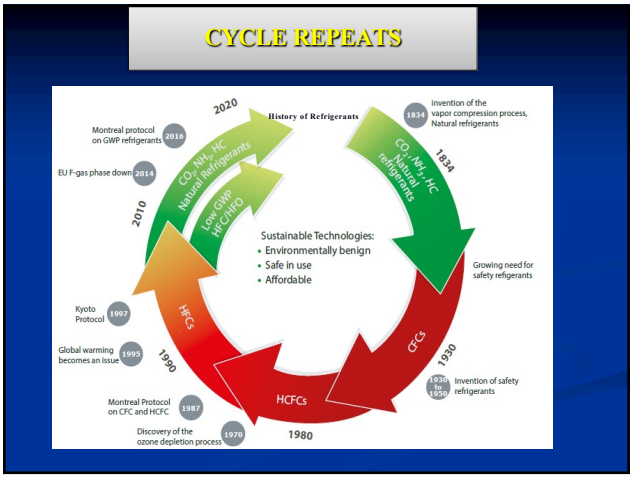
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Refrigerants Time-line
SO_2
NH_3
CH_3Cl
CFCs
HCFCs
HFCs
HCs
air
water
CO_2
1850
1875
1900
1925
1950
1975
2000
AMMONIA USE REMAINS UNINTURPED

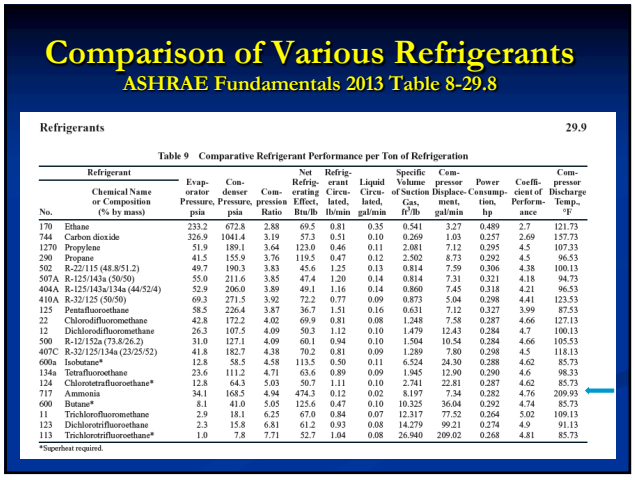
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AMMONIA TECHNOLOGY AND ITS APPLICATIONS
SHORT HISTORY OF REFRIGERANTS
Future
HCs
NH3 CO2
HFC
Kyoto Protocol 1997
2008
1834 ethyl-ether (R610)
Natural
CO2 NH3 methyl-chloride
SO2
HCs
1930
CFC
NH3 CO2
HC
HFC
(CFC) HCFC
NH3
1990
Montreal Protocol 1987
1950
HCFC
CFC
NH3
UNEP, ECA meeting, 2008
CYCLE REPEATS

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CYCLE REPEATS
History of Refrigerants
2020
2010
1980
1990
2000
1834
1930
Invention of the vapor compression process, Natural refrigerants
Montreal protocol on GWP refrigerants 2016
EU F-gas phase down 2014
Kyoto Protocol 1997
Global warming becomes an issue 1995
Montreal Protocol on CFC and HCFC 1987
Discovery of the ozone depletion process 1970
Invention of safety refrigerants 1936 to 1950
CO_2, NH_3, HC Natural Refrigerants
Low GWP HFC/HFO
CO_2, NH_3, HC Natural refrigerants
Sustainable Technologies:
• Environmentally benign
• Safe in use
• Affordable
Growing need for safety refrigerants
HFCs
CFCs
HCFCs

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Comparison of Various Refrigerants
ASHRAE Fundamentals 2013 Table 8-29.8
Refrigerants 29.9
Table 9 Comparative Refrigerant Performance per Ton of Refrigeration
No. | Chemical Name or Composition (% by mass) | Evaporator Pressure, psia | Condenser Pressure, psia | Compression Ratio | Net Refrigerating Effect, Btu/lb | Refrigerant Circulated, lb/min | Liquid Circulated, gal/min | Specific Volume of Suction Gas, ft³/lb | Compressor Displacement, gal/min | Power Consumption, hp | Coefficient of Performance | Compressor Discharge Temp., °F
170 | Ethane | 233.2 | 672.8 | 2.88 | 69.5 | 0.81 | 0.35 | 0.541 | 3.27 | 0.489 | 2.7 | 121.73
744 | Carbon dioxide | 326.9 | 1041.4 | 3.19 | 57.3 | 0.51 | 0.10 | 0.269 | 1.03 | 0.257 | 2.69 | 157.73
1270 | Propylene | 51.9 | 189.1 | 3.64 | 123.0 | 0.46 | 0.11 | 2.081 | 7.12 | 0.295 | 4.5 | 107.33
290 | Propane | 41.5 | 155.9 | 3.76 | 119.5 | 0.47 | 0.12 | 2.502 | 8.73 | 0.292 | 4.5 | 96.53
502 | R-22/115 (48.8/51.2) | 49.7 | 190.3 | 3.83 | 45.6 | 1.25 | 0.13 | 0.814 | 7.59 | 0.306 | 4.38 | 100.13
507A | R-125/143a (50/50) | 55.0 | 211.6 | 3.85 | 47.4 | 1.20 | 0.14 | 0.814 | 7.31 | 0.321 | 4.18 | 94.73
404A | R-125/143a/134a (44/52/4) | 52.9 | 206.0 | 3.89 | 49.1 | 1.16 | 0.14 | 0.860 | 7.45 | 0.318 | 4.21 | 96.53
410A | R-32/125 (50/50) | 69.3 | 271.5 | 3.92 | 72.2 | 0.77 | 0.09 | 0.873 | 5.04 | 0.298 | 4.41 | 123.53
125 | Pentafluoroethane | 58.5 | 226.4 | 3.87 | 36.7 | 1.51 | 0.16 | 0.631 | 7.12 | 0.327 | 3.99 | 87.53
22 | Chlorodifluoromethane | 42.8 | 172.2 | 4.02 | 69.9 | 0.81 | 0.08 | 1.248 | 7.58 | 0.287 | 4.66 | 127.13
12 | Dichlorodifluoromethane | 26.3 | 107.5 | 4.09 | 50.3 | 1.12 | 0.10 | 1.479 | 12.43 | 0.284 | 4.7 | 100.13
500 | R-12/152a (73.8/26.2) | 31.0 | 127.1 | 4.09 | 60.1 | 0.94 | 0.10 | 1.504 | 10.54 | 0.284 | 4.66 | 105.53
407C | R-32/125/134a (23/25/52) | 41.8 | 182.7 | 4.38 | 70.2 | 0.81 | 0.09 | 1.289 | 7.80 | 0.298 | 4.5 | 118.13
600a | Isobutane* | 12.8 | 58.5 | 4.58 | 113.5 | 0.50 | 0.11 | 6.524 | 24.30 | 0.288 | 4.62 | 85.73
134a | Tetrafluoroethane | 23.6 | 111.2 | 4.71 | 63.6 | 0.89 | 0.09 | 1.945 | 12.90 | 0.290 | 4.6 | 98.33
124 | Chlorotetrafluoroethane* | 12.8 | 64.3 | 5.03 | 50.7 | 1.11 | 0.10 | 2.741 | 22.81 | 0.287 | 4.62 | 85.73
717 | Ammonia | 34.1 | 168.5 | 4.94 | 474.3 | 0.12 | 0.02 | 8.197 | 7.34 | 0.282 | 4.76 | 209.93
600 | Butane* | 8.1 | 41.0 | 5.05 | 125.6 | 0.47 | 0.10 | 10.325 | 36.04 | 0.292 | 4.74 | 85.73
11 | Trichlorofluoromethane | 2.9 | 18.1 | 6.25 | 67.0 | 0.84 | 0.07 | 12.317 | 77.52 | 0.264 | 5.02 | 109.13
123 | Dichlorotrifluoroethane | 2.3 | 15.8 | 6.81 | 61.2 | 0.93 | 0.08 | 14.279 | 99.21 | 0.274 | 4.9 | 91.13
113 | Trichlorotrifluoroethane* | 1.0 | 7.8 | 7.71 | 52.7 | 1.04 | 0.08 | 26.940 | 209.02 | 0.268 | 4.81 | 85.73
*Superheat required.

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Survey of Refrigerants

Refrigerant	Group	Atmospheric life	ODP	GWP
R11	CFC	130	1	4000
R12	CFC	130	1	8500
R22	HCFC	15	.05	1500
R134a	HFC	16	0	1300
R404a	HFC	16	0	3260
R410a	HFC	16	0	1720
R507	HFC	130	1	3300
R717	NH3	-	0	0
R744	CO_2	-	0	1
R290	HC	< 1	0	8
R600a	HC	< 1	0	8

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Alternates for 134A, 404A,410A Refrigerants

Refrigerant	GWP	ODP[a]
R-410A	2,088	0
R-22	1,810	0.055
R-407C	1,774	0
HFO Blends	<1,032[b]	0
R-32	675	0
R-1234ze	6	0
R-1234yf	4	0
R-290 (propane)	3.3	0
R-744 (CO_2)	1	0

Ammonia ≤ 1 0

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AMMONIA IS THE BEST REFRIGERANT

1. Zero ODP
2. Near Zero GWP
3. Zero Atmospheric Life
4. Best Thermodynamic Efficiency compared to any other Refrigerant
5. Low cost
6. Lubricating oil inexpensive
7. Equipment manufactured in India- Compressors, condensers, evaporators
8. Available in all parts of country
9. Manufactured in India
10. Lighter than Air
11. Leaks easily detectable
12. Does not mix with oil-can be drained easily

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LATENT HEAT COMPARISON @ 4-5^{0}C

- Water R-718- 2489.04kJ/kg
- Ammonia – R717- 1247.85kJ/kg
- R410A- 214.48kJ/kg
- HCFC 22/R22- 201.79kJ/kg
- HFC 134a/R134a- 195.52kJ/kg
- R404A- 162.03kJ/kg

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WHY AMMONIA?

Ammonia C.O.P. (Efficiency)Comparison with other refrigerants for various applications

Refrigerant	For positive Temperature cold rooms- +40°C/2°C	For secondary fluids operation +40°C/-5°C	For low temperature cold rooms- +40°C/-25°C	Blast freezers/IQF +40°C/-40°C
Ammonia-R717	6.20	4.965	2.91	2.06
R410A	5.43	4.80	2.50	1.75
R134a	5.88	4.67	2.70	1.88
R404A	5.18	4.07	2.26	1.52
R22	5.93	4.74	2.79	1.98

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CARBON DIOXIDE AS REFRIGERANT

LATEST TRENDS

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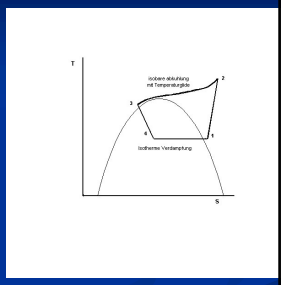
CARBON DIOXIDE AS REFRIGERANT

Crititcal Temperature	30.98 Deg C	73.77 bar a
Triple Point	-56.55 Deg C	5.1796 bar a
	45 Deg C	100 bar a
→	40Deg C	91.48 bar a
	0 Deg c	34.85 bar a
	-20 Deg C	19.696 bar a
	-40 Deg C	10.04 bar a
	-78.5 Deg C	Atmospheric Pr.

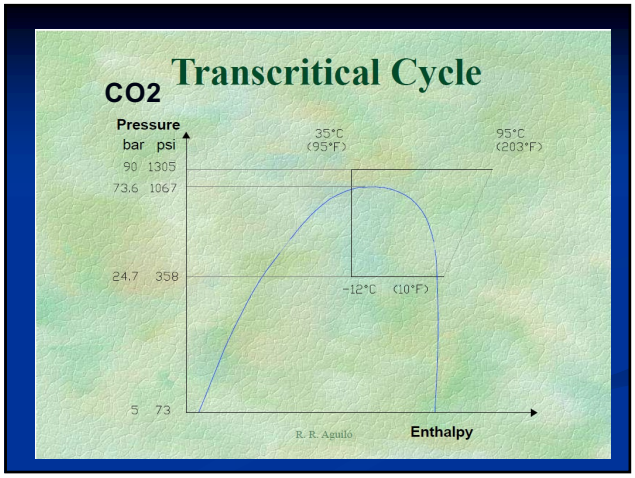
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CARBON DIOXIDE

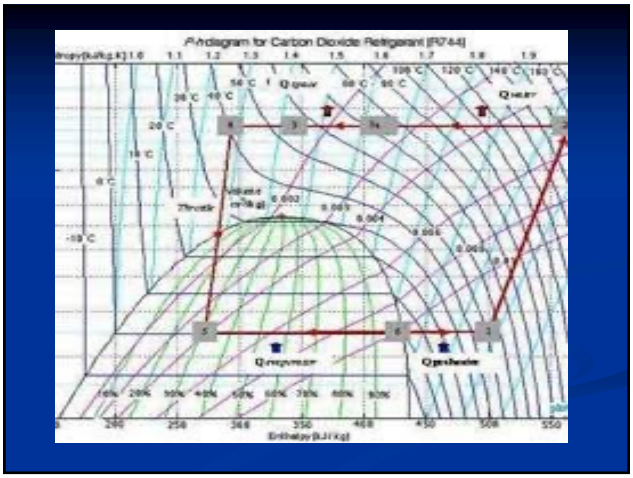
- Most promising refrigerant having zero ODP and near zero GWP
- Critical temperature is very low
- Cycle is trans-critical
- Operating pressure much higher than other refrigerants
- Higher volumetric capacity
- Non flammable, non toxic and cheap
- Compatible with normal oils
- excellent performance when used for water heap pump utilizing the temperature glide in gas cooler



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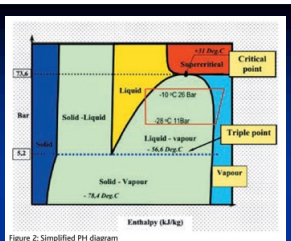


Figure 2: Simplified PH diagram

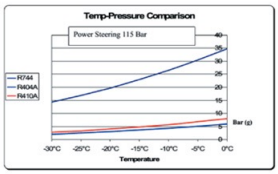
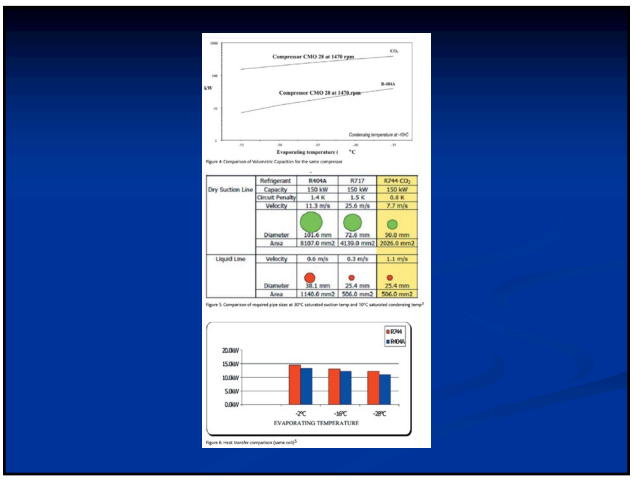
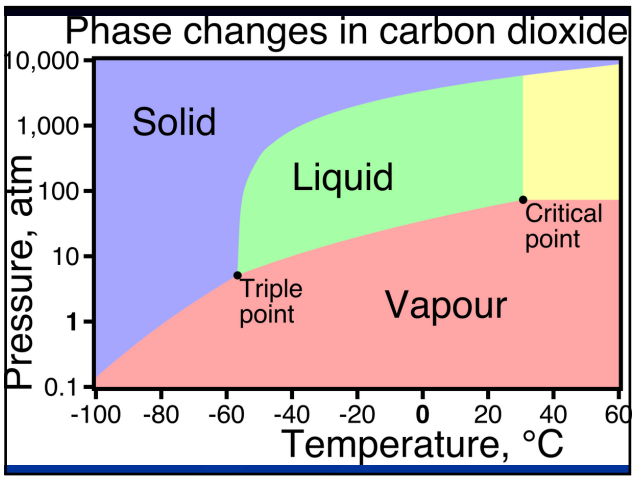


Figure 3: Pressure Temperature Relationship for Various Refrigerants

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CARBON DIOXIDE AS REFRIGERANT

ADVANTAGES AS REFRIGERANT

1. Low GWP/No ODP
2. Natural Refrigerant
3. Non- Toxic/Non- Flammable
4. High Density-Hence smaller system
5. Small Compressor Size-Nearly 6 to 8 Times smaller
6. Smaller Piping-Less insulation
7. High Heat transfer Coefficients
8. Smaller Condensers/Evaporators
9. Low Pressure losses
10. High Efficiency in Sub Critical Cascade Applications
11. Positive Pressures in Low Temperature Applications
12. Low Cost compared to any other refrigerant

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CARBON DIOXIDE AS REFRIGERANT

DISADVANTAGES AS REFRIGERANT

1. High Discharge Pressures
2. Very Low Critical Temperature- +31.8 deg C
3. Limited Flexibility in Applications
4. Cascade Coolers are More expensive
5. Heavier than Air-Suffocation in Higher Concentrations
6. 400 PPM in Atmosphere-Less than 800 PPM allowed –EN 13779-5000 PPM Max Work place concentration
7. Odourless-Detectors are required
8. Solid Phase above atmospheric Pressure-Safety Valves , drains open to atmosphere
9. Liquid to Gas expansion ratio is very high
10. Liquid Traps & also Gas Traps must be avoided
11. Liquid line leakage Most Dangerous- -78.5 Deg C Temperature
12. Moisture Less than 5 PPM-Not soluble in Refrigerant
13. Only Gas Charging-Liquid Charging Vacuum-Thermal Shock

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CARBON DIOXIDE AS REFRIGERANT

APPLICATIONS IN INDIA

SUB CRITICAL SYSTEMS-CASCADE

1. High Stage R134a, or R404A
2. Low stage Carbon Dioxide

OR

1. High Stage Ammonia
2. Low stage carbon Dioxide
3. OR
4. Secondary Coolant as brine in super markets

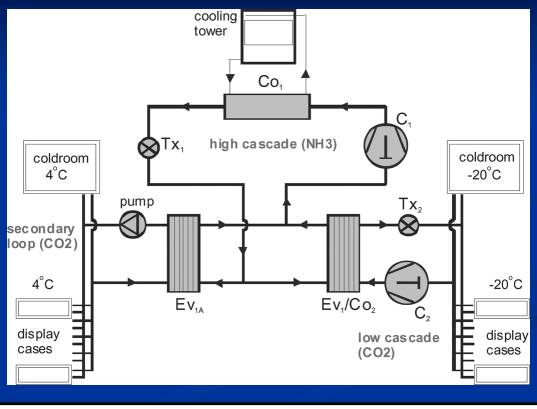
81

CO_2 in Domestic Application

Coca Cola Company uses both R134a and CO_2 for its 550-litre Refrigerators, with the result that systems operating with CO_2 consume 20 to 30% less energy. The application is in supercritical range i.e. condensing temperatures are above 31.2^0C

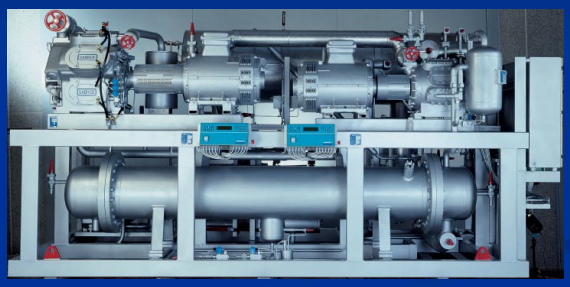
82

Cascade Ammonia CO2 system for super Markets



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CO2 Ammonia Cascade



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AMMONIA-CO_2 USED AS BRINE SYSTEM –FRUIT STORAGE-HOLLAND



85

CO_2 Bus Air Conditioning

CO_2 A/C installation: August 1996

Operation hours: 1700



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Non-Azeotropic Liquid Gas Blends-Advantage

1. Ammonia with Propane(290)
2. Ammonia with Octafluoropropane(R218)
3. Ammonia with Octafluorocyclobutane(R318)
4. Ammonia with isobutane(R600a)
5. 60% Ammonia and 40% dimethyl ether(R723)

Experiments have shown that compared to pure Ammonia, some blends tested have lower discharge temperatures, lower compression ratios,5-10% better refrigeration capacity and better oil solubility(PAG or PAO oils)

Ref: Monika Witt-Condenser magazine November 2008

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HYDROCARBONS AS REFRIGERANTS

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Typical applications for hydrocarbons are:

.Domestic refrigerators and freezers
•Bottle coolers
•Ice cream freezers and commercial freezers
•Commercial refrigerators
•Beer coolers
•Beverage dispensers
•Dehumidifiers
•Heat pumps
•Supermarket refrigeration (in combination with secondary cooling or as a high temperature stage in a cascade CO_2 system)
•Small air conditioners

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Most Important Hydrocarbons as Refrigerants

	Formula	Refrigerant	Boiling Point-^{0}C	Critical Temperature-^{0}C
N-butane	C_4H_{10}	R600	-0.5	152
Iso-butane	C_4H_{10}	R600a	-12	135
propane	C_3H_8	R290	-42	96.6
propylene	C_3H_8	R1270	-47.7	91
ethane	C_2H_6	R170	-88.7	91
Ethylene	C_2H_4	R1150	-103.8	9.5

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Hydrocarbons As Refrigerant As Replacement

HFC	HC alternative	Applications
R134a	R600a	Household appliances
R134a	R290/600a mixtures	Commercial applications
R404A,R507A	R290,R1270 & their mixtures	Industrial plants-Petrochemicals
R407C	R290,R1270	Air conditioning and heat pump systems
R410A	R1270/170 mixtures	Deviations due to refrigerating capacity & pressure levels
R23,R14	R170,R1150	Low temperature cascades
R227ea	R600a	High temperature applications

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Hydrocarbon as refrigerant

1. Butane has been used in more than 300 million Domestic Refrigerators and now finding use in smaller commercial systems.

2. Propane in central air conditioning systems report 10 to 30% energy savings and with minimum changes can be used in current installations using R22 refrigerant

3. Unilever uses propane in 360 liters ice cream freezers and compared to R404A reports on an average 9% power savings over R404A

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Hydrocarbons as refrigerant

Butane is very successful in more than 300 million domestic refrigerators currently being used.

Pepsi has compared the results and indicate that small drink chillers with 150g refrigerant consumes 27% less energy than those using R134a refrigerant

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1. With the support from international organizations, China has converted 18 room Air conditioner making plants to R290 which has a capcity of 45,00,000 units per year

2. They have also 3three no compressor production lines to produce 54,00,000 unit per year

3. Up to August 2019, 1,60,000 units have been installed as room Air conditioners

4. Godrej has introduced 6,00,000 units in the Indian market

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R-290 PROPANE A.C.-CHINA-(More than 3, million)



95

Energy-Efficient Propane (HC-290) Based Room Air Conditioners by Godrej & Boyce



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PROPANE FOR AIR CONDITINING

Germany-The Municipal corporation has installed unit using propane for cooling the servers and for air conditioning.

The system is of 20kW capacity using 2.5 kg of propane(R290).

The system is working since 2011.- Eurammon

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PROPANE FOR HEATING/AIR CONDITINING-2x250kW

For shopping center in Mythen center AG-Switzerland uses propane for heating and air conditioning.

The units are designed to work round the clock having high COP and EER by means of high performance-frequency controlled compressors. The system per unit uses 15kg of refrigerant

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PROPANE CO_2 CASCADE



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API 619 Propane Refrigeration Package
Caim Energy, Rajadthan

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PROPANE PACKAGE FOR PETROCHEMICAL REFINERY



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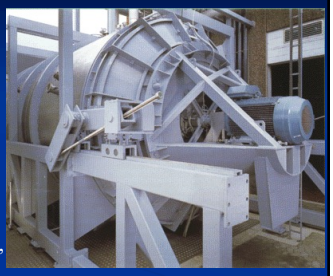
Water As Refrigerant

1. Evaporation of water has been always used for cooling as it keeps body cool through perspiration.
2. To use it commercially, Hugh flow of water vapour is needed to achieve cooling effect & requires deep vacuum & air tight systems.
3. The savings in energy are Hugh and 25% energy can be saved over 134a chiller units.
4. Research is currently in progress in France and Dresden/Germany and France on development of radial and axial compressors.

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Water as a Refrigerant

1. Thermodynamically attractive refrigerant
2. Low volumetric refrigeration capacity and relatively high pressure ratio
3. Higher COPs (7-10)
4. Can be used both as primary and secondary refrigerant
5. Systems use direct evaporators, with no ΔT & require no cleaning
6. Less corrosion because water is continuously de-aerated



Eco-chiller: 2-8 MW
Works close to the triple point
Can reach close to 0.5°C
Use an additive (in PPM)

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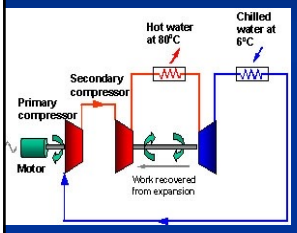
Ice Slurry or Binary Ice

1. Pump-able mixture of small ice crystals (17%-70%), water and a freezing point depressant
2. Ideal secondary refrigerant
3. Latent heat of ice made use of thus giving a large cooling capacity-(334kJ/kg)
4. Results in significant economical savings
5. Systems use scraped surface evaporator, Vacuum ice machine and Fluidized bed evaporator methods

Used for air cooling of South African gold mines and Lego Systems in Denmark

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Air Cycle for Heating & Cooling



- The air is compressed by a primary centrifugal compressor and then by a secondary (bootstrap) compressor.
- The hot air is then passed through a HX to provide heating.
- The high pressure air from the HX is cooled in a recuperator, to heat the air entering the primary compressor. Additionally, the air is also cooled before its entry to the expander.
- After expansion, the cold air is passed through HX to provide cooling. The air from HX is sent to the primary compressor to complete the cycle.

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Air Refrigeration System

1. Simple and compact
2. Non-toxic and non-flammable
3. No separate compressor and prime mover required
4. Easy to maintain and repair
5. Space and weight per ton of refrigeration is less
6. Relatively low COP
7. Used in aircrafts since 50s
8. Currently used in some German railways and some Bus A/Cs, with improved COP using high rpm motor-compressor-expander units

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White Paint That Could Reduce Need for AC

Purdue University engineers have created radiative cooling white paint that can keep surfaces up to 18°F (10°C) cooler than their ambient surroundings. According to the researchers, the paint would replace the need for air conditioning by absorbing almost no solar energy and sending heat away from the building and into deep space. Compared with commercial white paint, Purdue's paint maintains a lower temperature under direct sunlight and reflects more ultraviolet rays, according to the researchers.-29-10-2020 ASHRAE news

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THANK YOU
Questions?

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