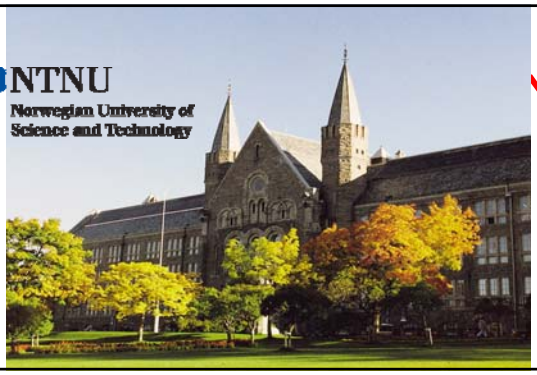

#1

An introduction to sustainable refrigeration technology

#4

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Norway
E-mail: armin.hafner@ntnu.no

Plan for the week

GIAN (Global Initiative for Academic Networks in higher education):

REFRIGERATION TECHNOLOGY WITH NATURAL REFRIGERANTS, SPECIALIZATION ON R744 (CO_2)

Content

- Introduction & Motivation
  - Fast phase in of NWF is needed, unsaturated HFCs are not sustainable
- CO_2 systems a viable option for many applications
  - **M**obile **A**ir **C**onditioning & Heat Pumps
  - Marine Refrigeration → High Quality Fish
  - Hot water heat pumps → local environment
  - Commercial refrigeration → food safety
- Summary
- Further Work & Cooperation's

Monday to Friday

Mo: - Introduction (Motivation & History of CO_2 refrigeration)
Tu: - Natural Working fluids (Hydrocarbons and CO_2)
We: - Heat- transfer / -exchangers and compressors
Th: - Various system designs,
- CO_2 safety aspects + How to commission a system
Fr: - Experimental investigation with pilot CO_2 unit

Non-Technological Barriers

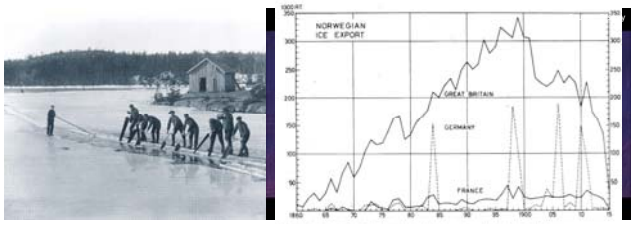
#6

hinder diffusion of already existing energy efficient and natural refrigerant based solutions

- Awareness barrier
- Knowledge barrier; Systems complexity increases, Interdisciplinary knowledge is required → training
- Social barrier; i.e. Some planners may not want to move from technology they are very experienced in → training
- Organisational barrier
- Legislative barrier; i.e. No strong legislative incentive towards energy efficient supermarkets as a whole and neither against inefficient ones

Introduction

150 years ago: ICE = refrigeration



Norwegian Ice Export from 1860 to 1915

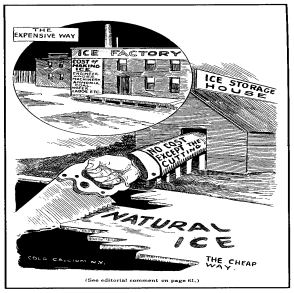
Working fluids history

Until 1930	Use of natural working fluids – Air, ethyl ether, SO_2, methyl chloride, ammonia, propane, isobutane, CO_2, etc.
1930-50	Introduction of synthetic working fluids, like CFC 12 and HCFC 22
1987	*Montreal protocol* established, CFC and HCFC ozone depletion due to chloride/bromine. Phasing out CFC (1995) and HCFC (2010)
1987	Hydrogen-Fluor-Carbons (HFC) introduced
1997	*Kyoto protocol* established, HFC regulated due to high GWP factor
2006/2007	EUs F-gas directive – Phase down of high GWP fluids
2015 →	EU F-gas regulation
1990-now	Increasing focus on use of natural working fluids, especially ammonia, hydrocarbons and CO_2

Three important 'drivers' in the late 19th century

Factors pushing the development of mechanical refrigeration technology from 1850 →

- "Artificial" ice production
- Brewing of beer (all year long)
- Transport of meat



1998 Children's Painting Competition by UNEP

LARGE NEED FOR NEW SOLUTIONS !

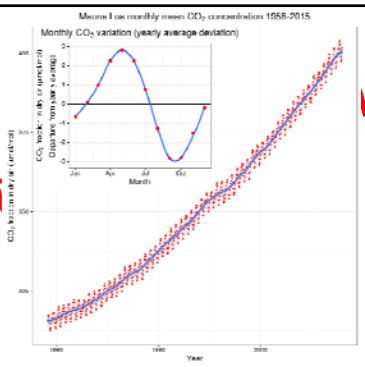
Image taken from the 2001 UNEP DTIE
OzonAction Programme Children's Painting Competition.
Painting by **Laila Nuri**, aged 8, **Indonesia**

History

Advertisement in ICE and REFRIGERATION, 1922, vol. 63

Image taken from the 2001 UNEP DTIE
OzonAction Programme Children's Painting Competition. Painting by **Mariam Salman Al Oraibi**, aged 12, Bahrain

CO_2 Concentration in air
Example: Hawaii (Mauna Loa)



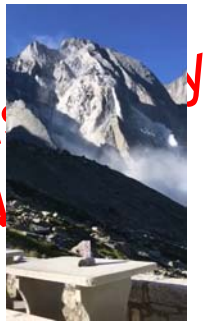
INTRO: 'New' synthetic refrigerants with ultra low GWP

Even if some people call these new fluids with another name, they are HydroFluoroCarbons (HFCs), i.e. organic compounds that contain only hydrogen, fluorine, and carbon

Motivation: Consequences of global warming ->

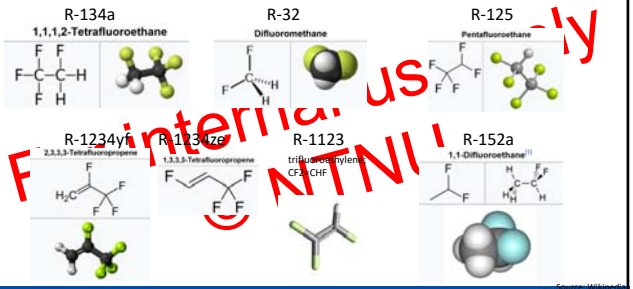
Far away…

However, when the permafrost is melting…



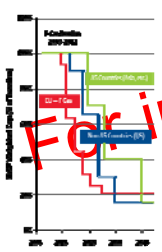
Piz Cengalo
Switzerland
24th Aug. 2017

INTRO: It's all about H, F and C



F-gas Regulation (in a nutschell)

Present conventional refrigeration systems **are not future long-term solutions:**
- Ban refrigerants GWP>150 from 2022 (centralized refrigeration system >40 kW, Primary Cycle in cascade configuration >1500)
- 79% Reduction of GWP related emission by 2030



Which options are available for stakeholders?

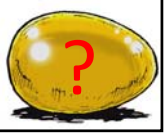
» **Business as usual** until 2020 and then usage of recycled gas until 2030;
- Availability/cost of the gas and equipment
- Future ban of service and maintenance
- Stricter leak detection and refrigerant recovery processes

» Convert/retrofit with **new synthetic low-GWP refrigerants;**
- **Total environmental impact un-known**, future regulation?
- Cost of the refrigerant?

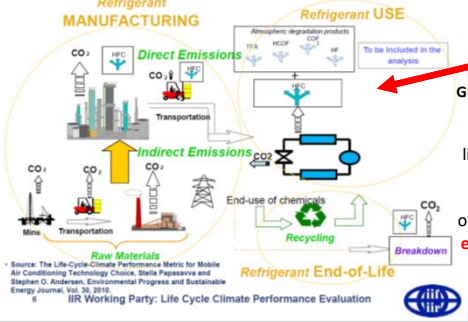
» **Natural refrigerant** business orientation.
- **Long term solution**
- **Investment cost no longer higher than traditional HFC**

INTRO: 'New' synthetic refrigerants with ultra low GWP due to short lifetime

How do we measure environmental impact?
- Which are the main parameters for the GWP-value?
  - The ability of the fluid to absorb infrared radiation
  - The lifetime in the atmosphere
- What includes the LCCP value?
  - CO_2 emissions from 'cradle to grave'…



Environmental Impacts of Refrigerants



Focus today: only GWP

Global **W**arming **P**otential

HFCs with ultra low lifetime do have a very low GWP value. Nevertheless all the other equally important **environmental aspects are either unknown or secret**

Daimler Test = HFK-1234yf is pyrophoric

Performed and documented by Daimler with an E 180 class Mercedes

Federal German authority for physical and chemical tests of materials and facilities (BAM) https://www.bam.de/_SharedDocs/DE/Downloads/Jahresbericht2014.pdf?__blob=publicationFile&v=5 Page 96 →

....

Carbonyl difluoride (COF2) may also develop in the case of fire. Carbonyl difluoride is the fluorine analogue of phosgene, the substance used as a poison gas in some wars. Fluorine phosgene (= carbonyl difluoride) can therefore be assumed to have a similar effect. The only question is whether COF2 is present long enough – or at all – to cause a health hazard to people present in the accident scenarios to be considered.

• • •

This has encouraged BAM experts dealing with safety engineering and analysis to investigate more scenarios and conditions under which COF2 is formed.

http://www.dailymail.co.uk/video/news/video-1005013/Daimler-video-claims-1234yf-dangerous-VW-says-CO2-best-refrigerant.html

INTRO: 'New' synthetic refrigerants with ultra low GWP due to short lifetime

Safety / HSE / Responsibility

- inflammable, liable to catch fire, combustible
- end use
- service people
- rescue personal

Lets look into the date sheets?

http://www.sciencedirect.com/science/article/pii/S0009261407015813
Chemical Physics Letters 450 (2008) 263–267

...The atmospheric lifetime of **(R1234yf) CF3CF CH2** is dictated by its reaction with OH radicals and is approximately 11 days. We show here that **CF3C(O)F** is the major atmospheric oxidation product of CF3CF CH2. The atmospheric fate of CF3C(O)F is hydrolysis which occurs on a time-scale of approximately 10 days to give CF3C(O)OH (TFA)...

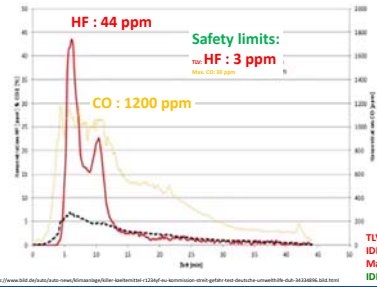
What happens to people inside maskin rooms, workshops, service cars, etc.?

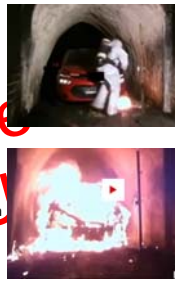
CF3C(O)F + H_2O → **CF3C(O)OH** + HF

The acidity of Trifluoroacetic acid (TFA) is approximately 34,000 times stronger than that of acetic acid. TFA is harmful when inhaled, causes severe skin burns and is **toxic for water organisms even at low concentrations**

Upon contact with moisture, including tissue, hydrogen fluoride (HF) immediately converts to hydrofluoric acid, which is **highly corrosive and toxic**, and requires immediate medical attention upon exposure. **Breathing in hydrogen fluoride** at high levels or in combination with skin contact **can cause death** from an irregular heartbeat or from fluid buildup in the lungs.

INTRO: **DUH did tests with R-1234yf**





TLV (Threshold Limit Value) = 3 ppm
IDLH (Immediately dangerous to life or health) = 30ppm
May also happen with HFC-134a
IDLH for ammonia is 300 ppm (30 min escape)

U.S. Department of Health & Human Services

https://emergency.cdc.gov/agent/hydrofluoricacid/basics/pdf/facts.pdf

- Hydrogen fluoride goes easily and quickly through the skin and into the tissues in the body. There **it damages the cells** and causes them to not work properly.
- The seriousness of poisoning caused by hydrogen fluoride depends on the amount, route, and length of time of exposure, as well as the age and preexisting medical conditions of the person exposed.
- **Breathing hydrogen fluoride can damage lung tissue** and cause swelling and fluid accumulation in the lungs (pulmonary edema).
- **Skin contact with hydrogen fluoride may cause severe burns** that develop after several hours and form skin ulcers.

http://www.solvay.com/en/binaries/trifluoroacetic_acid_GPS_rev0_Dec12-139538.pdf

General Statement

'Trifluoroacetic acid (TFA) is a **strong carboxylic acid**, widely used in organic chemistry. TFA is an important building block in the synthesis of pharmaceuticals, agrochemicals and performance products.

TFA is a liquid substance, colourless to pale yellow, and with a pungent odour.

TFA is a strong acid, it may cause irreversible **skin burns** and eye damage and vapours may cause an irritation of the upper respiratory tract.

TFA is harmful to aquatic environment with long lasting effects; any release to the environment must be avoided.

The pure substance is only used in industry, or for professional purpose; it must be handled under stringent safety conditions at the workplaces, in accordance with the risk management measures to control the risk of exposure and preserve human health and environment. Consumer exposure to TFA is not expected.

Clever strategy after Paris COP, Kigali & Marrakech Meetings:

Companies focusing on

Natural Working Fluids

will face no risk to invest into technologies being on the **phase out agenda** in the future

<=>

Safe & sustainable investment

INTRO: 'New' synthetic refrigerants with ultra low GWP due to short lifetime

- **What happens if the fluid leaks:**
  - **Into the machine room?**
  - **Into the workshop?**
  - **Inside the service van?**
  - **During service/assembly of systems?**

Who has the responsibility for health damages of people ?

Let's focus on integrated CO_2 systems

- It is possible to outperform current technology with non-natural-working-fluids on:
  - **Energy efficiency**
  - **Total cost of ownership**
  - **Environmental impact**

What about R-1234ze

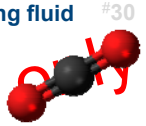
According to the manufacturer:

- A unique characteristic of this refrigerant is the absence of flammable mixture with air under 30°C of ambience.[1]
- Atmospheric Decomposition of R-1234ze breaks down into the same by-products of other commonly used fluorinated compounds at levels much lower than naturally present. F atoms degrade into HF which is then rained out and mineralised with no additional effect on Ozone or on Climate.[1]

Are we sure? => what about the effect on human beings in dense populations?

[1] HFO-1234ze Technical Data Sheet, Honeywell

R744 / CO_2 – environmentaly friendly working fluid



Molar mass: 44.01 g/mol

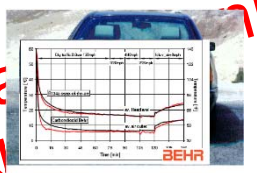
- Only real A1 fluid!
- CO_2 – appear naturally in the atmosphere
  - CO_2 concentration ca. 400 ppm (0,04%) ↑
- ODP = 0
  - Ozone Depletion Potential – reference ODP CFC11=1,0
- GWP = 1,0
  - Global Warming Potential – reference GWP CO_2=1,0
  - GWP CO_2=0 when used as working fluid – no new production of CO_2
  - Does not contribute to smog in the cities
- No environmental pollution at production
- Odour-free, not immediate toxic, not flammable
  - TLV 5.000 ppm (0,5%) – IDLH 50.000 ppm (5%)

Focus areas

- Mobile Air Conditioning & heat pump systems
- Hot water heat pumps
- Marine refrigeration systems
- Commercial refrigeration

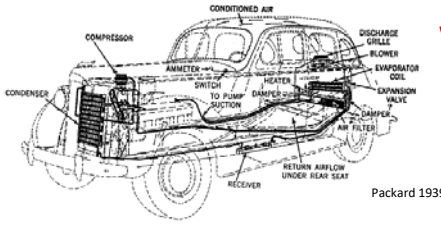
19 years ago!
CO_2 MAC in 1998: soon ready…

…the greenhouse gas effect of the car AC system can be cut by a third when applying carbon dioxide as a refrigerant



BEHR- Prototype Vehicle with CO_2 – Cycle, Death Valley 1998

The start of MAC in 1939



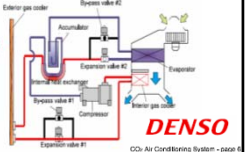
Packard 1939

First automotive air conditioning system (CFC-12) developed and implemented by Packard

Worlds first CO_2 Car AC system
Made in Japan

JAPAN: Toyota FCEV vehicle will have CO2 air conditioning

Courtesy, Denso



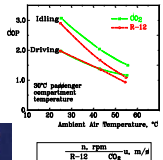
And even with a heat pump option!

Mobile Air-Conditioning

The start: 1989-91 in Trondheim

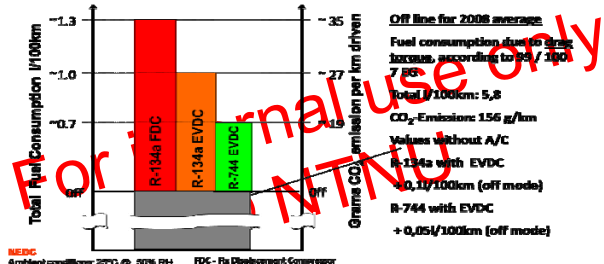
Main issue: Energy efficiency of R744 MAC system

R744 lab. prototype system (left) and BMW 520 CFC-12 system (right)



n, rpm	R-12	CO_2	n, m/s
Idling	700	840	1.0
Driving	1740	1800	2.5

11 years ago: CO_2 MAC: 30% lower fuel consumption



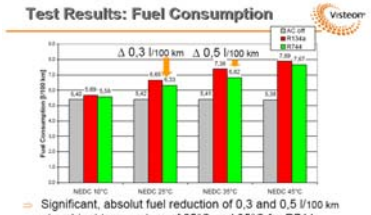
Off line for 2008 average
Fuel consumption due to drag torque, according to R744 / 100
7.8l
Total l/100km: 5,8
CO_2-Emission: 156 g/km
Values without A/C
R-134a with EVDC
+0,1l/100km (off mode)
R-744 with EVDC
+0,05l/100km (off mode)

NEDC
Ambient conditions: 25°C @ 50% RH
no sun load; Mode: fresh air

FDC - Fix Displacement Compressor
EVDC- Externally controlled Variable Displacement Compressor

11 Cooling Cars with Less Fuel, Paris, October 2006

Fuel consumption of a Toyota Yaris (MY 2006) with different mobile AC systems when driving a NEDC at various ambient temperatures



- Significant, absolut fuel reduction of 0,3 and 0,5 l/100 km at ambient temperature of 25°C and 35°C for R744
- Add on fuel reduction of 25 % at 25°C and 35°C of R744 in comparison to R134a

- Engine 3 cylinders, 1,0 l, 51 kW
- Test vehicle with 15.000 km
- TXV system
- Compressor with external control valve (90 cc)

VDA Alternate Refrigerant Winter Meeting 2007, Saalfelden, Austria.

Premium quality fish from R744 equipped vessels

CO_2 (R744) DEEP-FREEZING PLANT FOR *M/S ROALDNES*

Helge Hansen & Yves Ladam

KULDE TEKNISK

M/T ROALDNES

- Stern trawler
- Length : 33,95 m
- Width : 10,3 m
- Trawling:
  - haddock & pollock
- Capacity:
  - 120 metric tonn

KULDE TEKNISK

FINALLY

Mercedes-Benz S-Class

Since autumn 2016: Available with CO_2 AC (1st serial production car with R744 MAC)

R744 MAC should became mandatory for new sustainable cars

Premium quality fish from R744 equipped vessels

CONVERSION FROM HCFC 22 TO CO_2 (R744)

DEEP-FREEZING WITH CO_2 VS HCFC 22

	R 744 /CO_2	HCFC 22
Metric tonn/day	40	30
Freezing time	140 min	190 min
Defrost	faster	

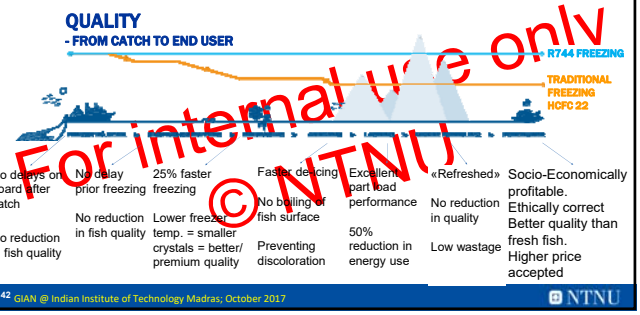
KULDE TEKNISK

KULDE TEKNISK

Marine R744 applications

- ✓ Premium quality fish from R744 equipped vessels
- ✓ Fishing vessels with R744 RSW unit outside Africa

Faster Freezing = Higher Food Quality



Premium quality fish from R744 equipped vessels

SUMMARY R744 (CO_2) IN MARIN APPLICATION

- deep-freezing time is reduced by 25%
- requires less space onboard
  - allows to apply smaller tubes / piping
  - approx. 20% less space for the unit
  - less freezers required for same freezing capacity
- CO_2 plate freezers achieve better food quality
- in general: service & maintenance becomes better and more easy

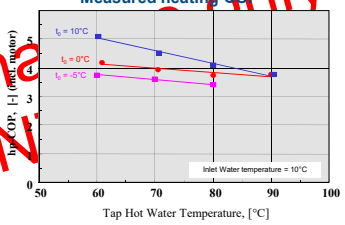
OTHER CO_2 UNITS FOR FISHING BOATS

Refrigerated Sea Water UNIT

One Vessel equipped with CO_2 – RSW unit was in operation around the Canarian Islands and is now outside Mauretania !

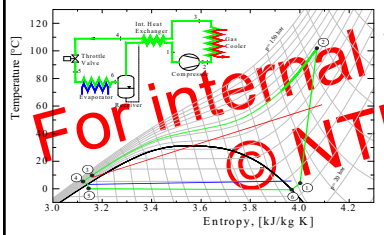
50 kW heat pump water heater laboratory prototype at SINTEF/NTNU (1995)

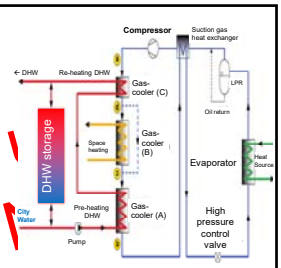
Measured heating COP



Water heating heat pumps

a perfect application for CO_2





Light commercial ref. units / standalone units

#47

Important players are joining:

Refrigerants, Naturally!

They have installed more than 3.5 million units using natural refrigerants – both in developing and industrialised countries.

This is real PHASE-IN of natural refrigerants!

CONGRATULATIONS

Water heating heat pumps

#45

Example Japan:

- First EcoCute* system in the market May 2001
- 1.700.000 units installed between 2001 and 2008
- By the end of 2013: 4.000.000 units installed

Large market potential for other regions towards 2020.

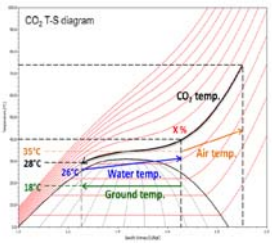
Natural refrigerant heat pump water heater

Chillers applying NR

provide comfort AC in building complexes and commercial buildings

#48

Split-Gascooler-Design



Simulation results show:

- COP increased by up to 20% to standard CO_2 chiller.
- Additional 10-20% COP increase expected by applying **ejectors**.

A new PHASE-IN application until 2020!

Ref.: Jin, Zhequan; Eikevik, Trygve M.; Nekså, Petter; Hafner, Armin.

Transport refrigeration in India?

#49

- Refrigerated transport of valuable food needs sustainable refrigeration technology to preserve the food and limit the environmental footprint.
  - Fishing vessels (HCFC 22 -> R 744)
  - Road transport (HFC xxx -> R 744)
- Public transport:
  - Train (HFC xxx -> R 744 or air)
  - Cars - MAC (HFC 134a & HFC 123xxxx -> R 744)

next

#52

Latest technology for high efficiency and the future of supermarket refrigeration for high-ambient climate zones

How to make real systems for a successful introduction to India?

#50

- **Ejectors** are widely used in refrigeration systems to pump lubricant inside compressors
- Since a few years many European OEM's are developing R744 ejectors for units with a cooling capacity above 5 kW
  - Supermarkets require high efficient systems with natural working fluids all across Europe and abroad
  - Laboratory and real pilot units are required for development
- More advanced system configuration requires good understanding during the design and implementation phase

Training and technology transfer is important

Commercial Refrigeration; Supermarkets

In future: supermarket refrigeration system provides entire energy flow and demand in the building (and surrounding)

- ✓ **Air Conditioning** (direct or chilled water)
- ✓ **Heat recovery**: hot water production, space heating, ice protection
- ✓ **Heat pump function** & export of heat

CO_2 (R744) is the preferred alternative of the end-users across Europe for new installations

- ✓ Predictable – no restrictions
- ✓ CO_2 booster units are proven technology with potential to further improve COP (parallel compression + ejector technology)
- ✓ Training and support is key for success

Promising global perspectives for a successful Phase-in

next

Commercial refrigeration

+ Market trends from Asia

Commercial Refrigeration; Supermarkets

The average annual refrigerant leakage rates:

- in Europe: **15-20 % of the total charge,** mainly HFC-404A
- Worldwide about **30 % of the charge**, mainly HCFC-22

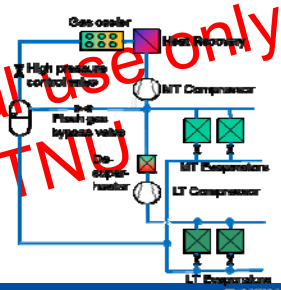
Evolution of R744 Commercial Refrigeration since 2003:

SEER: Seasonal Energy Efficiency Rating

CO_2 Commercial refrigeration: Generation 1

Standard CO_2 booster unit

- First unit in 2004/Switzerland (Linde)
- > 6000 units worldwide
- Higher SEER as HFC units in moderate climate regions
- No efficient integration of AC (only MT temperature level



Ejector system ≠ Ejector system

#58

Classic Ejector

- High pressure control with needle in motive nozzle
- High eff. at design point
- Part load operation challenges
- Low motive flow rate and
- Large mixing chamber
- Requires oil return strategy
- Ejector (low pumping ability) – superheat operation of evaporators
- Discontinues operations

Liquid Ejector only

- Enables flooded evaporators all year
- Applicable for booster and parallel compression system
- Simple on/off control
- Requires low pressure accumulator

Ejector supported parallel Compression

- Fixed nozzle ejectors: designed for pumping liquid and pre-compressing vapour (ex: Multi-ejector block)
- Enables flooded evaporators all year, requires small low pressure accumulator
- Higher load on auxiliary compressors.
- **Pressure lift can be adapted to provide efficient AC**

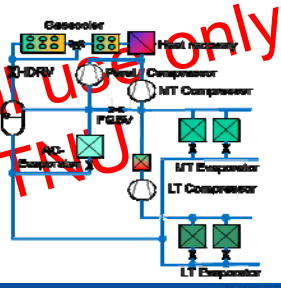
Venturi type

- Part load challenges

CO_2 Commercial refrigeration: Generation 2

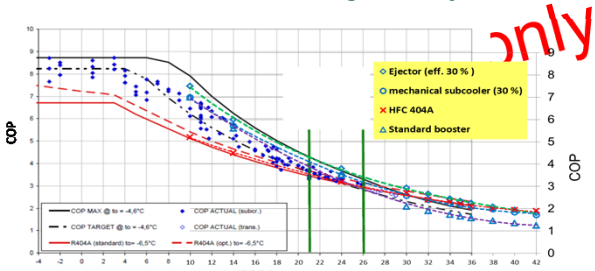
CO_2 Parallel Compression Booster

- First unit in Switzerland 2008 (enex)
- > 500 units worldwide
- Higher SEER as HFC units in most European regions
- Good / Efficient integration of AC possible



Performance of commercial refrigeration systems

#59



Ref: Finckh 2011 ICR 2011

Evolution of R744 Commercial Refrigeration

#57

SEER + 10%

SEER + 10-20%

R744 simple Booster (Baseline)

- simple
- many units in the market
- flash gas bypass
- low cost (below HFC in Scandinavia)
- COP / SEER baseline for moderate – cold ambient temp.

Parallel Compression

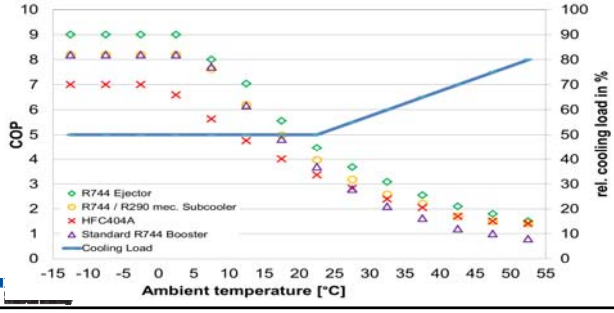
- advanced system
- higher investment cost
- flash gas (auxiliary) compression

Ejector System

- advanced system
- flooded evaporators: **possible**
- **simple (no pump)**
- **pre-compression**
- **higher load on auxiliary compressors**

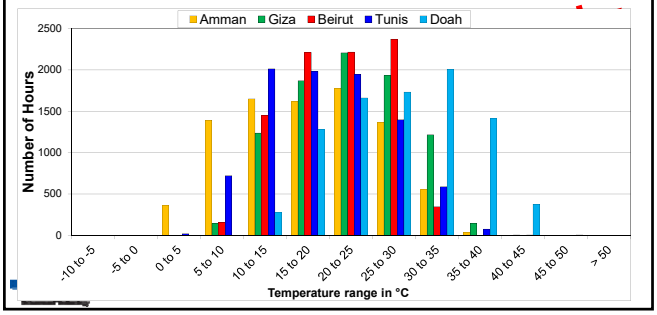
R744 ejector versus HFC404A

#60



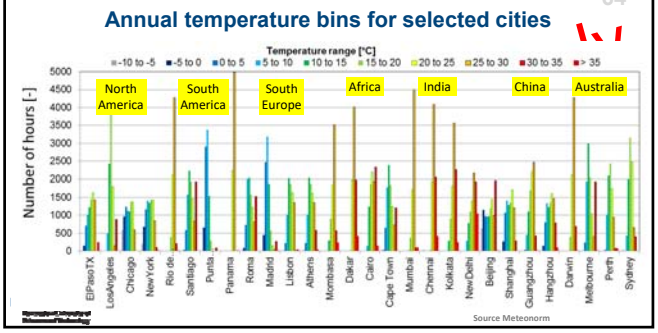
Annual temperature bins for selected cities (Example Middle East)

#61



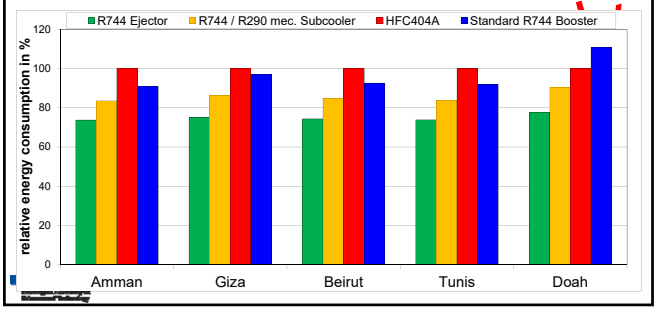
Annual temperature bins for selected cities

#64



Relative annual energy usage (Example Middle East)

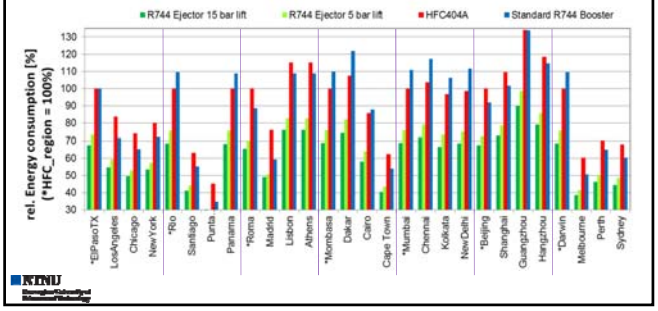
#62



Relative annual energy usage

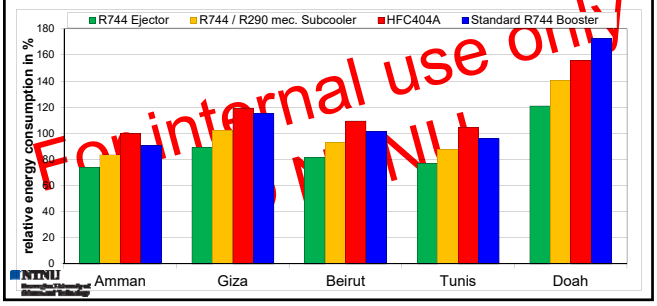
(exclusive AC part)

#65



Relative annual energy usage (Example Middle East)

#63



Number of transcritical CO_2 supermarkets

Source: sheccoBase (August 2017)

Example Supermarket
Lawson Convenience Store, Japan

#67

Energy efficiency measures implemented:

- Double-skin façade with insulation function
- Ground source heat pump
- 60 % energy reduction comparing to 2010 consumption levels of Lawson standard convenience stores

Standard Panasonic CO_2 systems are on average 27 % more efficient than the conventional HFC solutions in Lawson convenience stores

21 % energy saving in an Okinawa Lawson supermarket (hot and humid climate), comparing CO_2 and R404A convenience store solutions

#70

This is good news for INDIA!!!

- Energy efficient R744 systems for small shops are available!
- If they operate successfully in Indonesia (below the equator), why not in INDIA?

Market trends from Asia: Japan

Japanese proven CO_2 technology for CVS (Lawson&Panasonic)

Outdoor units for Refrigerators and Freezers were replaced by Panasonic CO_2 Units (10HP and 2HP) → The Total Energy Save: 27%

CO_2 System Installation Result (FY2016)

1,145 Stores in 47 Prefecture (at the End of Jan. 2016)
About 1,300 Stores Expected at the End of Feb. 2016

HFC → R744 -27% energy usage

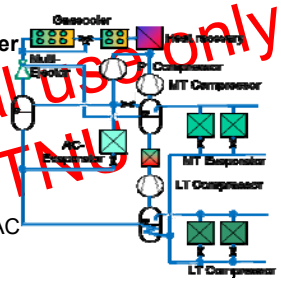
1600 stores with R744 in 2016

Source: http://www.atmo.org/events.details.php?eventid=36

CO_2 Commercial refrigeration: Europe
Generation 3

CO_2 Parallel Compression Booster with Ejector Support

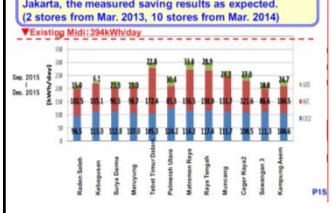
- First unit in Switzerland 2014 (Enex)
- < 100 units worldwide
- Higher SEER as HFC units globally
- Simple & efficient integration of AC
- Flooded evaporators all year



Market trends from Asia : Indonesia

Result of Energy Saving Project in Indonesia

Verification of energy saving is ongoing at 12 Stores in Jakarta, the measured saving results as expected.
(2 stores from Mar. 2013, 10 stores from Mar. 2014)



Result and Further Development of the Project

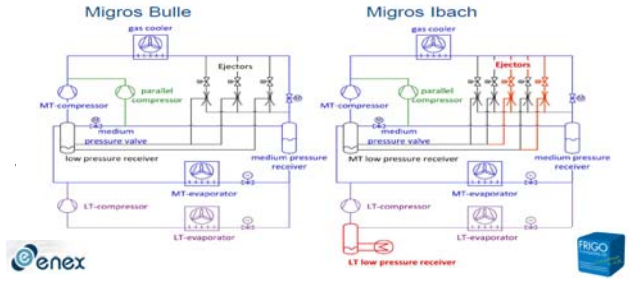
- **Benefit**
  - -Energy saving 20%
  - -Increasing average sales 15%
  - -Ambience store to be more comfort
- **Problem to be solved**
  - -High cost investment

12 stores with R744 in Indonesia!

Source: http://www.atmo.org/events.details.php?eventid=36

Pioneer R744 Ejector Installations

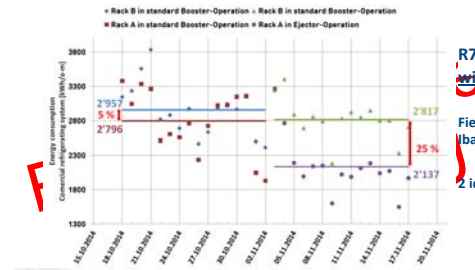
#72



Ref: Eric Wiedenmann, ATMOsphereEurope 2015

Pioneer R744 Ejector Installations

#73



R744-PC with and without Ejector

Field test results from Ibach / CH

2 identical R744 Racks

Ref: Eric Wiedenmann, ATMOsphereEurope 2015

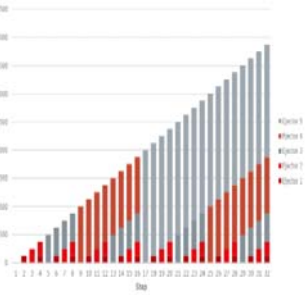
Current target developments

- Evaporative condensers
  - → very energy efficient when applicable / doable
- Reduce number of compressors per ref. rack
  - → Pivoting compressor
- Reliable booster systems for the Nordic market
  - → Winter – mode – solution
- Integrated solutions
  - → All in one solution to replace all H(C)FC applications in a supermarket
  - → Direct heating and cooling inside the shopping area (no water loop)
- Cold thermal storage
  - → Close to valuable food, Smart Grid applications

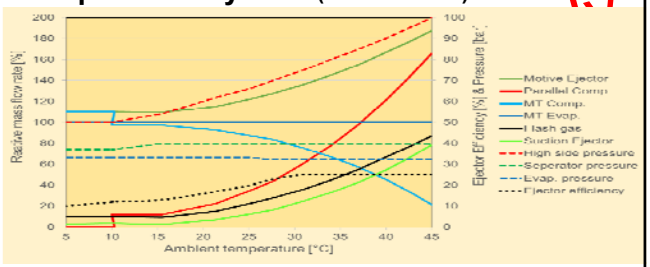
Example: Multi-ejector module

- Modular design (ejector cartridges placed into a monoblock casing) developed by Danfoss in cooperation with SINTEF/NTNU
- Up to six fixed-geometry ejectors → high flexibility to control the high side pressure

Example: control steps with 5 ejectors

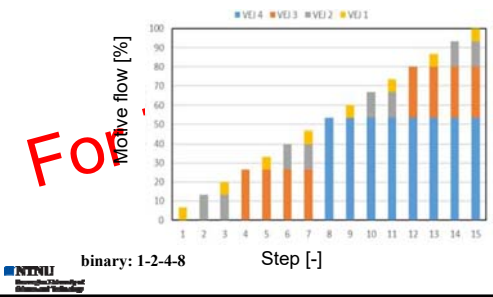


Behaviour of ejector supported parallel compression system (Generation 3)

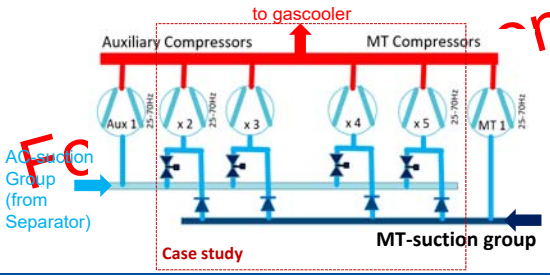


Example: Control of Flow (4 mulit-ejectors)

#75



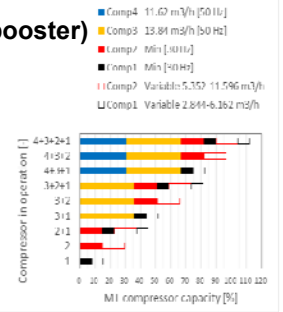
Example: 4 Pivoting Compressors



Example 4 Compressors: single suction unit (simple booster)

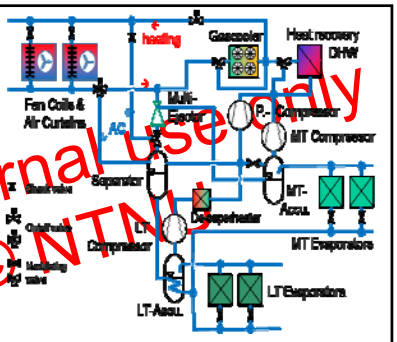
Fits very well in Nordic region

- 8-100% capacity range without gap



CO_2 ref. - Pack
Integration of direct heating and cooling

- Alternative MultiPACK * solution



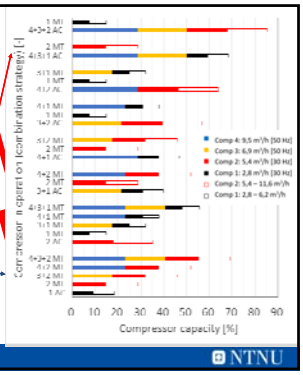
* www.ntnu.edu/multipack

Example 4 Compressors:
MT and AC suction unit (parallel compression)

Pivoting principle:

- Four compressors:
  -> min/max suction flow rate: 2,8 / 34,2
- High summer AC load
- Low load on parallel compressor (spring/fall)

Reduction in investment cost!

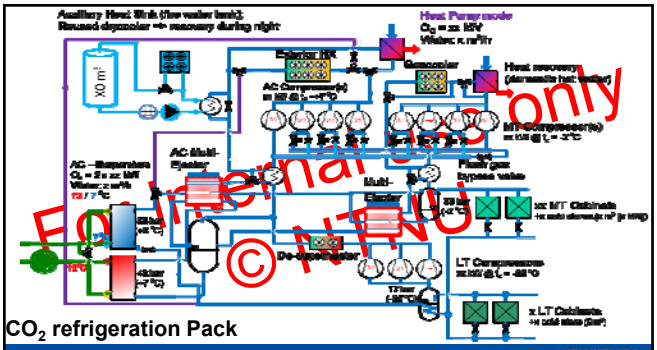


CO_2 ref. - Pack
Integration of direct heating and cooling

- Alternative MultiPACK * solution

Direct heating and cooling fan coil unit inside a Supermarket (Girotto 2016).

* www.ntnu.edu/multipack



CO_2 refrigeration Pack

Summary (I of III)

- Knowledge transfer regarding the risks of introducing another kind of HFC has to be improved and expanded : END USERS must be aware of that applying working fluids which can turn into **substances used as a poison gas** in some ways are not real alternatives.
- Remarkable development since the revival of R744 / CO_2 in the late 1980s.

Summary (II of III)

- When focus is given to further development of systems to improve the energy efficiency
  - evaporative condensers,
  - parallel compression with ejector support,
  - flooded evaporator, etc.

  a successful introduction at reduced total al cost of ownership.

- The integration of further functions → key success factor
  → replacing HCFC and HFC systems globally.

Further development

We are looking for a Indian partner to get this pilot compressor ready for the global market.

Table 2 Main Compressor data

	Value / Range
Height x Width x Length [mm]	500 x 440 x 830
Weight [kg]	286
Volume flow rate [m^3/h]	18 - 90
Displacement [cm^3]	380
Max power consumption [kW]	100
Revolutions per minute [rpm]	800 – 4 000
Frequency range [Hz]	53 - 267

Summary (III of III)

- OEM's can supply safe air/CO_2 heat exchangers, enabling a direct integration of heating and cooling functions.

- Cold thermal energy storage as close as possible to the valuable food will become another important feature, since it guarantees the preservation of the food's quality, even when the power supply is unstable or as an alternative to electrical batteries for locally produced electricity from renewable energy sources.

22 year ago a wise person said:

Prof. Gustav Lorentzen (1915-1995)

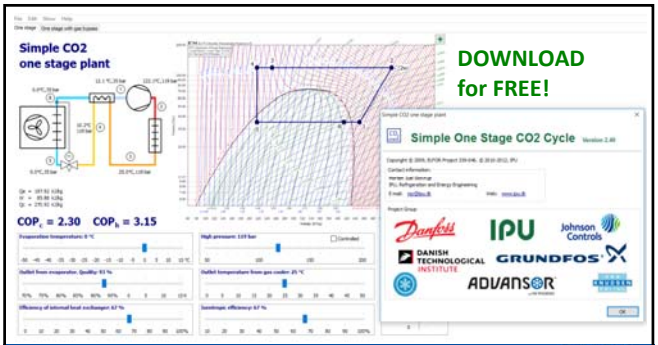
We have heard a great deal lately of the **harmful effects to the environment when halocarbon refrigerants are lost to the atmosphere**. This should **not really** have come as **a surprise** since similar problems have happened over and over again! Numerous cases are on record where **new chemicals**, believed to be a benefit to man, **have turned out to be environmentally unacceptable**, sometimes even in quite small quantities (DDT, PCB, Pb etc.).

In the present situation, when the CFCs and in a little longer perspective the HCFCs are being banned by international agreement, it does not seem very logical to try to replace them by another family of related halocarbons, **the HFCs, equally foreign to nature**.

Int. Journal of Refrigeration 9. Vol. 18, No. 3, pp 190 197, **1995**

Further work

- Inform the end-users & exchange information
  - SuperSmart
- Further improve the energy efficiency
  Show demonstration projects (MultiPACK, etc.)



Summary (CO_2 - R744)

- Tremendous development of CO_2 technology since 1988
- Energy efficient CO_2 systems have been introduced in the market
- CO_2 systems enable flooded evaporators and offer to integrate: Ref. + HVAC + Eco-Cute
- Adapted ejector technology offer high system performances and COP's, even at high ambient
- CO_2 is a viable natural refrigerant PHASE-IN candidate for many applications, globally

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