AMMONIA AS A REFRIGERANT

By

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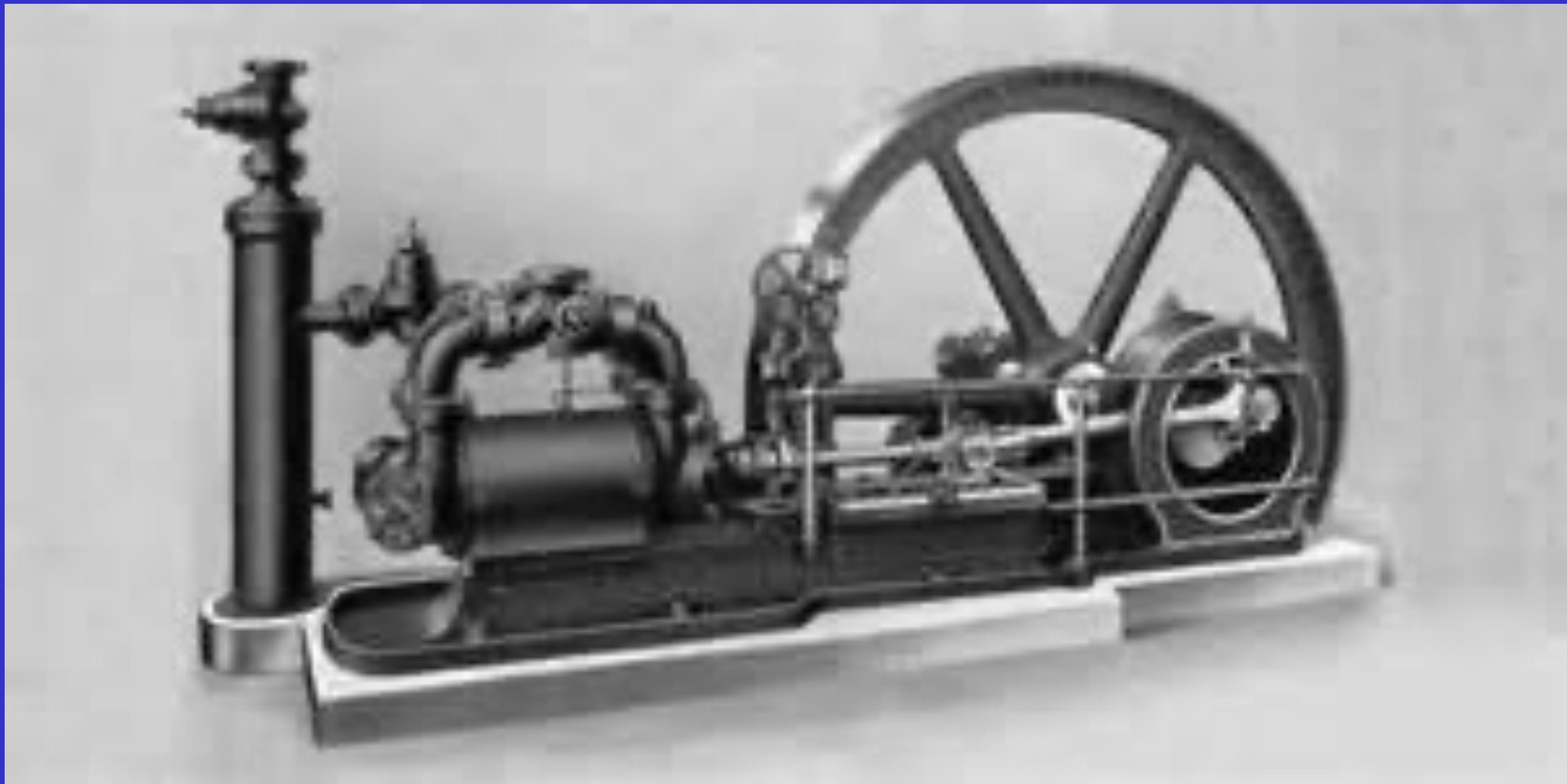
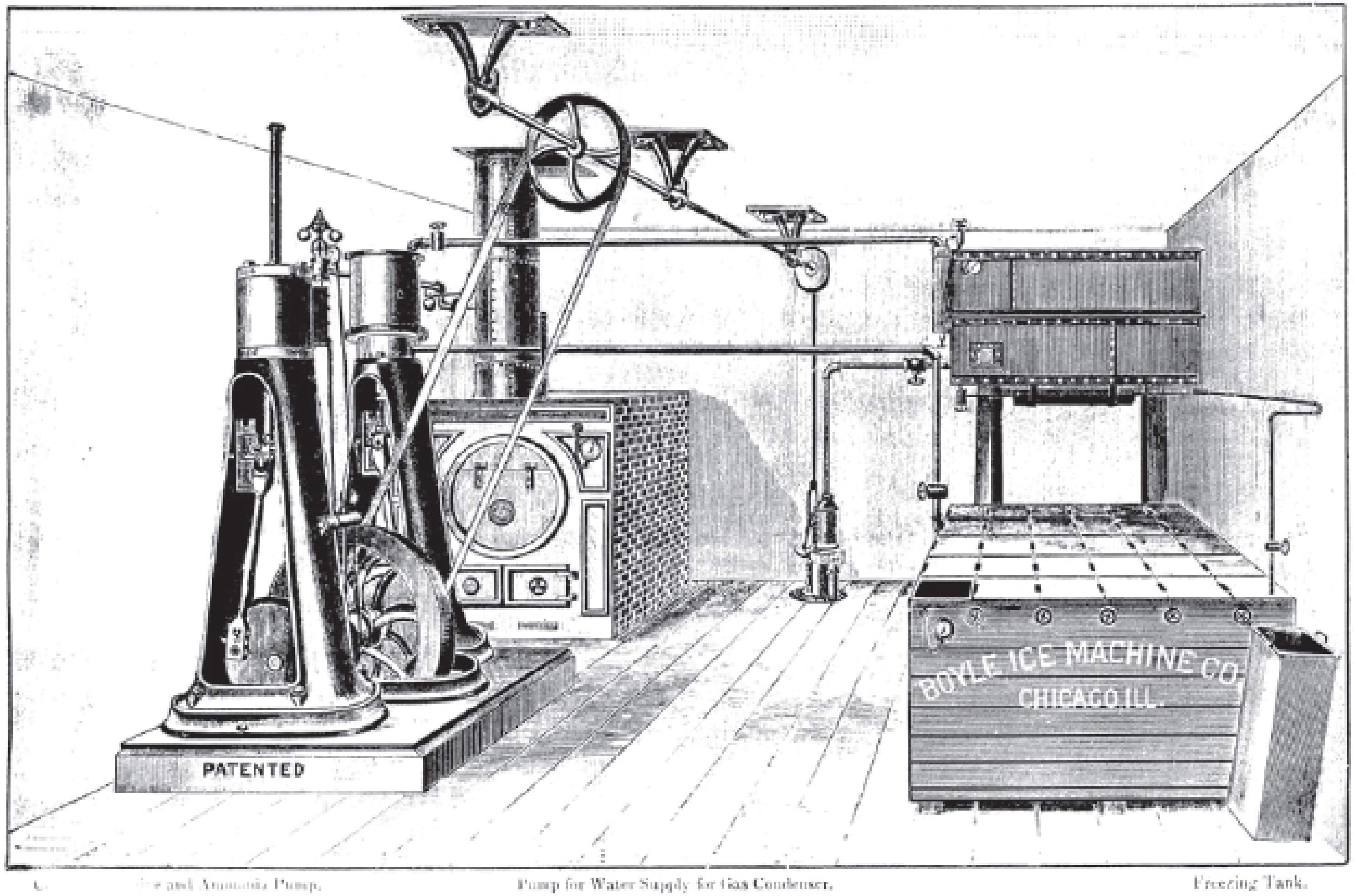
ASHRAE Fellow Life Member

History-Linde's first ammonia reciprocating compressor built in 1876., The first compressor was installed in a brewery and exhibited in Paris in 1878



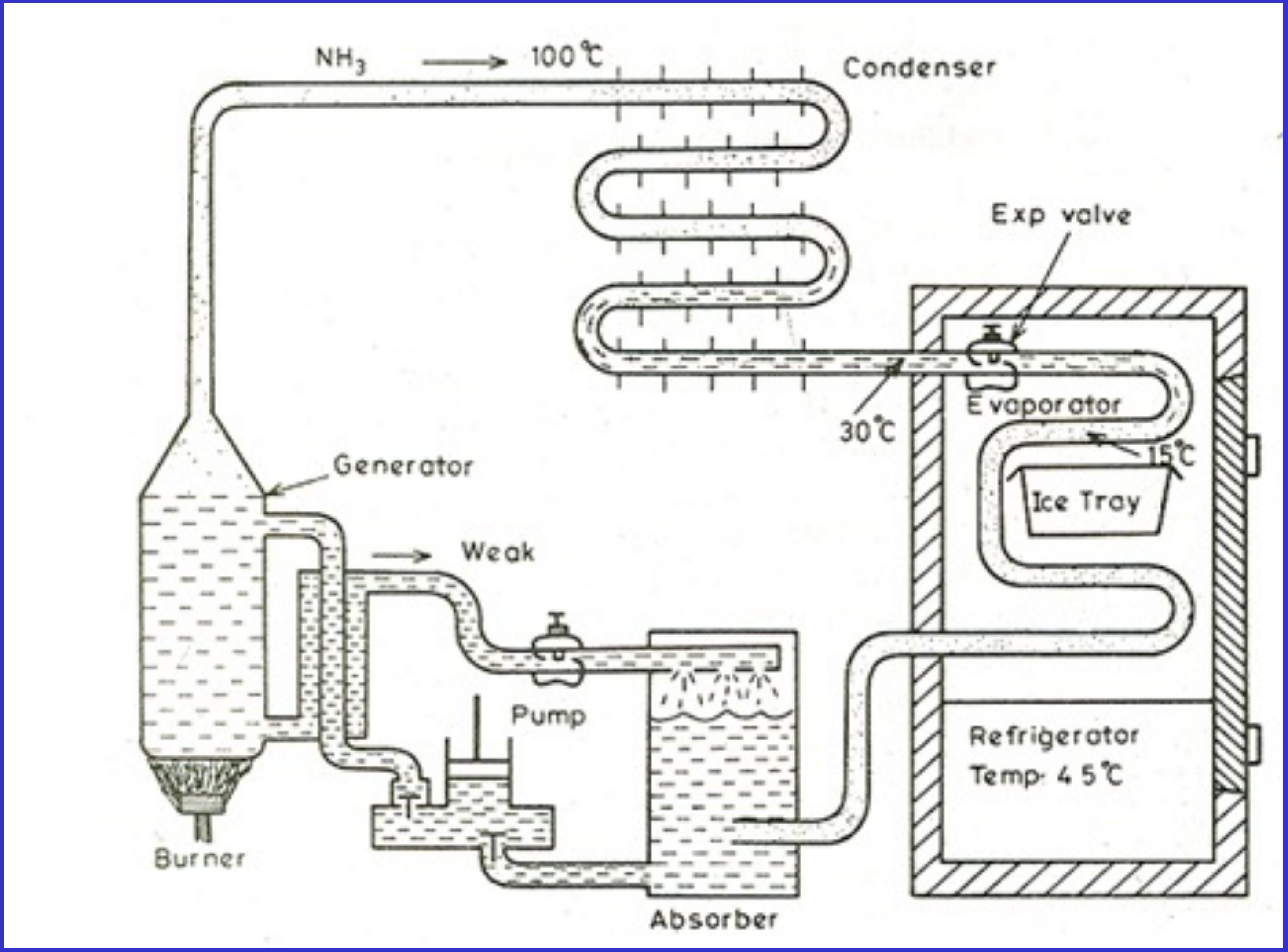
History-Block Ice machine -Ammonia compressor driven by steam engine-year1879



ONE-TON SIZE, BOYLE ICE MACHINE.

A can ice machine by Boyle Ice Machine Co., 1879.

First Domestic Refrigerator using Ammonia

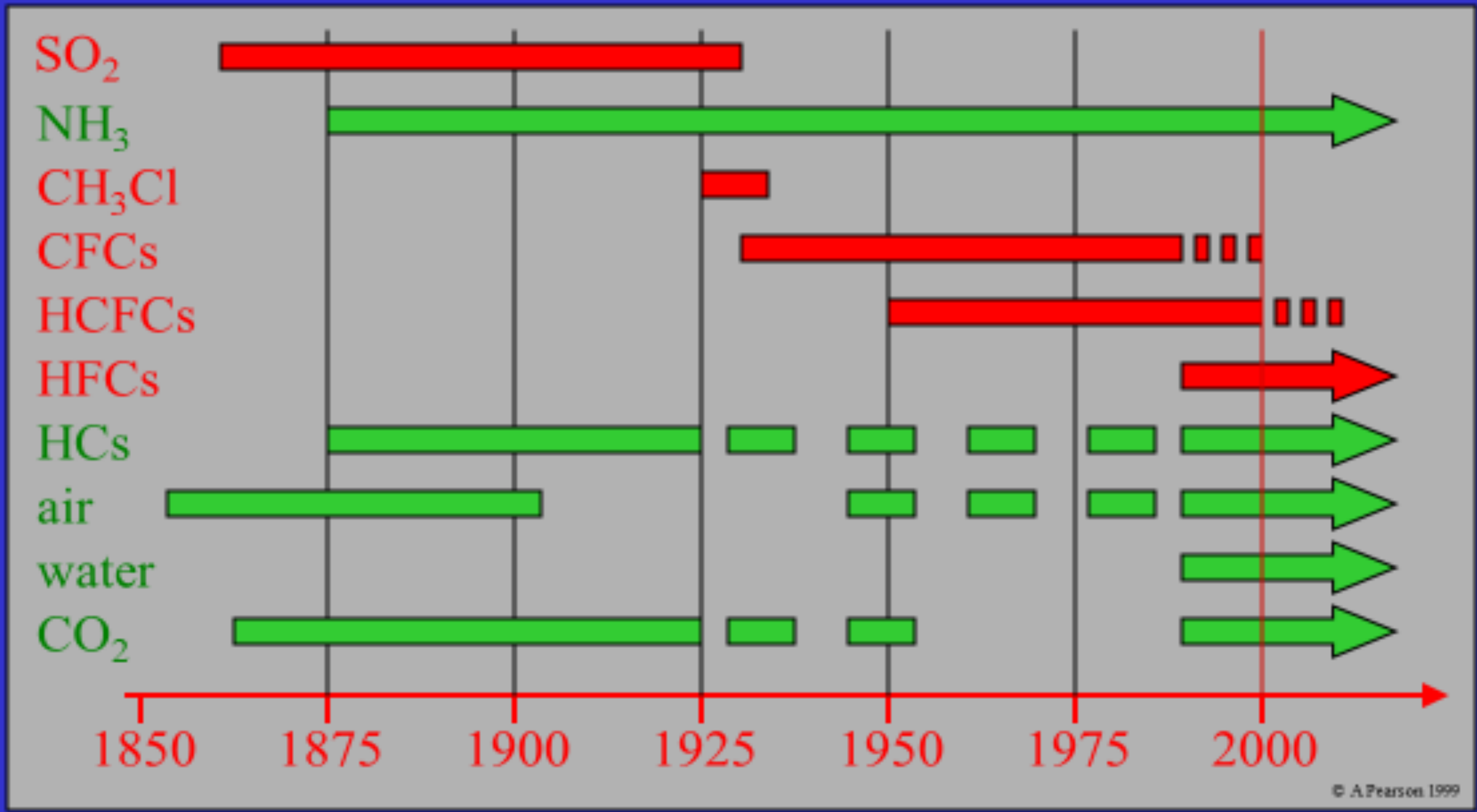


History of HVAC&R Refrigerants

1st Generation *"What Ever Worked"*	2nd Generation *"Safety and Stability"*	3rd Generation *"Ozone Protection"*	4th Generation *"Global Warming"*
1830's – 1930's	1930's – 1990's	1990's – 2010's	2010 - ??
• Limited applications mainly industrial • "Poor safety & cost"	• Innovation enabled exponential societal improvements	Preserved 2nd gen. innovations, safety, stability and efficiency	• Fewer optimal choices • Safety and design challenges
• NH_3 • CO_2 • Various Hydrocarbons • H_2O • Sulfur Dioxide • Methyl Chloride (R40)	• NH_3 • CFCs and HCFCs o R11 o R12 o R22 o R502	• NH_3 • HCFCs & HFCs o R123 o R134a o R410A o R404A o Many Blends	• NH_3 • Low GWP HFCs & HFOs o R1233zd (E) o R1234yf & R1234ze(E) o HFC/HFO blends • Renewed "Natural" interest o CO_2 o Hydrocarbons

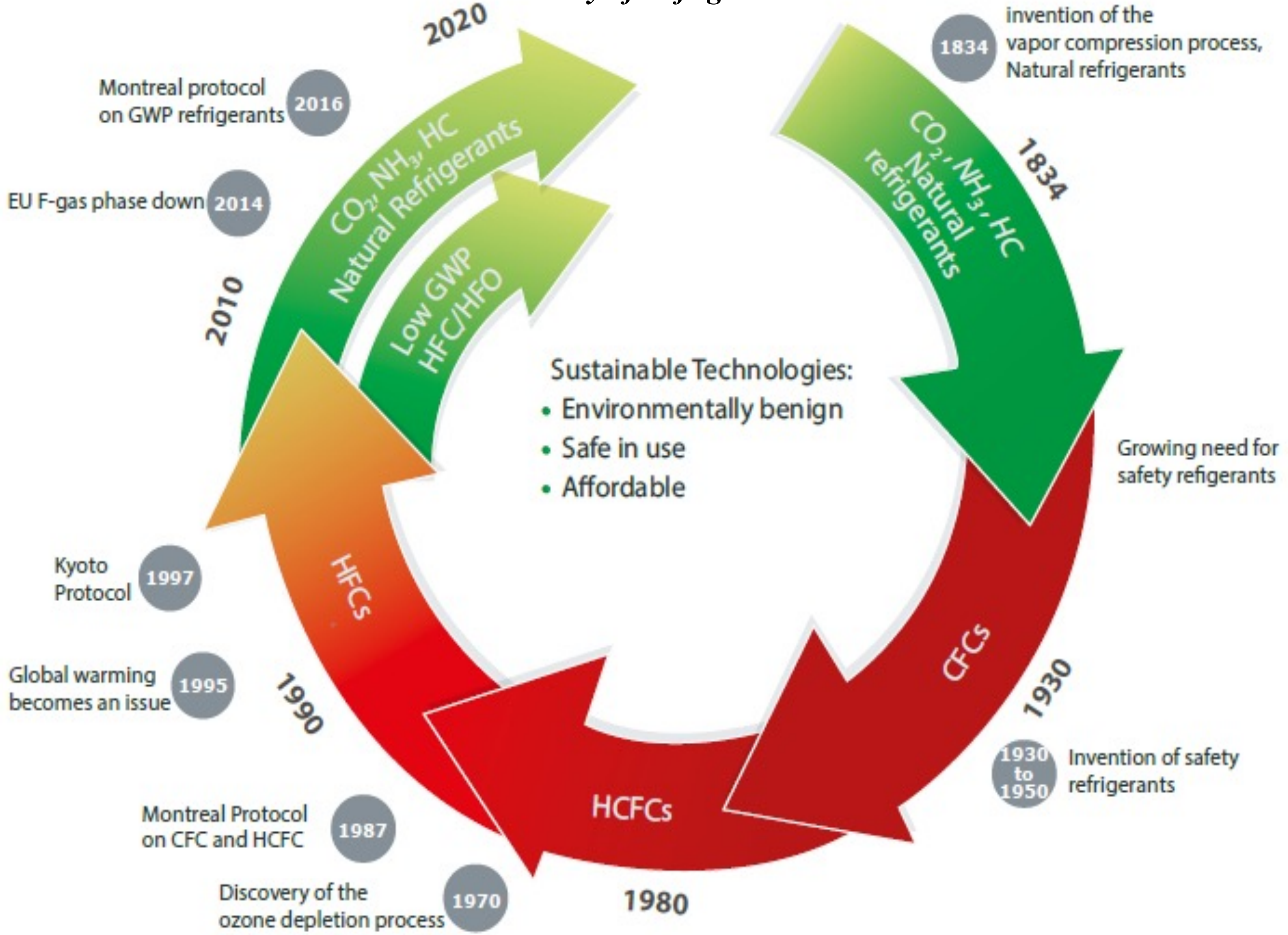
Ammonia Refrigerant has Unbroken History

Refrigerants Time-line



Introduction(Cont.)

History of Refrigerants




ISSUES NEED TO BE ADDRESSED
• Global Warming
• Energy Efficiency
• Environmentally Friendly Solutions
• Alternate Technologies

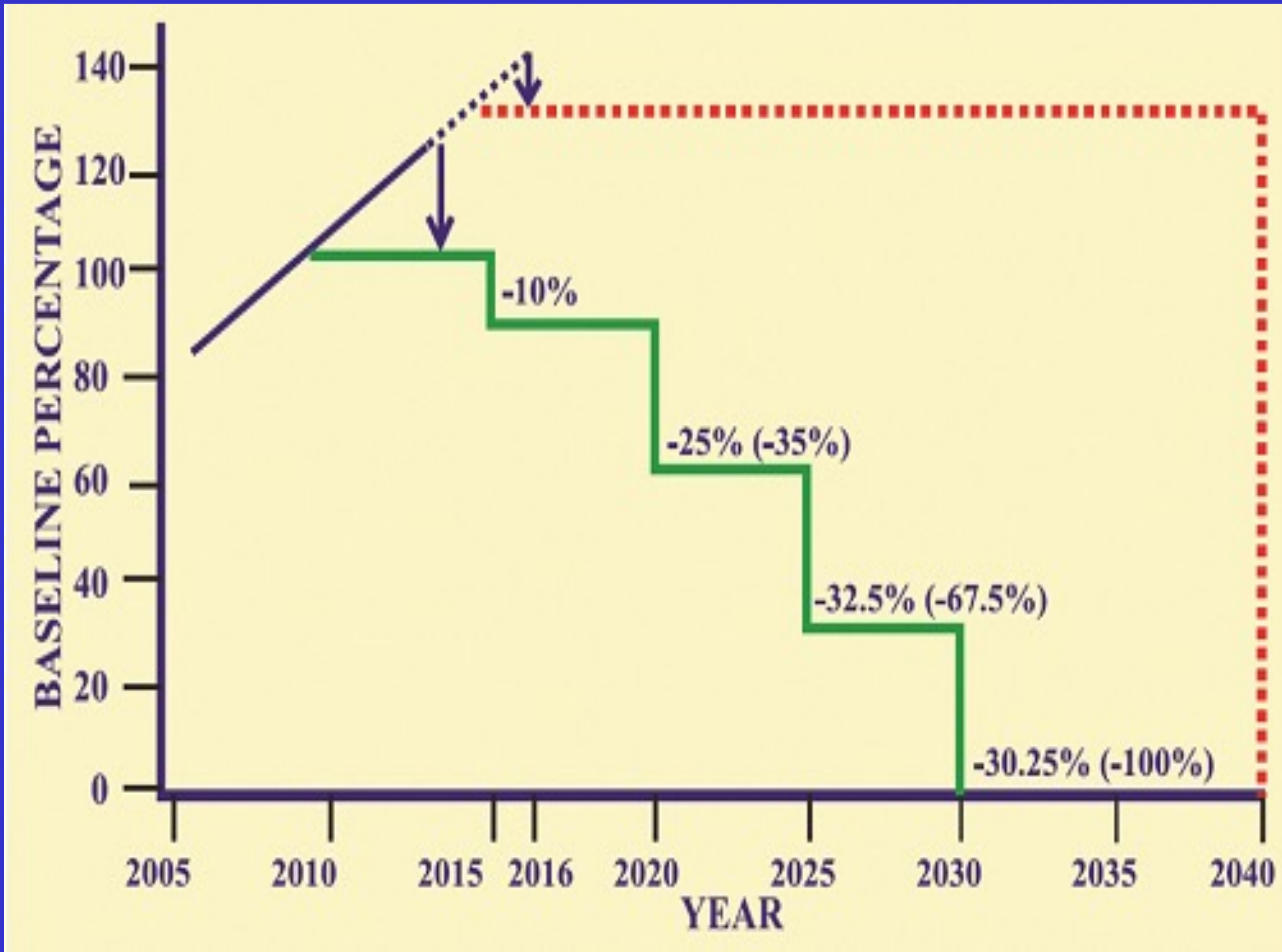
KIGALI AGREEMENT-25th October 2016

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

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%

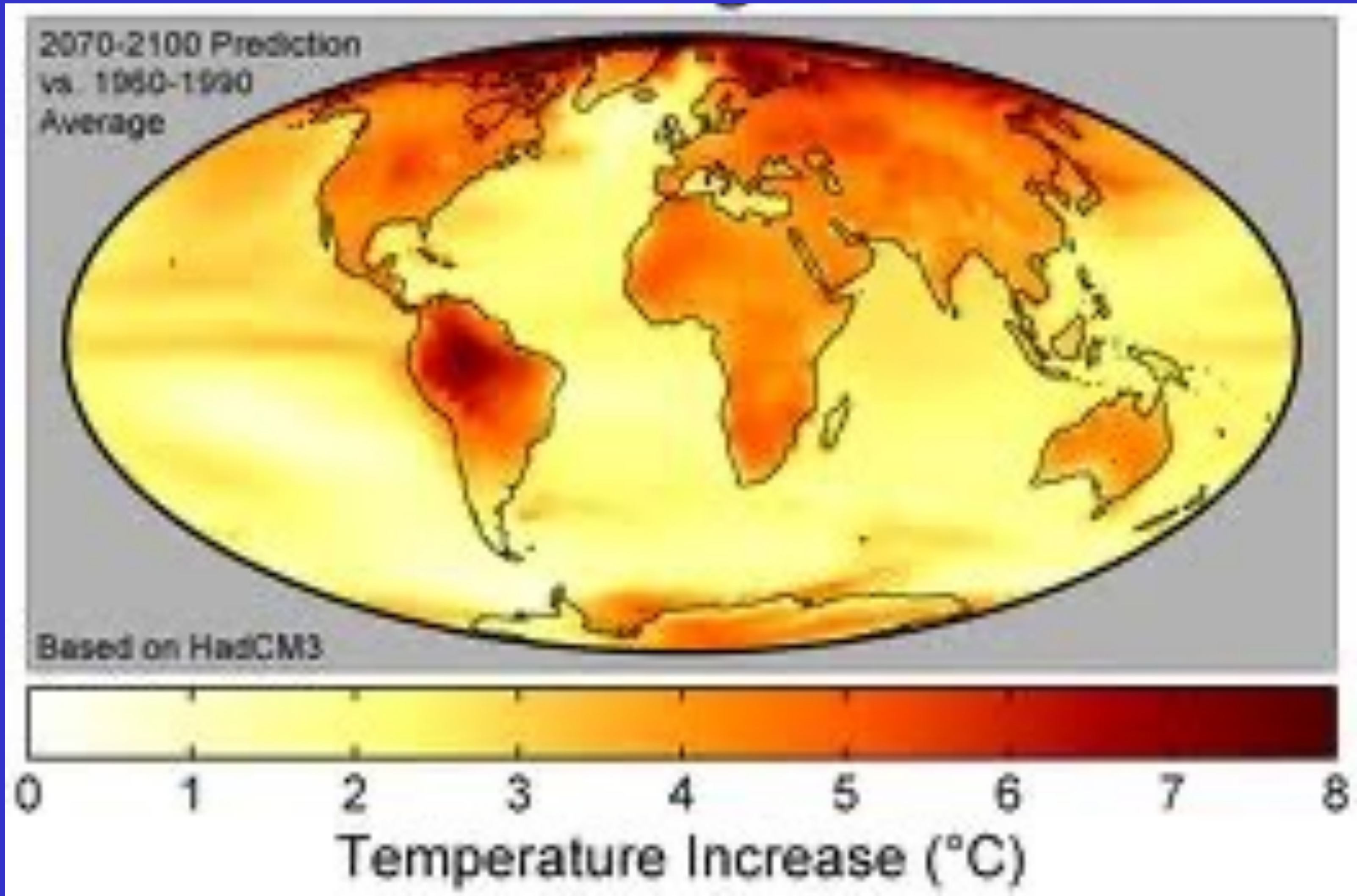
Phase out Schedule



Federal Register Rules and regulations formed in July 2015 has stated following as a time table to phase out these refrigerants.

End Use	Substitutes	Decision
Retail Food refrigeration below 2200 Btu/hr.	R404A, R407C, R410A, R505A	Unacceptable as of Jan., 1,2019
Retail Food refrigeration greater 2200 Btu/hr.	R404A, R407C, R410A, R505A	Unacceptable as of Jan., 1,2020
Retail food refrigeration Low temperature	R404A, R407C, R410A, R505A	Unacceptable as of Jan., 1,2020
Retail food refrigeration standalone retrofits temperature	R404A, R407C, R410A, R505A	Unacceptable as of July 20, 2016

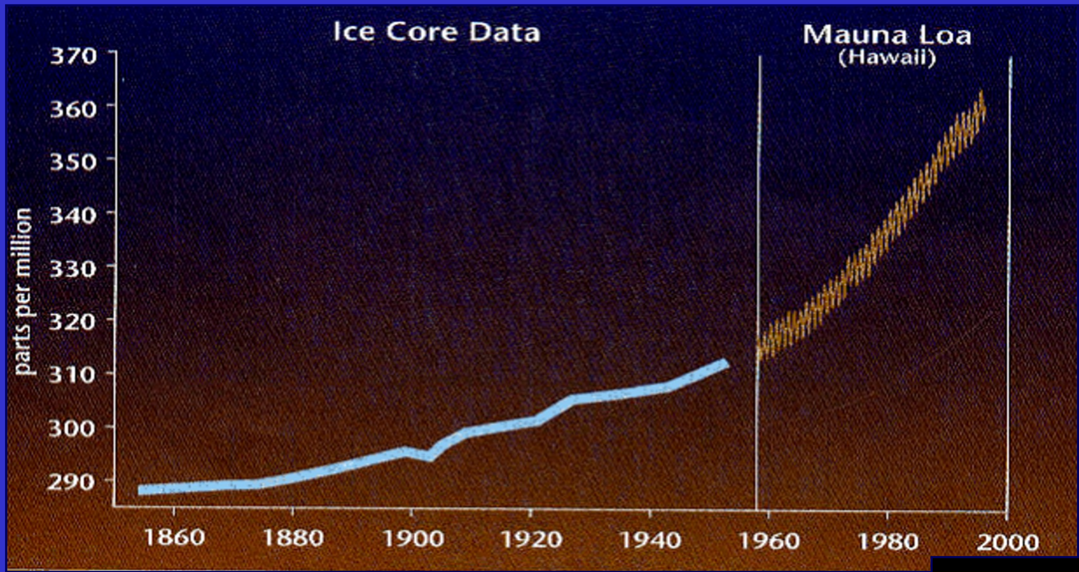
Safety of Environment



THINK SAFETY
BEFORE YOU START

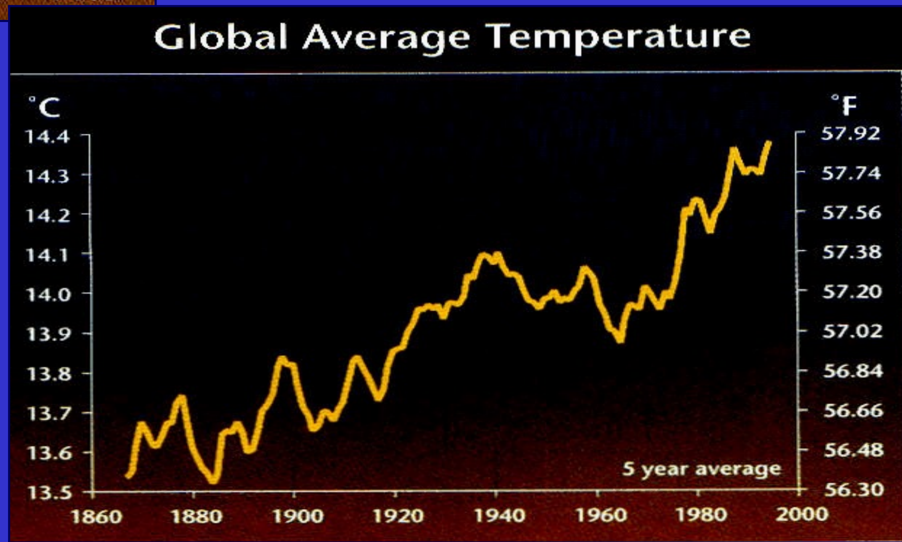
Global Warming

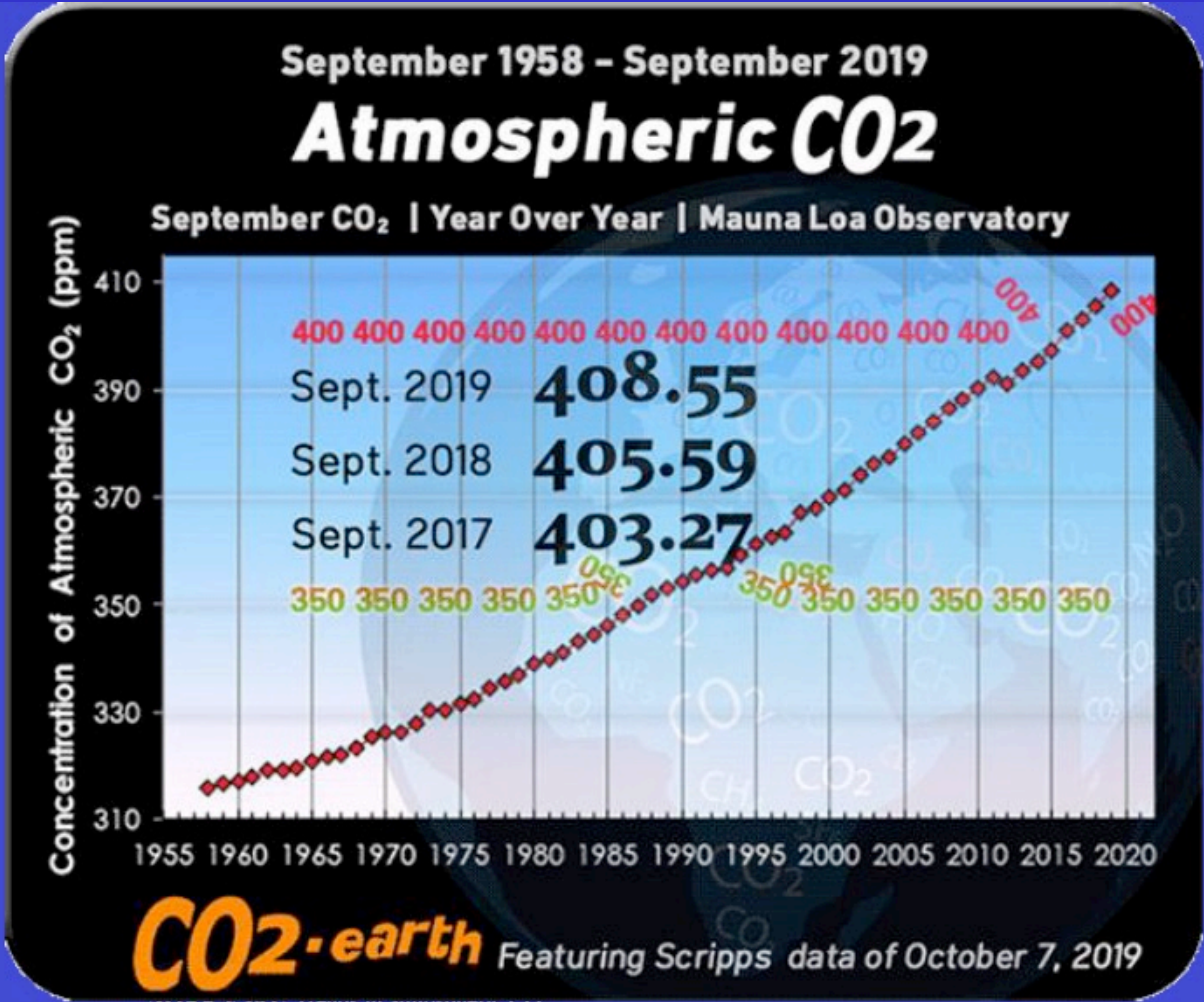
Climate is Changing!



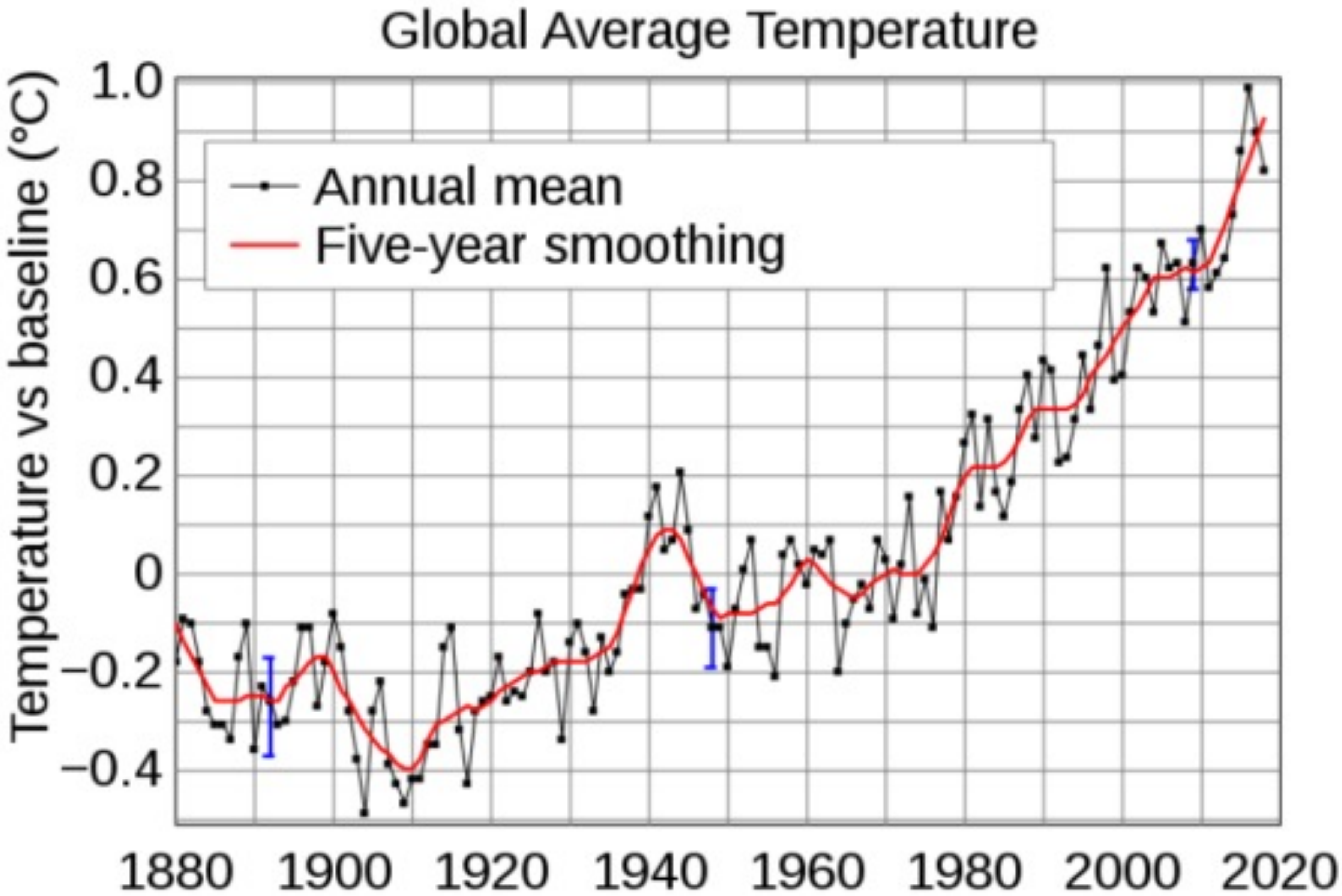
CO_2 concentration has been continuously increasing.

Global temperature has also been continuously increasing.





NOAA-ESRL Trends in atmospheric CO_2


Global Average Temperature
Temperature vs baseline (°C)
1.0
0.8
0.6
0.4
0.2
0
−0.2
−0.4
Annual mean
Five-year smoothing
1880
1900
1920
1940
1960
1980
2000
2020

Global warming is caused predominantly by CO_2 content in the atmosphere

Two types of global warming caused by HVAC&R industry are: -

1. **Direct global warming** due to leakage of refrigerants which depends on type of refrigerant used and quantity of refrigerant in the system

2. **Indirect global warming** equivalent to CO_2 emission due to energy consumption over the life time (TEWI) by the HVAC&R system.

It is important to note that **90% Global Warming contribution comes from energy consumption and only 10% from leakage of refrigerant.**

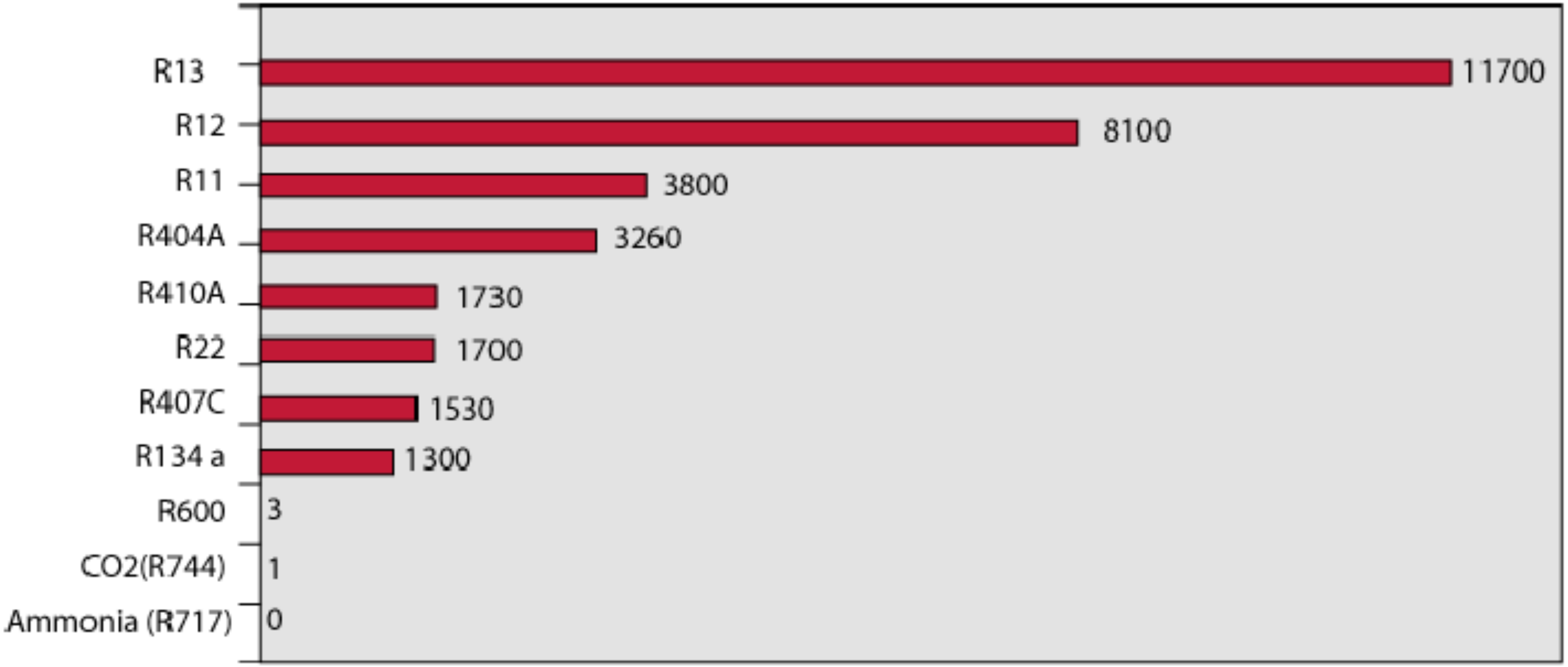
DIFFERENT LEVELS OF CO_2 IN THE ATMOSPHERE AND IT'S EFFECTS ON HUMANS

(ppm = parts per million ,1 ppm = 0.0001% ,10000 ppm = 1.0%)
To convert PPM to mg/m^3 use multiplier 0.7 to get mg/m^3

Level of CO_2	EFFECT
250-350ppm	Normal - should be required in outdoor fresh air
600-800ppm	Normal limit for indoor air quality
1000ppm-0.1%	Prolonged exposure can affect powers of concentration
1000-2000ppm	Complaints of drowsiness and poor air circulation
2000-5000ppm	Headaches, sleepiness, Nausea, increased heart rate
5000ppm-0.5%	Continuous exposure leads to health disorder
10,000ppm 1.0%	Breathing rate increases
15,000ppm 1.5%	Permissible short-term exposure for working in hazardous applications
20,000ppm 2.0%	Extremely dangerous to health, gets severe headaches, and tiredness

Quit

GLOBAL WARMING POTENTIAL



CONTRIBUTION TO GLOBAL WARMING RELATIVE TO 1 Kg OF CARBON DIOXIDE

TEWI :- Total Equivalent Warming Impact

- OVERALL WARMING EFFECT FOR ENTIRE LIFE
- MADE UP FROM
  - a. DIRECT CONTRIBUTION EMISSION DURING AND AFTER LIFE OF SYSTEM
  - b. INDIRECT CONTRIBUTION EMISSION OF CO_2 DURING GENERATION OF ELECTRICITY TO DRIVE SYSTEM

AEL :- Allowable Exposure Limit

- REFRIGERANT CONCENTRATION - (PPM)

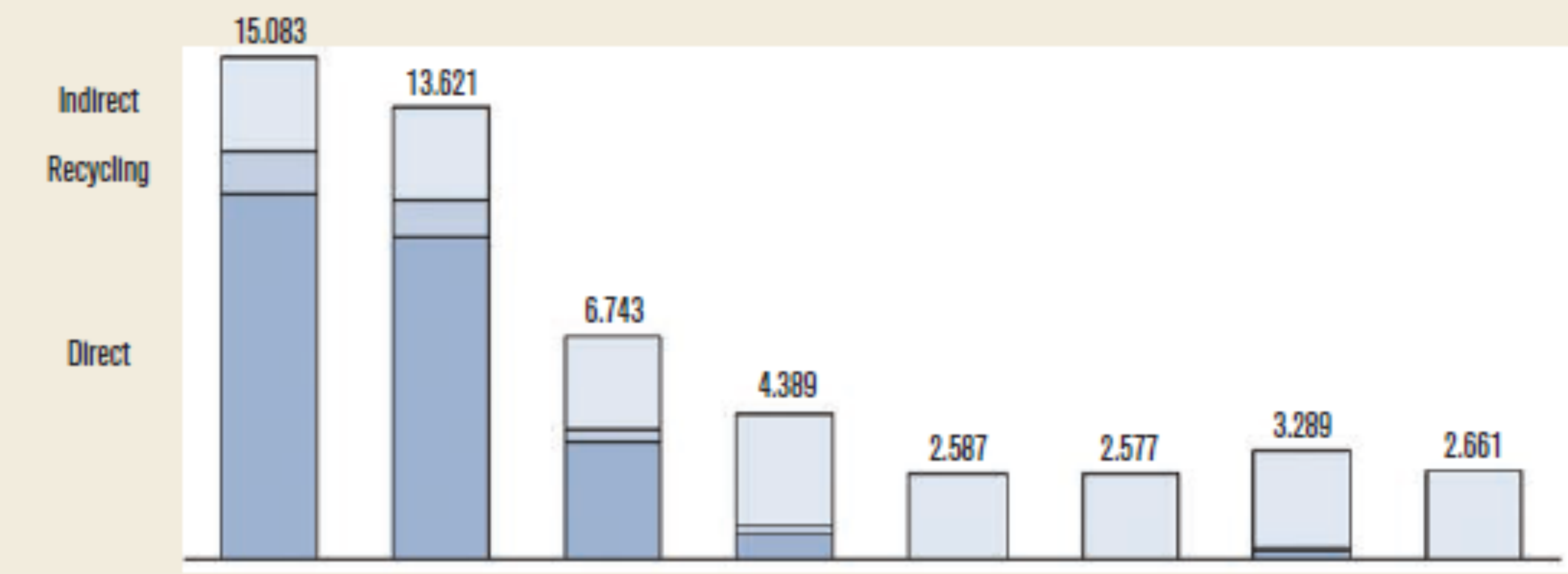
TEWI=Total Equivalent Warming Impact

- $TEWI = (GWP \times L \times n) = (GWP \times m\ [(1 - a_{recovery})]\ ) + (n \times E_{annual} \times \beta)$
- L= leakage rate per year
- n= system operating time in years
- m-refrigerant charge- kg
- $A_{recovery}$ = Recycling Factor
- E_{annual}=Energy consumption per year- kWh
- β = CO_2 Emission per kWh

Total Equivalent Warming Impact

REF: ASHRAE Journal Aug 2013

FIGURE 2 Total Equivalent Warming Impact of benchmark and alternative systems (New York climate, β=0,676 kg CO_2/kWh).



Alternative System	Reference System	(1) R-404A/ CO_2 Cascade	(1) R-134a/ CO_2 Cascade	(2) R-404A Chiller	(3) Propane Chiller	(3) Ammonia Chiller	(3) R-134a Chiller	(4) Transcritical CO_2 Booster
MT	R-404A DX	R-404A DX	R-134a DX	Prop. Glycol	Pumped CO_2	Pumped CO_2	Pumped CO_2	CO_2 DX
LT	R-404A DX	CO_2 DX	CO_2 DX	CO_2 DX	CO_2 DX	CO_2 DX	CO_2 DX	CO_2 DX

TEWI- COMPARISON OF DIFFERENT REFRIGERANT

for an evaporation temperature t_0=−20 °, a condensing temperature t_c=35 °C, and an operating time of 15 years.

Refrigerant	Direct Effect		Indirect Effect	
	Operating Leak (kg CO_2)	Fluid Recovery Leak (kg CO_2)	Drive Energy Generation (kg CO_2)	TEWI (kgCO_2)
R22	1,033,500	68,900	1,805,400	2,907,800
R134a	911,625	60,775	1,884,150	2,856,550
R407C	999,352	66,623	2,104,650	3,170,625
R410A	1,049,555	69,970	1,962,900	3,082,425
R717	0	0	1,457,550	1,457,550

Use of Natural Refrigerants

There is therefore increasing demand to explore use of all-natural refrigerants like ammonia, water, air, Carbon Dioxide as well as hydrocarbons, since these refrigerants are in the atmosphere since life came in to existence on earth and properties as well as effects of them on human body and environment are fully known to mankind and do not contribute to global warming.

Ammonia refrigerant naturally leads the race.”

ASHRAE POSITION STATEMENT IN ASHRAE JOURNAL SEPTEMBER 1991

"ASHRAE considers that the **continued use of Ammonia is necessary for food preservation and air conditioning**. ASHRAE would promote a variety of programs to preserve the economic benefits of Ammonia refrigeration while providing for management of risks.

ASHRAE will:

1. Promote authoritative information on Ammonia by seminars and publications.

2. Continue research on Ammonia topics such as handling application, operation and control of emissions.

3. Maintain and develop standards and guidelines for practical and safe application of Ammonia.

4. Provide programs and publications of innovative designs and applications using Ammonia

5. Advise govt. and officials with information regarding Ammonia.

Quit

STANDARD DESIGNATIONS OF REFRIGERANTS

ASHRAE STANDARD 34

METHANE SERIES			
NUMBER	**CHEMICAL FORMULA**	**CHEMICAL NAME**	**SAFETY CODE**
R11	$CCL_3 F$	TRICHLORO FLUROMETHANE	A1
R12	$CCL_2 F_2$	DICHLOROFLUROMETHANE	A1
R22	$CHCLF_2$	CHLORODIFLUOROMETHANE	A1
ETHANE SERIES			
R113	CCL_2FCCLF_2	TRICHLOROTRI FLU ROETHANE	A1
R114	$CCLF_2CCLF_2$	DICHLOROTETRAFLUROETHANE	A1
R123	$CHCL_2 CF_3$	DICHLOROTRIFLUROETHANE	B1
R 134a	CH_2FCF_3	TETRAFLUROETHANE	A1
PROPANE SERIES			
R290	$CH_3CH_2CH_3$	PROPANE	A3
ZEOTROPIC BLENDS (% BY MASS)			
R404A	R125/ R143a / R 134a	(44/ 52 / 4)	A1/A1
R407C	R32/ R125 / R134a	(23 /25 / 52)	A1/A1
R41 OA	R32/ R125	(50 / 50)	A1/A1

contd...

STANDARD DESIGNATIONS OF REFRIGERANTS

ASHRAE STANDARD 34

contd...

NUMBER	CHEMICAL FORMULA	CHEMICAL NAME	SAFETY CODE
AZEOTROPIC BLENDS			
R500	R12/ 152a	(73.8 / 26.2)	A1
R502	R22 / R 115	(48.8 / 51.2)	A1
HYDROCARBON			
R600	$CH_3CH_2CH_2CH_3$	BUTANE	A3
R600a	$CH\ (CH_3)_3$	METHYLE PROPANE	A3
INORGANIC COMPOUNDS (NATURAL REFRIGERANTS)			
R717	**NH_3**	**AMMONIA**	**B2*L***
R718	H_2O	WATER	A1
R744	CO_2	CARBON DIOXIDE	A1
R764	$S0_2$	SULPHUR DIOXIDE	B1

Natural Refrigerants

(Zero ODP & Ultra-low GWP Refrigerants)

- Hydrocarbons (HC-290, HC-600a)
- Ammonia (R-717)
- Carbon Dioxide (R-744)
- Water (R-718)
- Air

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 ($(CH_2)_5$)

HYDROCARBONS AS REFRIGERANT AS REPLACEMENT

HFC	HC ALTERNATIVE	APPLICATIONS
R134a	R600a-ISOBUTANE	HOUSEHOLD APPLIANCES
R134a	R290/600a mixtures-propane/isobutane mixtures	COMMERCIAL APPLICATIONS
R404A/R507C	R290,R1270 and their mixtures	Industrial plants - Petrochemicals
R407C	R290.R1270-Porppane/Propylene mixtures	Air conditioning and heat pumps
R410A	R1270/170 mixtures-Propylene/Ethane mixtures	Deviations due to capcity & pressure levels
R23,R14	R170/R1150-Ethane/Ethylene mixtures	Low temperature cascades
R227ea	R600a-Isobutane	High Temperature Applications

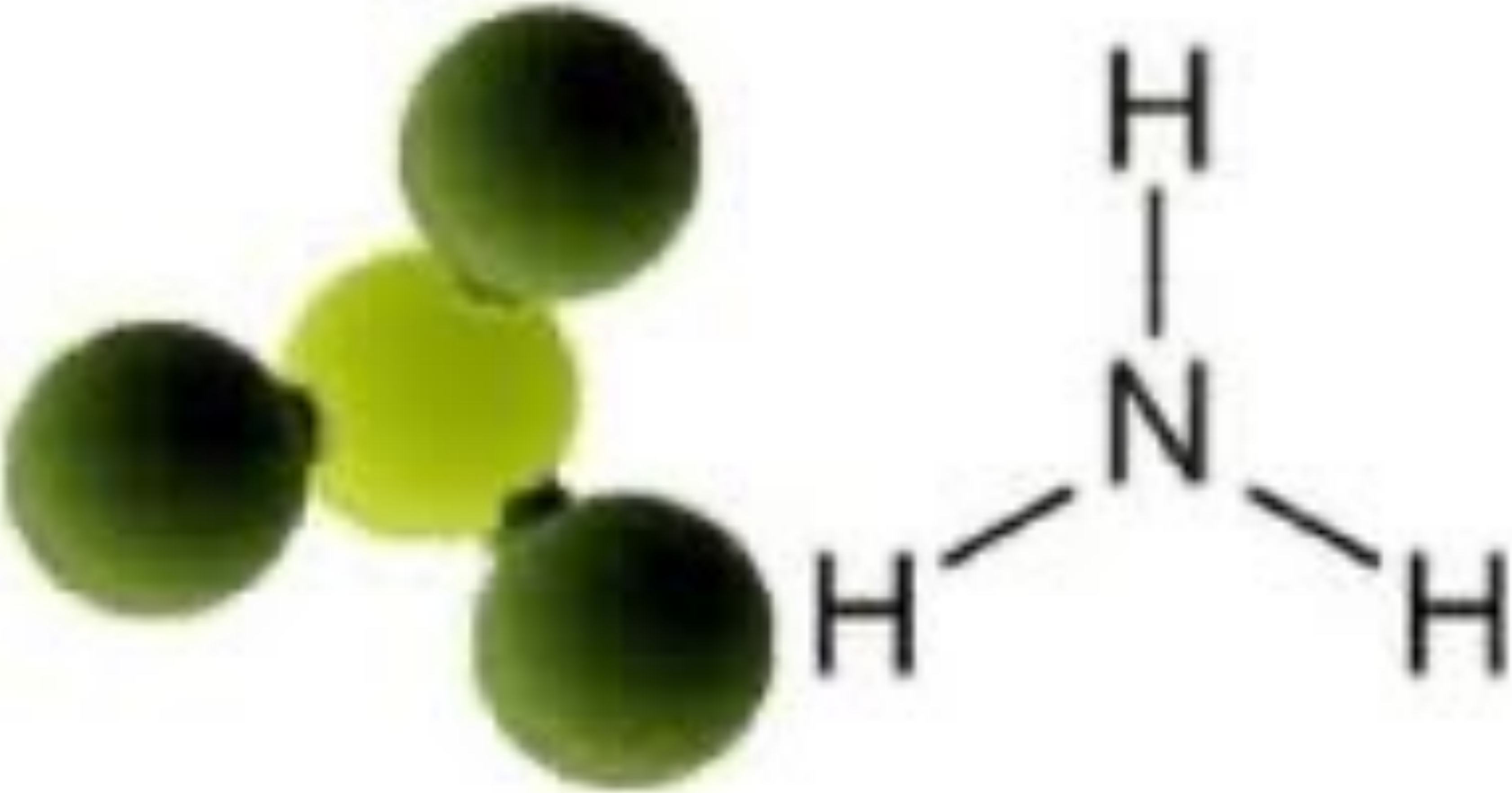
Refrigerant evaluation process

1. ENVIRONMENT
2. PERFORMANCE
3. ENERGY EFFICIENCY
4. TOXICITY/SAFETY
5. FLAMMABILITY
6. MATERIAL CPMPATIBILITY
7. STABILITY
8. COST

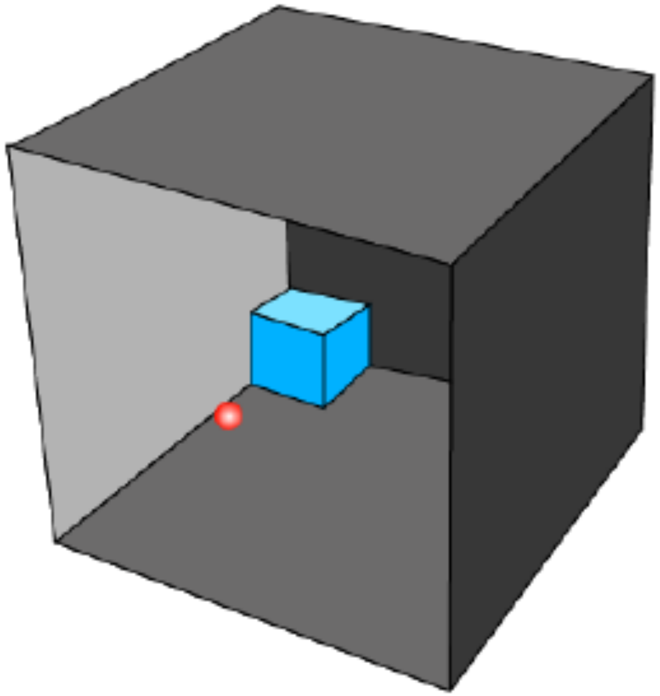
Thermal/physical properties

- BOILING POINT
- DISCHARGE TEMPERATURE
- DISCHARGE PRESSURE
- SPECIFIC VOLUME
- DENSITY
- LATENT HEAT OF VAPORISATION
- COMPRESSOR DISPLACEMENT
- HORSE POWER PER TON
- COP(Coefficient Of Performance)

NH_3 ammonia



PER YEAR IN THE WORLD



All ammonia in nature
(1 → 3) x 1.000.000.000 ton

Produced by Man
(100 → 120) x 1.000.000 ton

Ammonia used as refrigerant
(3→ 5) x 100.000 ton

Ammonia – A Natural Refrigerant

Ammonia is produced in a natural way by human beings and animals; 17 grams/day for humans.

Natural production	3000 million tons/year
Production in factories	120 million tons/year
Used in refrigeration	6 million tons/year

Ammonia is natural refrigerant, present in the atmosphere and available in nature in abundance. In nature, it is produced by biological processes and is naturally decomposed & does not add to GWP.

Each human being produces approx.17g of ammonia per day.

Human liver has capacity to convert 130 g. of ammonia into urea each day.

The volume of ammonia generated by man is only about 3% of the total ammonia present in the nature.

Out of this only little under 5% is used as a refrigerant. Most of the ammonia is produced in a “Fertilizer grade” or commercial grade where the specifications are 99.5% purity whereas for refrigeration grade the purity required is 99.95% minimum and is called anhydrous ammonia.

Ammonia Refrigeration Grade Purity Requirements

Ammonia Content	99.95% Min.
Non-Basic Gas in Vapour Phase	25 ppm max.
Non-Basic Gas in Liquid Phase	10 ppm max
Water	33 ppm max.
Oil (as soluble in petroleum ether)	2 ppm max.
Salt (calculated as NaCl)	None
Pyridine, Hydrogen Sulphide, Naphthalene	None

Refrigeration Grade Ammonia Properties

Molecular symbol	NH_3-R-717
Appearance	Colourless
Odour	Characteristic, pungent
ODP (Ozone Depleting Potential)	0
GWP (Global Warming Potential)	0
Atmospheric life in years	<0.019165(Ref IIAR)
Ammonia content-minimum	99.95%-99.98% as per ASHRAE
Water content	33 PPM max.
Oil content	2 PPM max.
Non condensable	0.2ml/g
Salts content	None
Pyridine, Hydrogen sulfide, Naphthalene	None
Molecular weight	17.031g/mol.
Alkaline pH	11.6

Refrigeration Grade Ammonia Properties

Boiling Point at one atmosphere (101.33 kPa)	-33.33^{0}C (239.82K)
Freezing point at one atmosphere/Triple point	-77.66^{0}C (195.5K)
Critical temperature	132.22^{0}C(405.37K)
Critical Pressure	115.6kg/cm^2 g-(11.34MPa) 113.3bar-ab. (1643.29psig)
Latent heat at -33^{0}C & at one atmosphere	1.369MJ/kg (588.8 Btu/lb.) /327.1Kcal/Kg
Relative density of vapour compared to air at 0^{0}C	0.5967- (lighter than air)
Vapour Density at -33^{0}C	0.8896kg/m^{3}or (0.5554 lb./ft^3.)
Sp. Gravity of liquid at -33^{0}C compared to water @ 4^{0}C	0.6816
Liquid Density at -33^{0}C and at one atmosphere	681.6kg/m^3 or (42.55 lb./ft^3)

Refrigeration Grade Ammonia Properties

One cubic foot of liquid at 60^0F	Expands to 850 cubic feet of gas
Specific volume of vapour at 0^0C at one atmosphere	$1.299 m^3/kg$-(20.80 $ft^3/lb.$)
Lower Flammability limit by volume (LFL) at atmospheric pressure	15-16%-108.000mg/m^3
Upper Flammability limit by volume (HFL) at atmospheric pressure	25-28%- 240,000 mg/m^3
Flammability classification (Non-Flammable)	B2L as per ASHRAE Classification
Ignition temperature	651.1^0C(924.13K) -(1204^0F)
Ignition energy (20^0C, 101Kpa)	14mJ
Sp. heat at constant pressure-C_p	2.1706kJ/kg k(0.5184Btu/lb^0F)
Sp. heat at constant volume-C_v	1.6444 kJ/kg k (0.3928 Btu/lb^0F)

Refrigeration Grade Ammonia Properties

Thermal conductivity of liquid at 0^0C	**$518.5x10^{-3}$ W/mK**
Kinematic viscosity of the liquid at 0^0C	**$2.66x10^{-7}$ m^2/s**
Ratio of sp. heats at 15^0C and 1 atmosphere ($Y= C_p/C_v$)	**1.320**
Ammonia produced daily in human beings	**17 g^{-1}mol**
Concentration in human blood	**0.8-1.7PPM**
Solubility in water(20^0C-1bar)	**0.517kg or 650-g or 1.ltr of water**
United Nations Chemical ID No.	**I.D. # (1005)**

Reasons for Selecting Ammonia Refrigerant

- ODP-0
- GWP < 1
- Atmospheric Life- 0.01 years
- Natural Refrigerant
- Highest Efficiency-Better Heat Transfer Properties
- Easier Oil Management
- Low Cost-Easy Availability
- Smaller pipe sizes

Comparison of ODP and GWP values and atmospheric life of currently used refrigerants. (ASHRAE Fundamentals 2013-page 29.5) & Wikipedia

Refrigerant	ODP	GWP	Atmospheric Life-years
R-22 (HCFC -22)	0.055	1790	11.9
R-134a	0	1370	13.4
R404A	0	3700	16
R407C	0	1700	5.6
R410A	0	2100	16
R507C	1	3300	40.5
R32	0	675	4.9
R290-Propane	0	3.3	12.0
R1234Ze	0	6.0	0
R1234yf	0	4.0	0
R744=CO2	0	1.0	29-36
Ammonia, R717	0	0	<0.02

Molecular Weight comparison of Various Refrigerants

Refrigerant	Molecular weight	Density kg/m3 @ 20^0C. 1atm
R717	17.03	0.716
Air R729	28.97	1.204
R744	44.01	1.839
R290	44.1	1.865
R410A	72.58	3.062
R407C	86.2	3.639
R22	86.47	3.651
R134a	102	4.336

THE GASES LIGHTER THAN AIR

HYDROGEN	H2	0.07
HELIUM	He	0.14
METHANE	CH4	0.55
AMMONIA	NH3	0.59
HYDROFLUORIC ACID	HF	0.59
NEON	Ne	0.70
HYDROCYANIC ACID	HCN	0.93
CARBON MONOXIDE	Co	0.97
NITROGEN	N2	0.97

Quit

LIOUID -DENSITY AT 86 Deg. F, LB/CFT

AMMONIA	37.22
R-22	73.22
R-12	80.82
OIL	55.5

AMMONIA BEING LIGHTER FLOATS ON OIL, LUBRICATION DOES NOT SUFFER, R-22/R 12 HAVIER THAN OIL-DILUTES OIL, FOAMING PROBLEMS, CRANKCASE HEATER NEEDED.

RANGE OF HEAT TRANSFER COEFF. BTU/HR-Deg F-Sq.ft		
	AMMONIA	R-22
Condensation outside tube	1300-2000	300-500
Boiling outside tube	400-800	250-350
Boiling inside tube	550-850	250-500

Ref. W. F. STOECKER

COMMERCIAL CONSIDERATI0NS

PRICE	AMMONIA	Rs. 25/ Kg
	R-22	Rs. 600/ Kg.

AVAILABILITY AMMONIA- ALL OVER COUNTRY

Critical Temp/Pr., Boiling point & Density of various Refrigerants

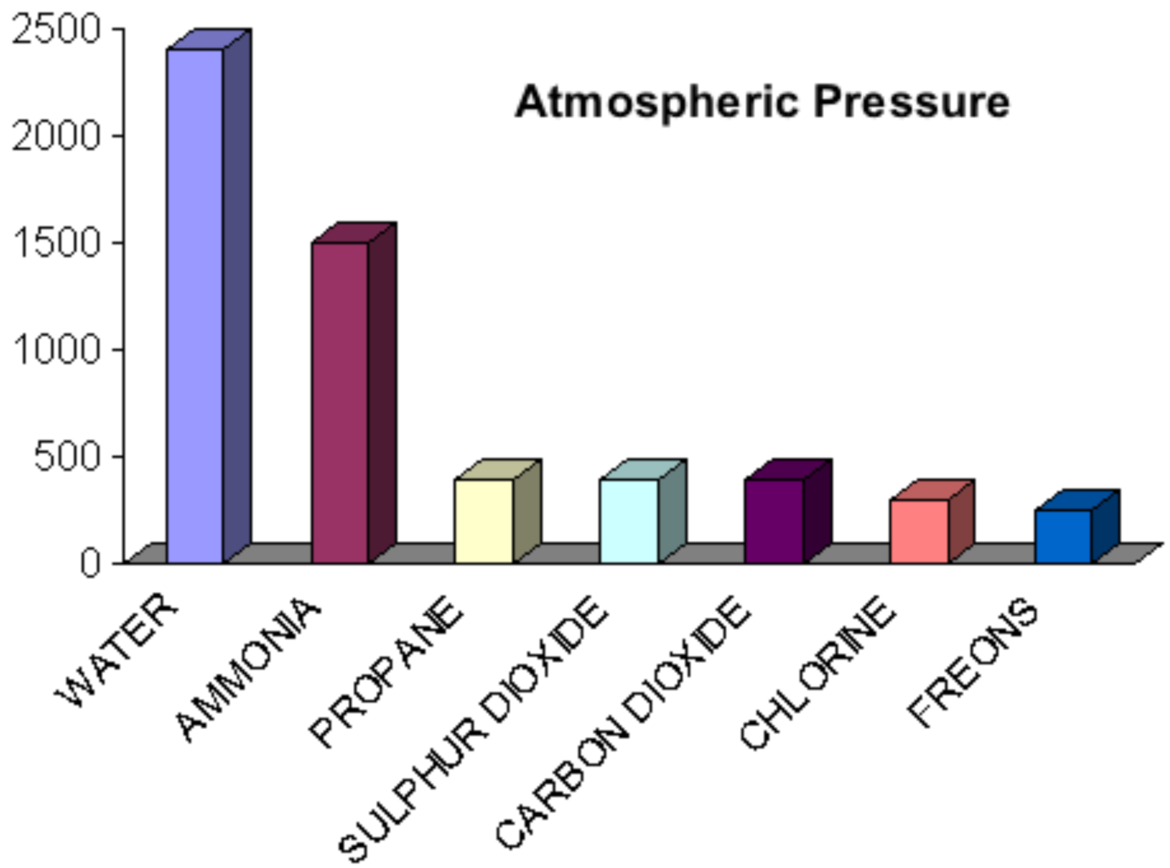
Refrigerant	Critical Temperature -^0C	Critical pressure-MPa	Boiling point	Critical Density-kg/m^3
R717-Ammonia	132.25	11.333	-33.33	225.0
R134a	100.06	4.0593	-26.07	511.0
R22	96.15	4.99	-40.81	523.8
R1234yf	94.7	3.3822	-29.49	475.6
R32	78.11	5.782	-51.65	424.0
R404A	72.05	3.729	-46.22	486.5
R410A	71.36	4.903	-51.55	459.5
R744	30.98	7.377	-	467.6

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

Quit

LATENT HEAT



Critical temperatures and pressures:

Ammonia –R717	**134.4^{0}C-113bar**
HCFC-22	**96.15^{0}C-49.9bar**
HFC134a	**101.06^{0}C—40.59bar**
R404A	**72.05^{0}C-37.28bar**
R410A	**71.36^{0}C-49.02bar**

volume flow rates comparison capacity of 1kW at -35/+35^{0}C can be compared for various refrigerants

	R-717	R-22	R-134a	R-404A
Specific enthalpy variation(kJ/kg)	1049.6	147.7	128.2	94.1
Mass flow rate (kg/s)	$0.95x10^3$	$6.79x10^3$	$7.80x10^3$	$10.63x10^3$
Specific volume (m^3/kg)	1.217	0.166	0.284	0.115
Volume flow rate (m^3/s)	$1.16x10^3$	$1.13x10^3$	$2.22x10^3$	$1.22x10^3$

Ammonia mass flow rate is Less compared to other refrigerants

Compression Ratio (γ), Discharge Temperatures.

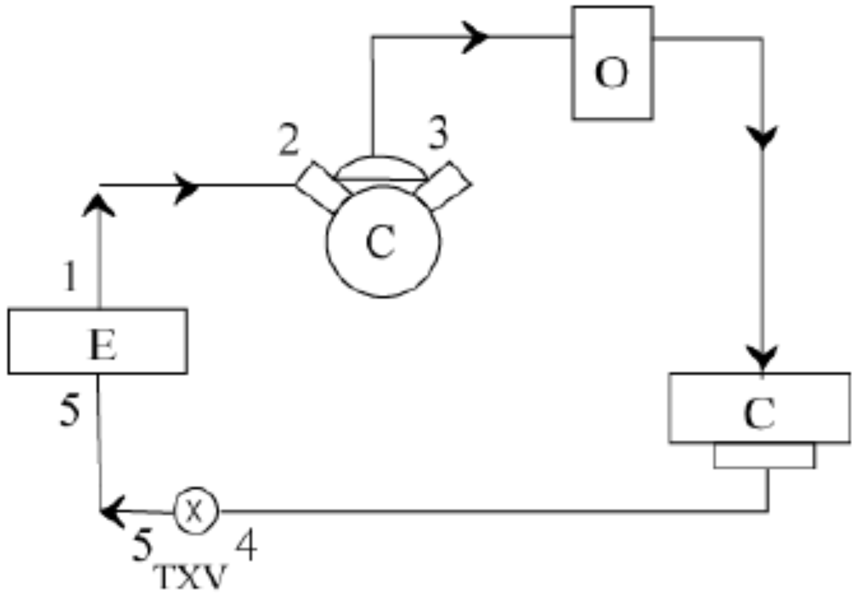
Refrigerant	Cp/Cv at boiling point or at Atmospheric pressure	Approximate isentropic Discharge Temperature ^0C
R22	1.236	75
R134a	1.154	55
R404A	1.166	58
R410A	1.244	70
R717(Ammonia)	1.348	145

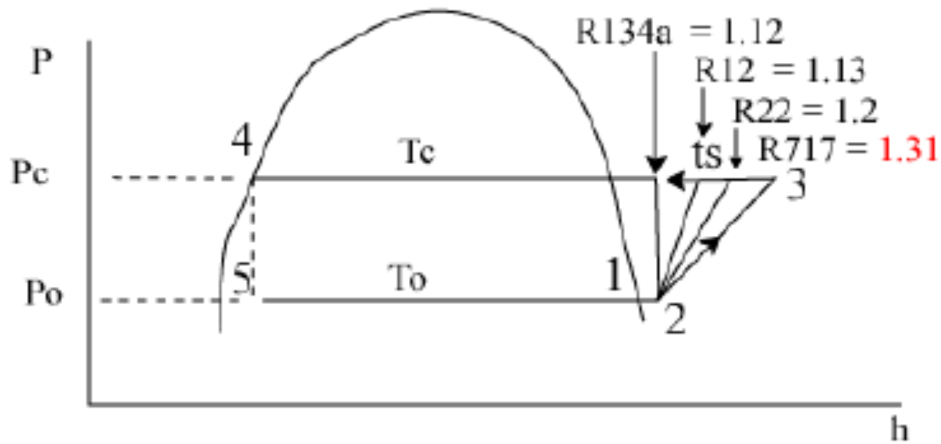
Ammonia Refrigerant v/s R-22

1. Specific heat of liquid is 4 times - 4 to 1
2. Latent heat of vaporization is- 6 to 1
3. Liquid thermal conductivity is -5.5 to 1
4. Viscosity is less- 0.8 to1
5. Liquid density is less - 0.5 to 1

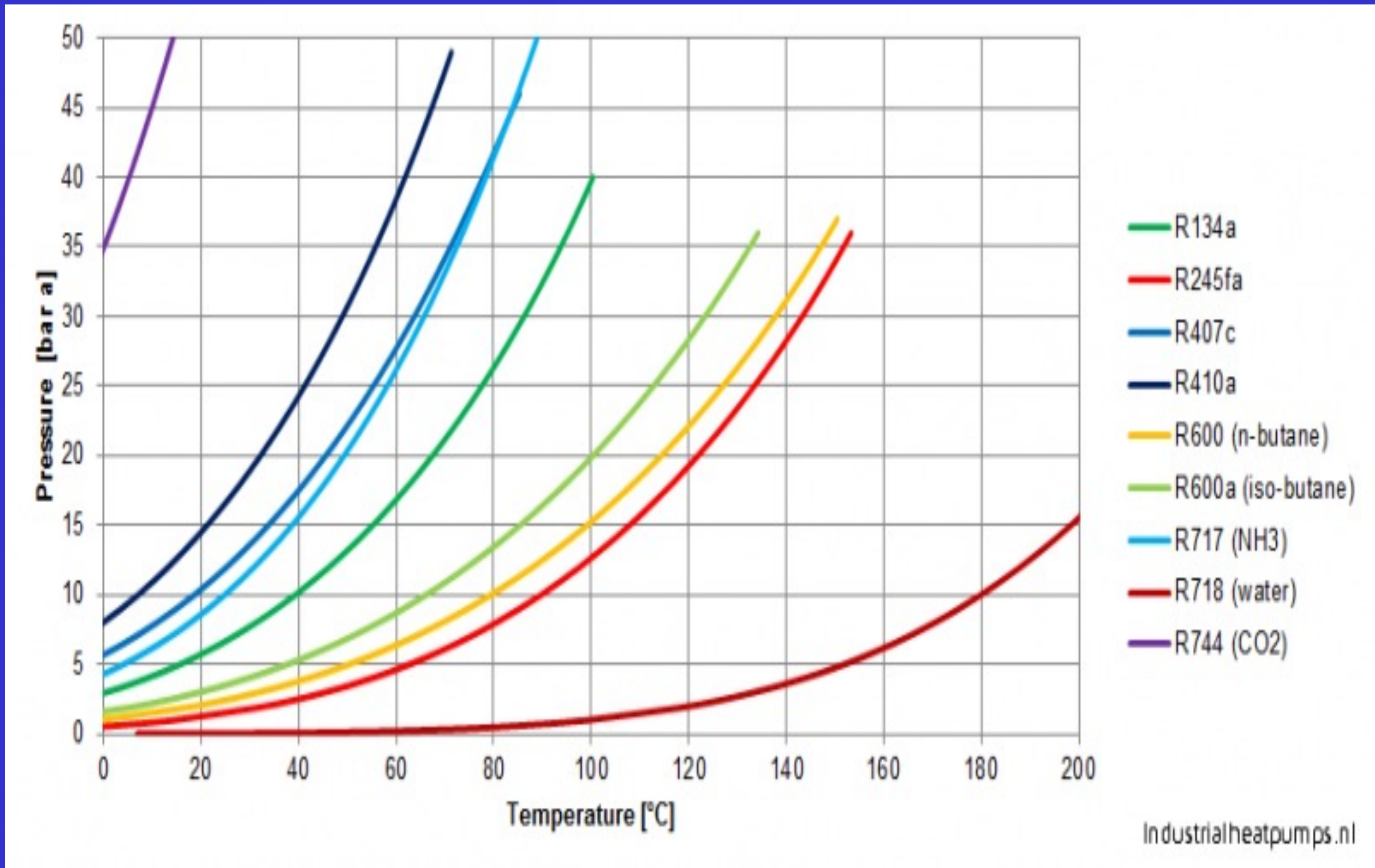
Quit

SINGLE STAGE





DISCHARGE PRESSURE V/S TEMPERATURES



COMPARITIVE REFRIGERANT PERFORMANCE / TON OF REFRIGERATION

5^0 F EVAPARATING / 86^0 F CONDENSING TEMPERATURE

ASHARE 1993 FUNDAMENTALS

Refrigerant	Ev. Pr.	Cond.Pr.	Compressor displacement CFM	Horse Power HP	COP	Comp discharge temp ^{0}f
Ammonia	34.17	168.795	3.450	0.989	4.77	210
R22	42.963	172.899	3.546	1.011	4.67	128
R502	50.561	191.290	3.569	1.067	4.42	98
R12	26.505	107.991	5.83	0.992	4.75	100
R134a	23.79	111.630	6.021	1.070	4.41	108
R11	2.937	18.318	36.425	0.939	5.02	110
R123	2.290	15.90	46.018	0.974	4.84	94

OIL MISCIBILITY-MINERAL OILS

	R22	R12	AMMONIA
50 Deg C	100 %	100 %	Immiscible
25 Deg C	100	100	-do-
0 Deg C	10	100	-do-
-25 Deg C	4	100	-do-
-40 Deg C	2	12	-do-

DISADVANTAGES OF PARTIAL MISCIBILITY

- OIL EVERYWHERE IN SYSTEM
- CRITICAL PIPING DESIGN-OIL RETURN
- OIL RETURN DIFFICULT IN FLOODED CHILLERS
- OIL COATS TUBES-REDUCING HEAT TRANSFER
- REFRIGERANT DILUTES OIL —LUBRICATION SUFFERS

Recommended Pipe Line Velocities

a) Suction line (NH_3)	15.0-17.5m/sec
b) Discharge line (NH_3)	17.5-20.00m/sec
c) Liquid line (NH_3) condenser to receiver	0.5 - 0.6 m/sec
d) Liquid line (NH_3) receiver to system	1.0to 1.5 m/sec
e) Wet return line (NH_3)	8 to 10 m/sec
f) Suction line (H_20)	1.0to 1.2 m/sec
g) discharge line (H_20)	2.0-2.5 m/sec

Piping Size Comparison

Refrigerant	Suction line – mm OD	Discharge Line-mm OD	Liquid line – mm OD
Ammonia –R717	50	40	20
HCFC-22	80	65	32
HFC134a	80	80	40
R404A	80	65	40
R410A	65	50	32

Refrigeration capacity in kW for different refrigerants for same operating conditions+40^{0}C condensing and + 5^{0}C evaporating Temperature say for 50mm pipe size

Line size	Refrigerant	Suction line-kW	Discharge line -kW	Liquid line-kW
50mm	R22	106.4	150.5	707.5
	R134a	70.10	106	546
	R404A	96.18	137.33	758.2
	R410A	160.19	229.98	1320.9
	R717-Ammonia	218.6	374.7	2840.5

The above table clearly indicates that for the same line size, ammonia refrigerant has the highest refrigeration capacity for all 3 lines mainly suction, discharge and liquid- Ref: ASHRAE 2014 Refrigeration volume

Comparison of Various Refrigerants

ASHRAE Fundamentals 2013 Table 8-29.8

Table 9 Comparative Refrigerant Performance per Ton of Refrigeration

Refrigerant 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, ft^3/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.

100kW capacity, at 40^0C condensing and -15^0C evaporating temperature Mass Flow rate Comparison

Refrigerant	Capacity kW	Power kW	C.O.P.	Press. ratio	Mass flow kg/hr.	Volume flow- m^3/hr.
Ammonia	100	26.686	3.75	6.583	340.704	173.0421
R-22	100	27.897	3.58	65.186	2401.91	186.4804
R134a	100	28.583	3.50	6.193	2723.76	326.6467
R404A	100	33.418	2.99	4.955	3732.48	204.5811

Comparison at -20^0 F/+95 ^{0}F

Refrigerant	Capacity-TR	Shaft Power	HP/ TR
R 717	104.4	245.2	2.349
R-22	104.7	264.9	2.530
R134a	53.8	148.6	2.762
R404A	97.9	290.8	2.970
R 507	102.2	302.3	2.958
R410A	151.5	415.3	2.741

COMPARISON@-+40^{0}C/+2^{0}C

Refrigerant	Capacity-kJ/kg	Power consumption-W-	C.O.P.
Ammonia-R717	1076.335	173.473	6.20
R410A	155.467	28.647	5.43
R134a	142.197	24.201	5.88
R404A	106.254	20.530	5.18
R22	156.419	26.376	5.93
Propane-R290	290.557	46.659	5.80
R507	111.904	20.452	5.47
Isobutate-R600a	263.125	43.728	6.02
Water –R718	2337.240	403.211	5.80
CO_2-(+31^{0}C/-5^{0}C)	104.106	26.692	3.90

COMPARISON@-+40^{0}C/-5^{0}C

Refrigerant	Capacity-kJ/kg	Power consumption-W-	C.O.P.
Ammonia-R717	1068.731	215.255	4.965
R410A	159.327	32.416	4.80
R134a	138.124	29.551	4.67
R404A	102.346	25.142	4.07
R22	153.832	32.416	4.74
Propane-R290	263.01	56.917	4.62
R507	109.137	25.096	4.35
Isobutate-R600a	253.671	52.966	4.79
Water –R718	2324.327	525.501	4.42
CO_2-(+31/-5)	107.718	35.701	3.02

COMPARISON@-+40^{0}C/-25^{0}C

Refrigerant	Capacity-kJ/kg	Power consumption-W-	C.O.P.
Ammonia-R717	1043.211	358.501	2.91
R410A	142.662	57.08	2.50
R134a	126.048	46.768	2.70
R404A	90.272	39.978	2.26
R22	145.666	52.230	2.79
Propane-R290	240.649	89.845	2.68
R507	100.675	40.348	2.50
Isobutate-R600a	226.378	82.130	2.76
Water –R718	2287.299	1024.183	2.23
CO_2-(+31/-5)	111.222	66.772	1.67

COMPARISON@-+40^{0}C/-40^{0}C

Refrigerant	Capacity-kJ/kg	Power consumption-W-	C.O.P.
Ammonia-R717	1020.824	496.672	2.06
R410A	80.654	53.063	1.52
R134a	116.693	61.965	1.88
R404A	80.854	53.063	1.52
R22	138.945	70.159	1.98
Propane-R290	223.32	118.890	1.88
R507	93.932	54.234	1.73
Isobutate-R600a	207.398	107.450	1.93
Water –R718	2259.468	1603.402	1.41
CO_2-(+31/-40)	109.446	96.160	1.14

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

Refrigerant	For positive Temperature cold rooms- $+40^0C/2^0C$	For secondary fluids operation $+40^0C/-5^0C$	For low temperature cold rooms- $+40^0C/-25^0C$	Blast freezers/IQF $+40^0C/-40^0C$
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

Cost Comparison W.R.T.- R22

All values relative to R22

Based on prices from 12 different markets world wide

No obvious solutions for tuna freezing at -70C°

The system price is a different issue

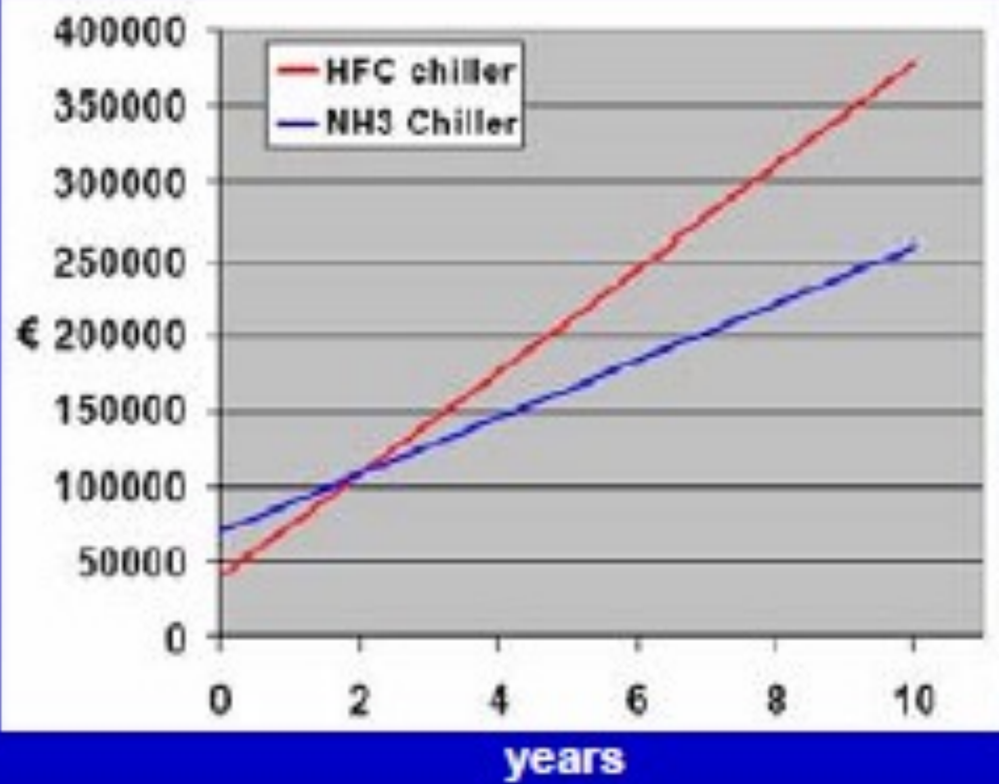
R22	1.00
R134a	1.68
R404A/R507	2.06
R410A	2.03
R407C	2.30
R717	0.38

Many refrigerant blends have been introduced

There are not many low-GWP refrigerants but many blends using old HFC components

No blend address the requirements needed for tuna ultra low freezers

Cost comparison: HFC chiller vs NH_3 chiller



Total accumulated costs
Investment and energy costs according to ARI standard 550/590 IPLV

12% @ 25% load
45% @ 50% load
42% @ 75% load
1% @ 100% load

Source: Sabroe (Denmark)

Assumptions, Energy cost: 8 eurocent/kWh; Operation: 365 days/year

CONCERNS WITH AMMONIA REFRIGERANT

Background

- Concerns with ammonia:
- Toxicity
- Flammability
- Regulations (> 10,000 lbs)
- OSHA –Process Safety Management (PSM)
- EPA –Risk Management Program (RMP)
- DHS –Chemical Facility Anti-Terrorism Standards (CFATS)

Physical properties-Ammonia

TOXICITY	HOW MUCH HOW LONG
FLAMABILITY	Ignition temperature -650^{0}C
EXPLOSIVENESS	16 to 25% by volume
ODOUR	PUNGENT DETECTABLE-5PPM ONWARDS Tolerable- 500-1000PPM
LEAKAGE TENDENCY	LESS LOSS-PURGING/LEAKS 8.2CFT/LB AGAINST1.2CFT/LB FOR R-22
MOISTURE TOLERENCE	IMMENSE-AQUA/AMMONIA
OIL MISCIBILITY	IMMISCIBLE

Toxicity classifications

Class A signifies refrigerants where toxicity has not been identified at concentrations ≥ 400 ppm v based on TLV–TWA data or consistent indices

Class B signifies refrigerants for where there is evidence of toxicity at concentrations < 400 ppm, based on TLV-TWA data or other consistent indices

Flammability classifications

1 – No flame propagation

2 – Exhibits flame propagation, a LFL > 3.5% and heat of combustion < 19,000 kJ/kg

2L – burning velocity not greater than 10 cm/s*

3 – Exhibits flame propagation, a LFL ≤ 3.5% and heat of combustion ≥ 19,000 kJ/kg

IS 16656 : 2017 and ISO 817 Product Safety Considerations

Safety Classification

	Lower Toxicity (A) OEL > 400ppm	Higher Toxicity (B) OEL < 400PPM
Highly Flammable (3) HOC >= 19000kJ/kg LFL <= 3.5%	A3	B3
Flammable (2) HOC >= 19000kJ/kg LFL > 3.5%	A2	B2
Mildly Flammable (2L) BV =< 10cm/sec		
Practically Non-Flammable (1) No Flame Propagation at 60C	A1	B1

Examples:

Propane	A3
R-152a	A2
HFC 32	A2L
R-134a	A1

Figure 2 – Safety Classification of Refrigerants in ASHRAE Standard 34

Flammability			
Flammability	Higher Flammability	**A3** R-290 Propane R-600a Isobutane	**B3**
Flammability	Lower Flammability	**A2** R-152a	**B2**
Flammability	Lower Flammability	**A2L*** R-32 R-1234yf R-1234ze(E)	**B2L*** R-717 Ammonia
Flammability	No Flame Propagation	**A1** R-22 R-134a R-410A R-1233zd(E) R-404A R-407C R-507A R-744 Carbon Dioxide	**B1** R-123
		Lower Toxicity	Higher Toxicity
		Toxicity	

*A2L and B2L are lower flammability refrigerants with a minimum burning velocity of ≤10 cm/s.

ASHRAE Standard 34.1-2013-Toxicity/Flammability

Flammability in Air @ 60°C & 101.3 kPa	ASHRAE Standard Safety Group	
Higher Flammability LFL or $ETFL_{60} \leq 100\ g/m^3$ OR HOC $\geq$ 19 MJ/kg	A3	B3
Lower Flammability LFL or $ETFL_{60} > 100\ g/m^3$ & HOC < 19 MJ/kg	A2	B2
Lower Flammability LFL or $ETFL_{60} > 100\ g/m^3$ & HOC < 19 MJ/kg with a maximum burning velocity of $\leq$ 10 cm/s	A2L	B2L
No flame Propagation	A1	B1
Flammability in Air @ 60°C & 101.3 kPa	Lower Toxicity OEL $\geq$ 400PPM	Higher Toxicity OEL < 400 PPM
LFL = Lower Flammability Limit $ETFL_{60}$ = Elevated Temperature Flame Limit @ 60°C HOC = Heat Of Combustion, OEL-Occupational Exposure Limit		

Toxicity Levels of Ammonia refrigerant

5 PPM	**Onwards Detectable**
25 PPM	**Detected by most – no health hazard exposure 10 – 15 years**
100 PPM	**No dangerous effects, minor irritation.**
400 – 700 PPM	**Irritation Eyes, Nose, Mucous . Lead to dryness**
1700 PPM	**Cough, Cramp, Serious Irritation, Injuries**
2000 PPM	**Can Lead to Death**
7000 PPM	**Lethal within few minutes**

Effects on the human body due to ammonia leaks at various concertation levels:

5 ppm (3.5mg/m3)- Minimum perceptible odour. Low temperature and high humidity makes it easier to smell.

25 ppm(17mg/m3) -MAC value = maximum allowable concentration

50ppm(35mg/m3)

40 ppm -The smell is very distinct. An person reacts and wants to get away from the area

100 ppm -Eye and nose irritation begin after a short period of exposure

250ppm(175mg/m3)

400 ppm -Strong irritation of eyes, nose and respiratory organs. Injuries can occur

500-1000ppm(350-700mg/m3)

700 ppm-490mg/m3 Coughing and cramp. After 30 minutes, serious injuries may occur.

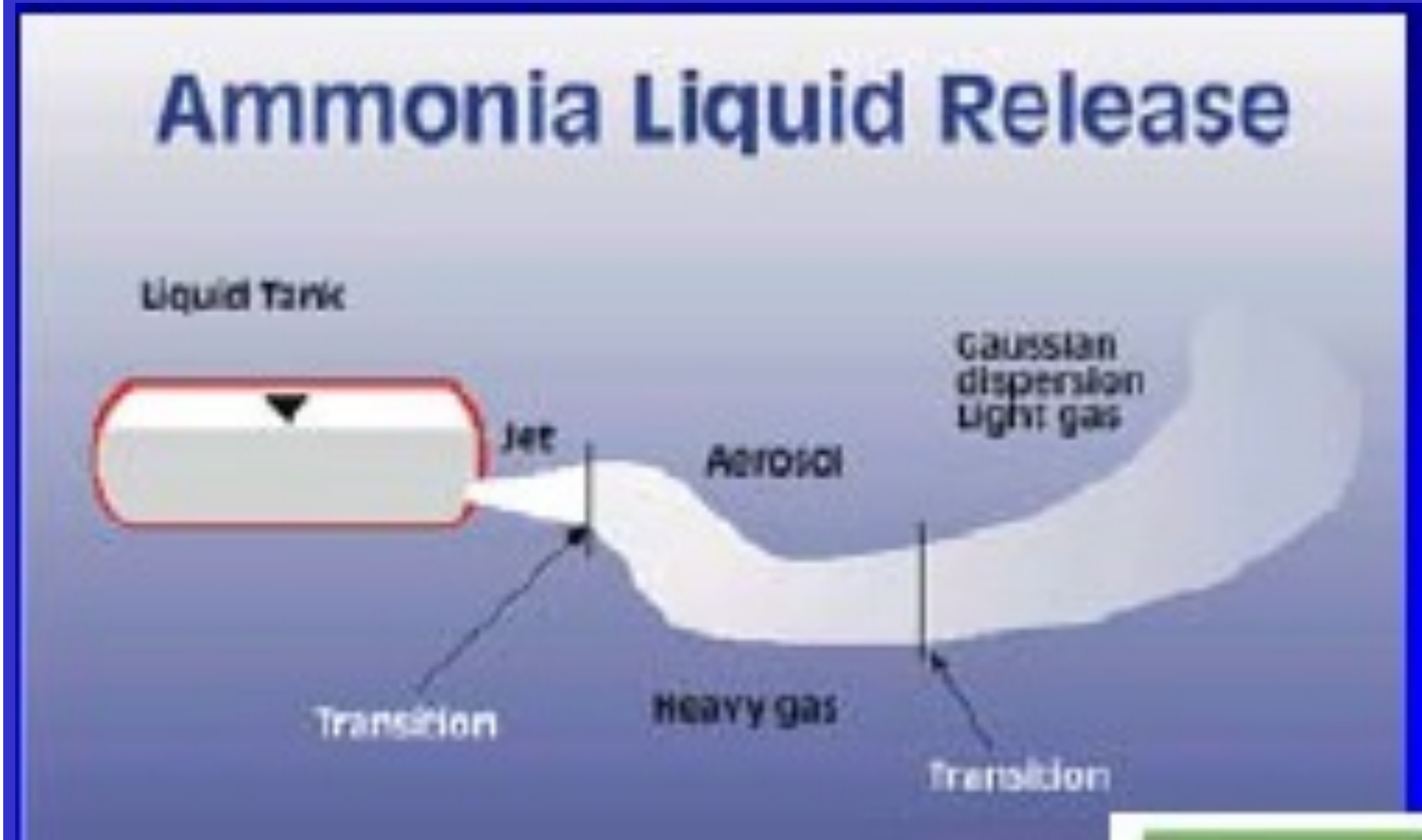
1700 ppm -1190mg/m3 Fierce coughing and cramp. Death can occur in less than 30 minutes

5000 ppm -3500mg/m3 and above Immediate unconsciousness. Death occurs within a few minutes

To convert PPM to mg/m3 use multiplier 0.7 to get mg/m3

3 phases of Ammonia

1. Liquid
2. Gas
3. Aerosol-small drops, White cloud of more than 45,000ppm R717.The visibility is only 30 to 40 cm and the temperature is down to -74^{0}C.The cooling effect of the continuously evaporating fine droplets cools the cloud so that it becomes more denser than air and hence very dangerous to inhale.


Ammonia Liquid Release
Liquid Tank
Jet
Aerosol
Gaussian
dispersion
Light gas
Transition
Heavy gas
Transition


MORRELL

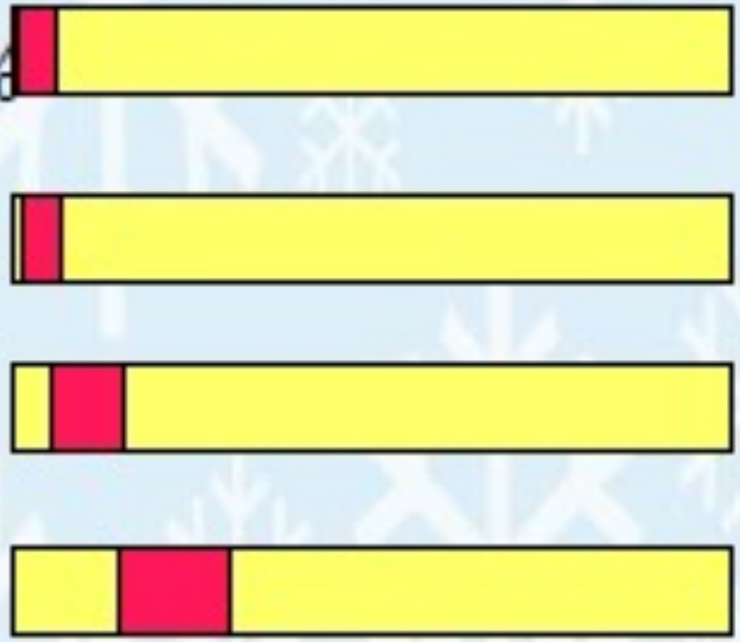
Gas' explosive range

Diesel = 0,6 - 6,5 %

Petrol = 1,2 - 7%

Methane = 5 - 15%

Ammonia = 15 - 30%

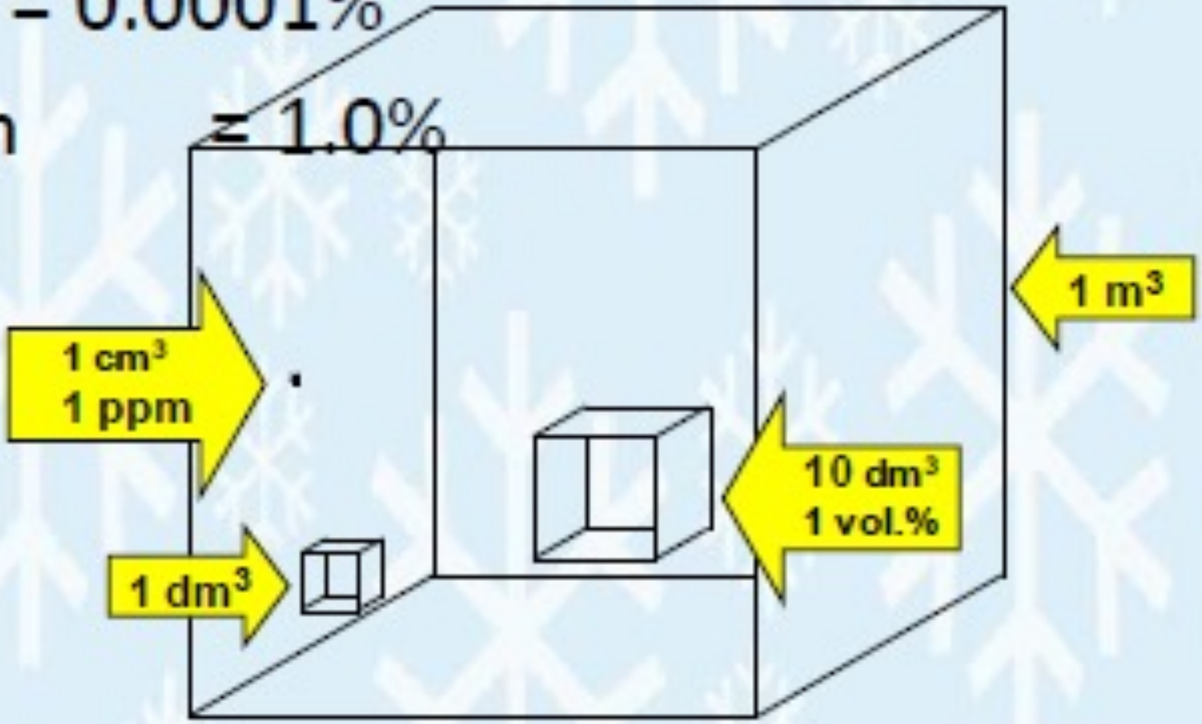


What is the unit ppm ?

ppm = parts per million

1 ppm = 0.0001%

10000 ppm = 1.0%



AMMONIA LEAKS DETECTABLE -AT 3mg/m^3 level

	Refrigerant class	Practical limit according to EN 378
R134a	L1	0,25 kg/m3
R404A	L1	0,48 kg/m3
R407C	L1	0,31 kg/m3
R410A	L1	0,44 kg/m3
R507	L1	0,49 kg/m3
R717	L2	0,00035 kg/m3

AMMONIA REFRIGERATION APPLIATIONS

Fields of Applications

1. Ice Plants-commercial/amusement centers
2. Cold storages-Fruit/Vegetables/meat/Fish/Seeds/Dry fruits
3. Freezing of foods-Fish/meat/Fruits/Vegetables
4. Breweries/ Dairies/ice-cream making
5. Chemical/Dyestuff –process cooling
6. Concrete cooling-Dams/Roads/Runways
7. Water Chillers-Air conditioning
8. Thermal storages-Heat Pumps
9. Super markets-Ammonia/CO_2 cascade
10. Industrial Process/Fertilizer plants
11. Bottling Plants-Coca Cola/Pepsi

Field of Applications

12.Concrete cooling applications for river dams, airport runways and concrete expressways

13.Fertilizer plants

14.Maximum use is of ammonia is in agricultural industry as a fertilizer with 99.5% minimum content of ammonia of commercial grade.

15.Recently many Super markets are also using ammonia/carbon dioxide(R717/R744) or ammonia/secondary fluids like propylene glycol systems

16. Liquefaction of gases like Chlorine,carbon dioixide & other gases

17. Pharmaceutical plants for process cooling

18. Mettalergical industry, ammonia is used as a source of inert gas, or for nitriding of metal surfaces.

19. In environmental protection, ammonia plays an important role in removing nitrogen oxides and sulpher dioxide from the smoke emitted by power plants.

Field of Applications

20. Air conditioning of large complexes like Air ports, telegraph, and other commercial office premises – more details given subsequently, using chilled water systems.

21. Skating ice rings for amusement parks

22. Space shuttles

23. Heat Pumps.

24. Industrial heat pumps

25. Marine Refrigeration and many other

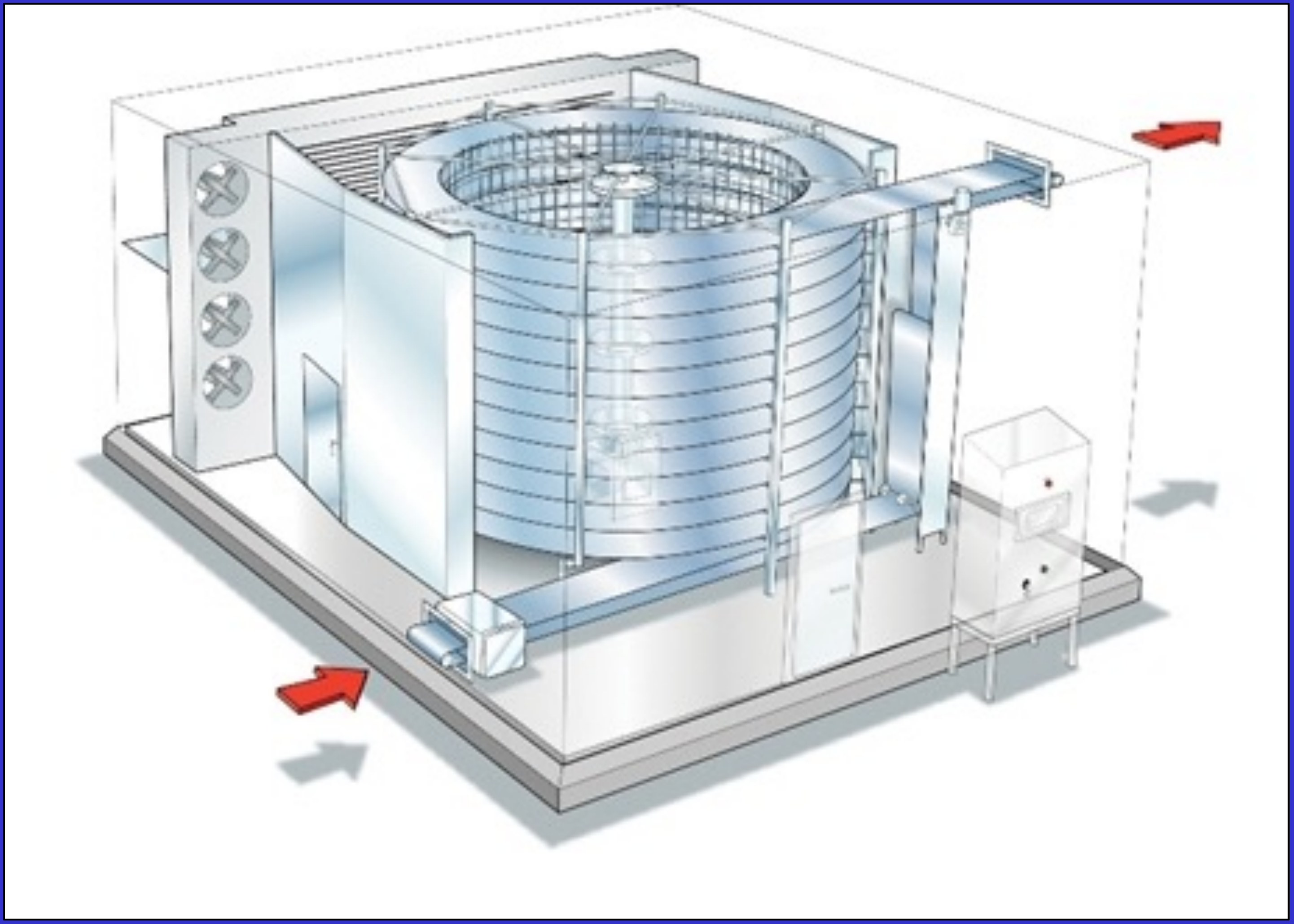
Food Processing

Dairy

IQF

IQF

SPIRAL FREEZER



SPIRAL FREEZER

PLATE FREEZER

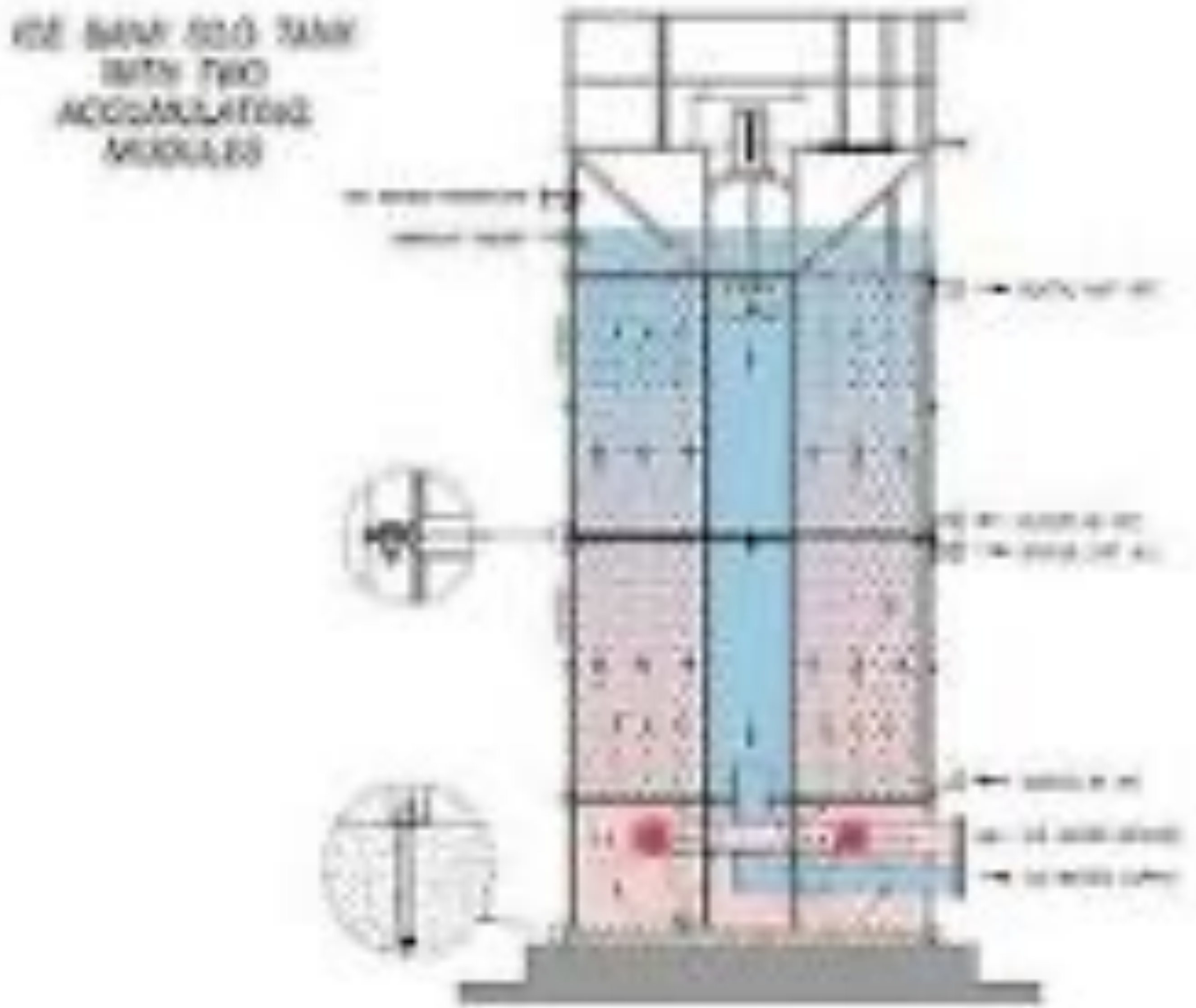
Falling Film Water Chill*er*

Conventional Block ice maker

Ice Bank Tank in Dairy Industry

Ice water Silo

Ice water Silo



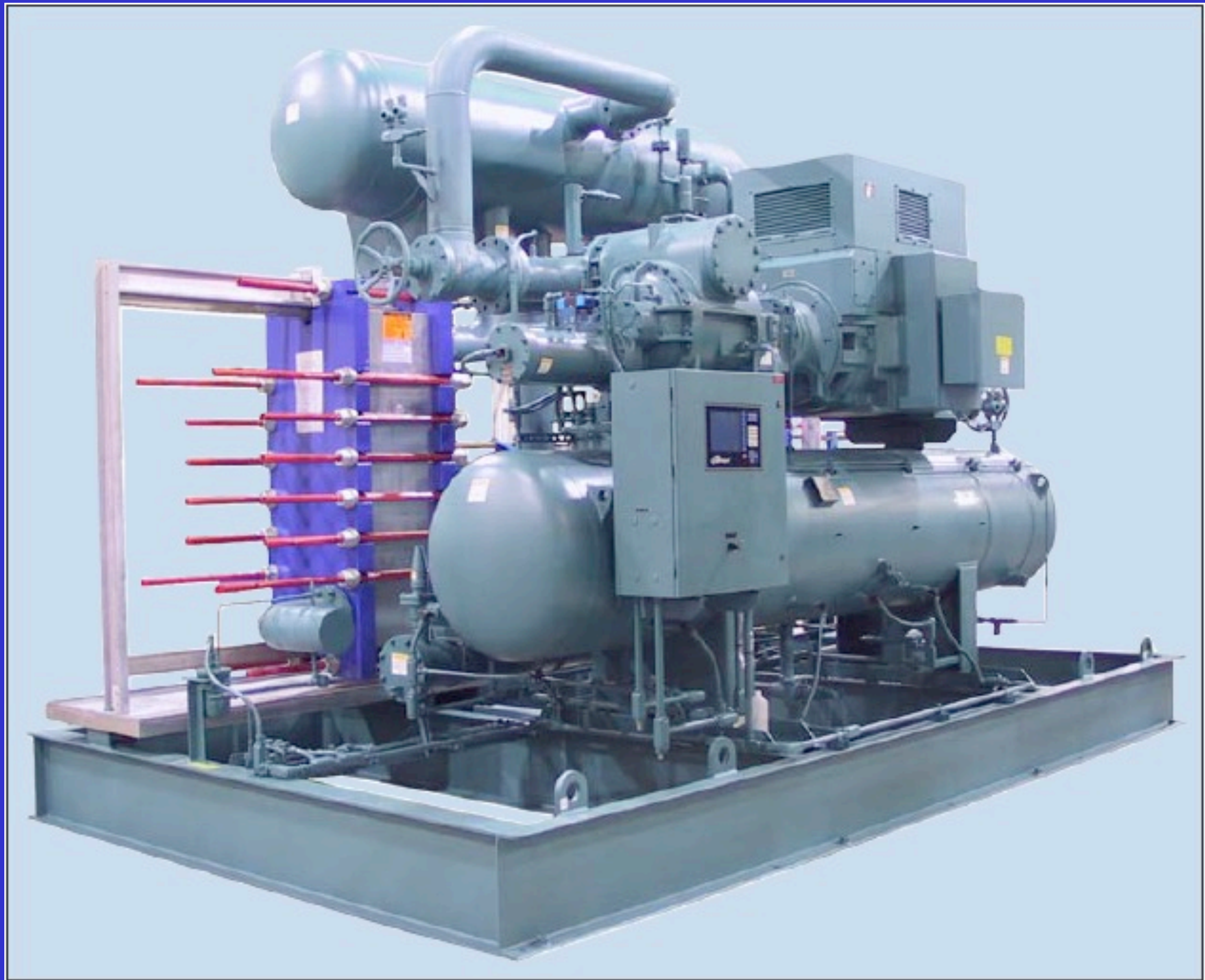
Flake ice maker

Tube Ice maker

Petrochemical plant

Brewery

A duel Purpose Chiller for Food Processing Plant and and comfort Air conditioning

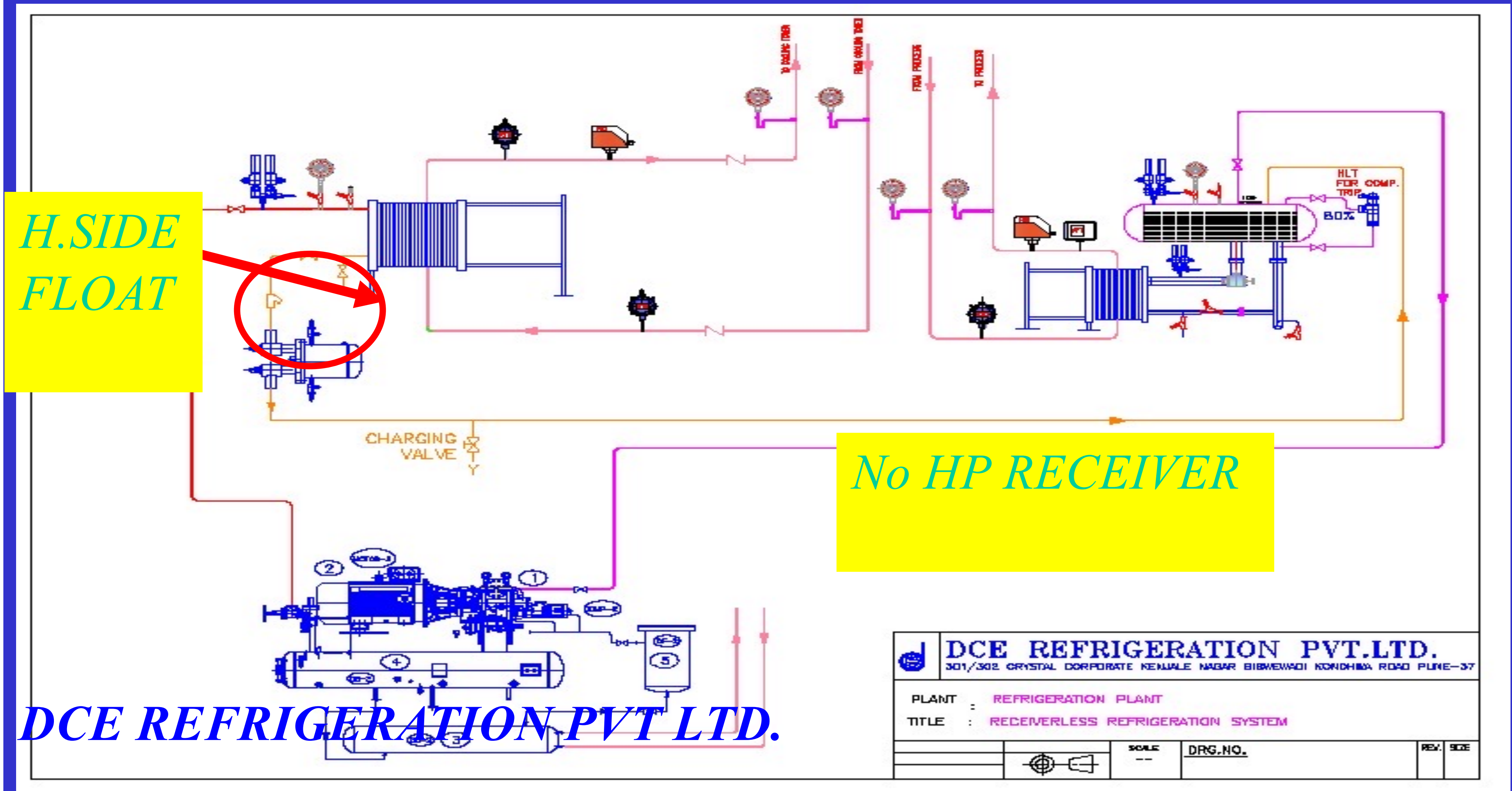


Ammonia package brine chiller

Modern Packaged Ammonia Systems

- New design (PHEs or spray type shell & tube evaporator)
- Liquid injection system
- Better efficiency (>30%) than HFC134a
- Less charge (0.02 to 0.5 kg/kW) for dry and flooded evaporation
- Higher discharge pressure (up to 40 bar)
- Safety level increased significantly towards “zero leak”
- Used in Europe for both display cabinets and space conditioning

LOW CHARGE AMMONIA REFRIGERATION SYSTEM WITH HIGH SIDE FLOAT & NO RECEIVER



Star Refrigeration U.K. Roof Top Units using Low charge Ammonia systems

Star Refrigeration U.K. Roof Top Units using Low charge Ammonia systems

Use of Ammonia in Air Conditioning

USE OF AMMONIA REFRIGERANT IN COMFORT AIR CONDITIONING

1. Oslo Air Port -Norway
2. Heathrow Terminal -5
3. Singapore Air Port

4.Dusseldorf Airport

5.Zurich Airport

6. New Zealand Christchurch Airport

7.Stuttgard Airport Terminal 3-2300kW Grasso

8.Exchange- Copenhagen

8. Space Shuttles

9.Process Plant -Halls

USE OF AMMONIA REFRIGERANT IN COMFORT AIR CONDITIONING

10. Thermal storage systems for Malls, Cinema Halls
11. KWN Greenpeace Headquarters-Vienna
12. Sabb-Linkoping-Sweeden-4 ammonia chiller of 2 megawatt
13. Berlin Ostbanhof train station-Grasso system for three storey building complex
14. Roche Headquarters in London -930 kW- Star Refrigeration
15. Mulligan Letter sorting center-Switzerland-Johnson Controls
16. Ozeaneum in Stralsund-Johnson controls-500kW A/C
17. Telephone Exchange-Copenhagen

Ref: Eurammon issue-Refrigerants by nature-2012/2016

Ammonia for A/C and Commercial Refrigeration

- Ammonia A/C with central plants
- Ammonia display freezer cabinets
- Independent circuits
- Secondary refrigerants used
- Risk free AC&R

Air conditioning

One of The Four package Ammonia Chillers being installed at Heathrow Airport

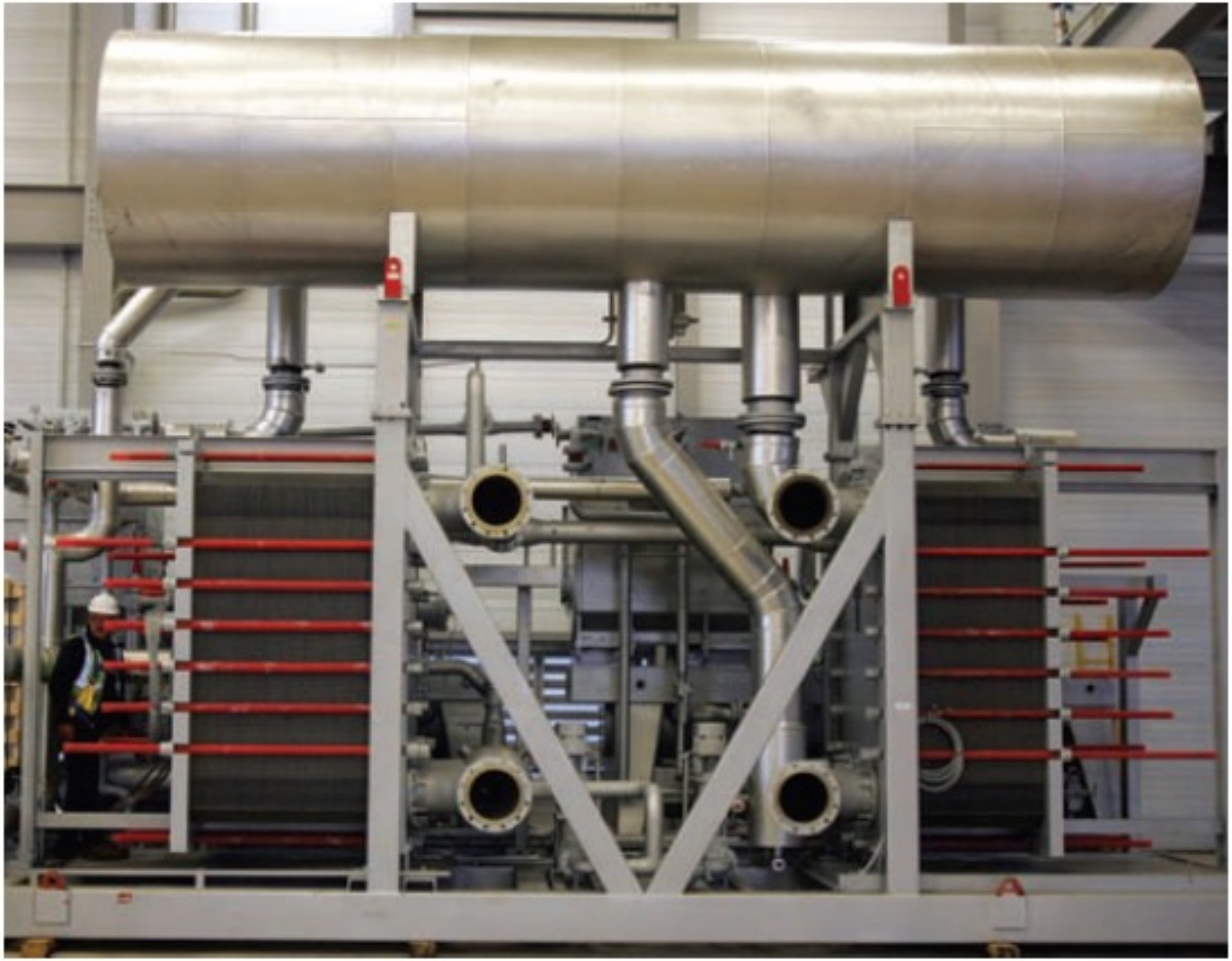


Photo 3: Ammonia chiller at Heathrow Airport (picture courtesy of JCI/Sabroe).

ASHRAE HVAC&R INDUSTRY NEWS

Semi-Hermetic Ammonia System Heats, Cools Dutch Business, Apartment Complex

EINDHOVEN, The Netherlands—An ammonia heat pump has been installed to heat and cool 40,000 m^2 of apartments and business premises in the Netherlands. The re-modeled office complex, a former factory for conglomerate Philips, will use the 800 kW ammonia heat pump system fitted with two twin screw compressors for space heating during the winter and air conditioning during the summer. One of the compressors is redundant in case the system fails. An ammonia heat pump was selected to heat and cool the building complex due to its high-efficiency, zero global warming potential and zero ozone-depleting potential, said the developer.-

18th October 2018

HVAC Plant Room at Oslo Airpoprt, Norway

Stuttgart Airport Changes over to Ammonia refrigeration system

Air conditioning

The complete Ammonia Chiller package including electric starter panel and all wiring at the P&T building, Copenhagen.

Saab office roms in Linkoping Sweden

Jhomson controlss uses ammnia system to air condition 5000 sq.m of of office area using Four ammonia water chilling units each of 2MW capacity

Philips Building in Eindhoven

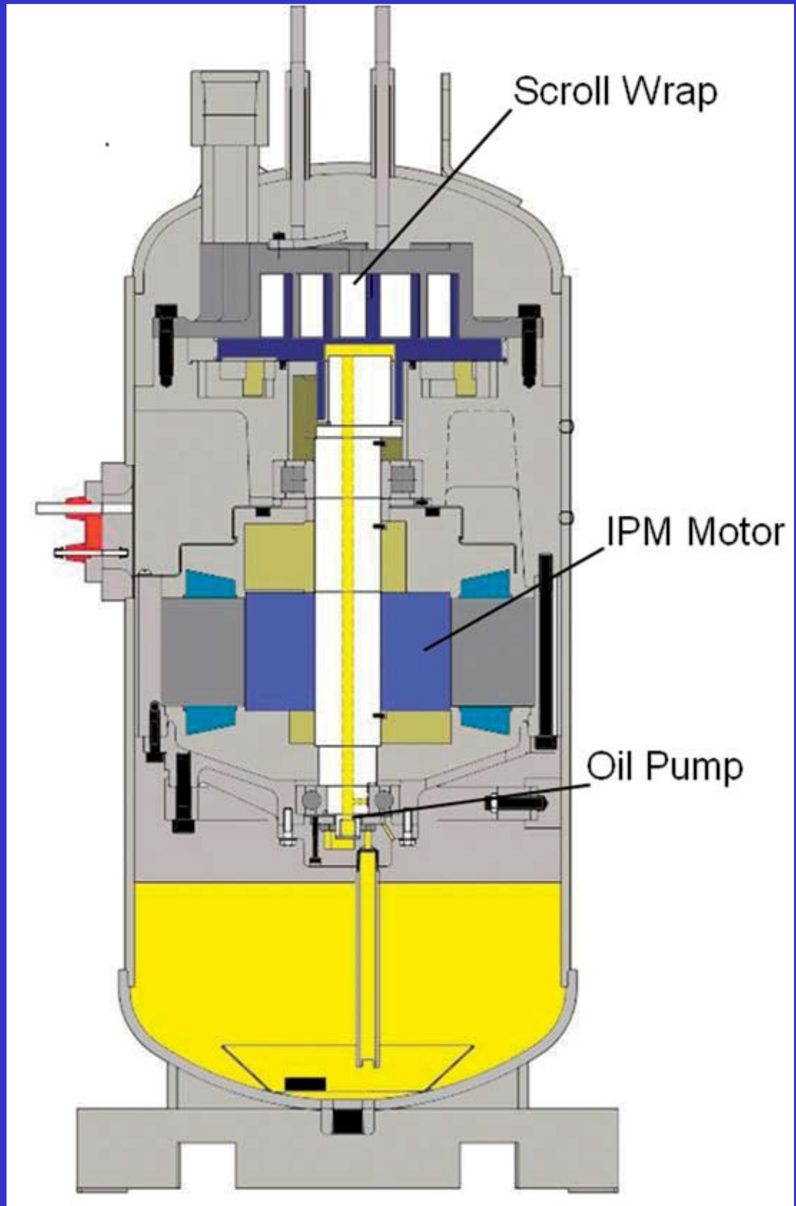
- **Recent Developments in Ammonia Refrigeration Technology**

5H Carlyle Ammonia Compressor

Semi Hermetic Ammonia Compressor

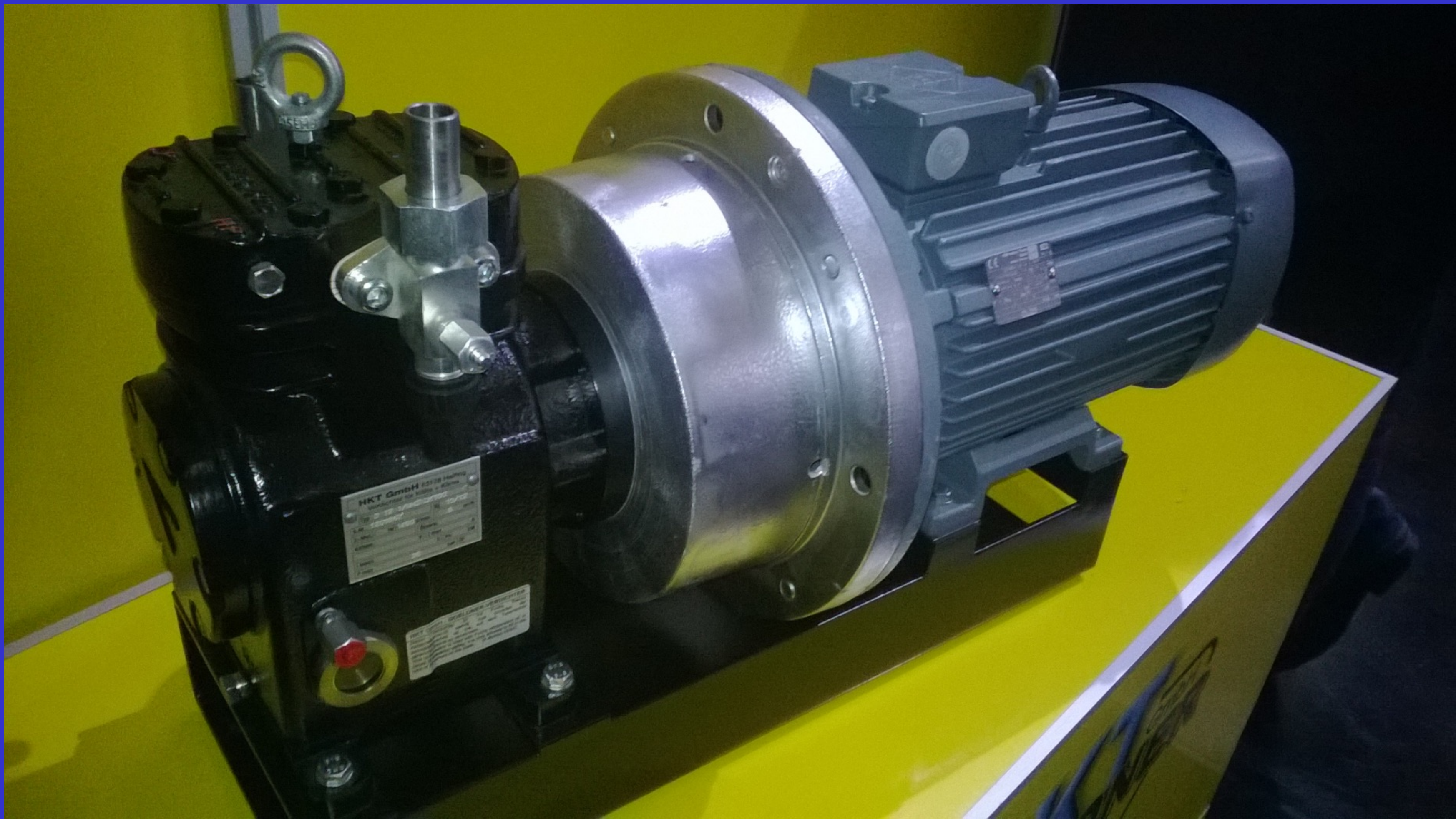
Package Chiller using Semi Hermetic Ammonia compressor

SEMI HERMETIC AMMONIA SCROLL COMPRESSOR

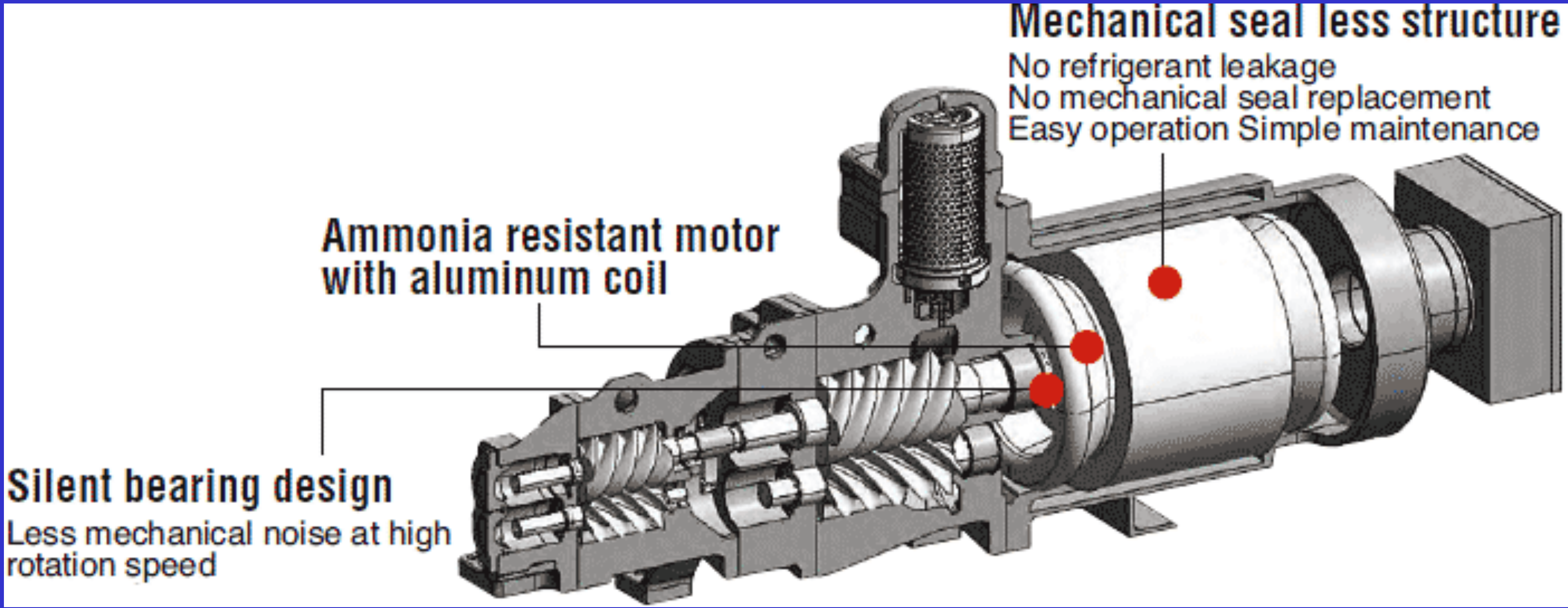


7kW Ammonia Reciprocating Compressor

HKT-GOELDNER-GERMANY



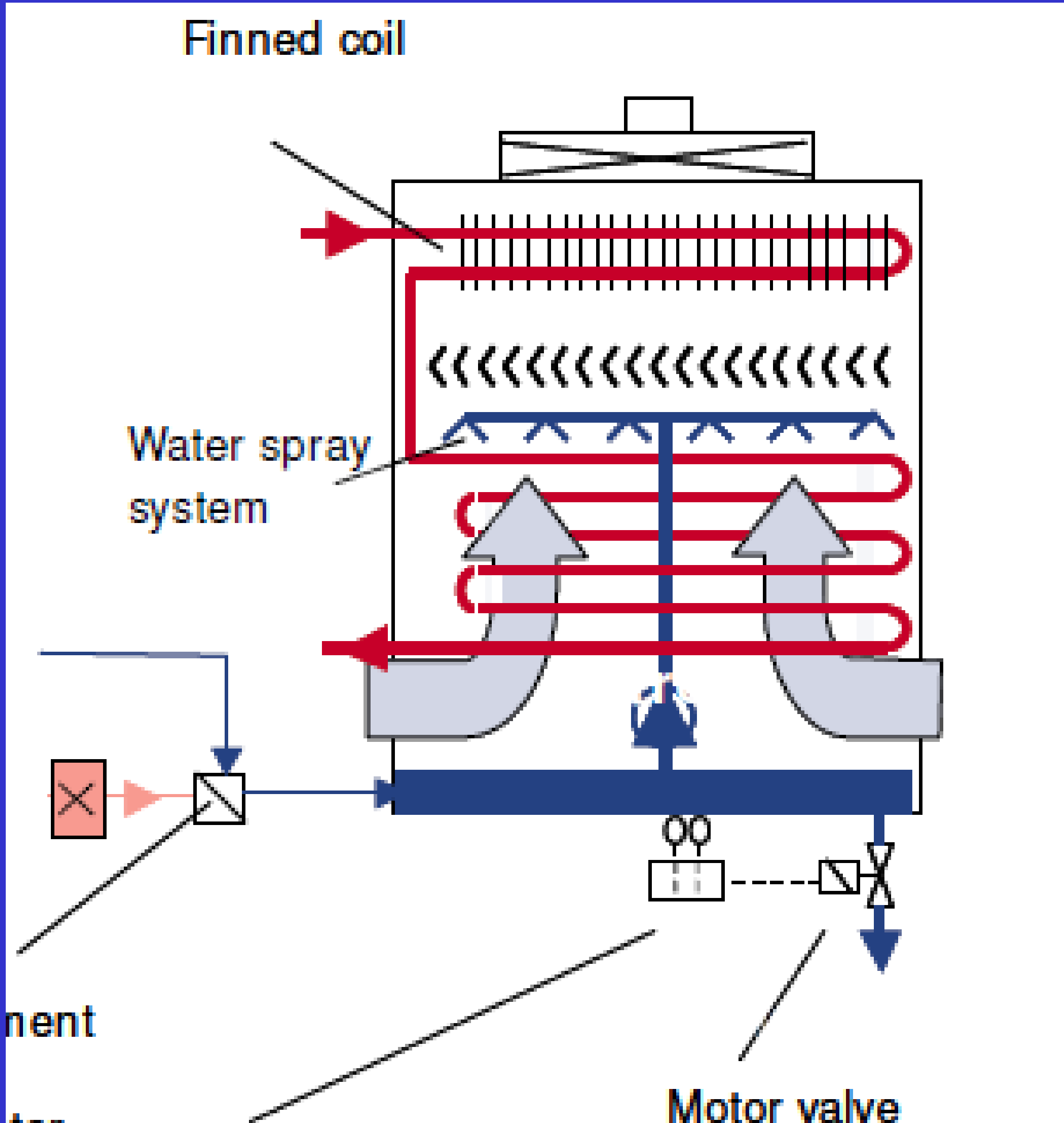
AMMONIA SEMI HERMETIC COMPRESSORS

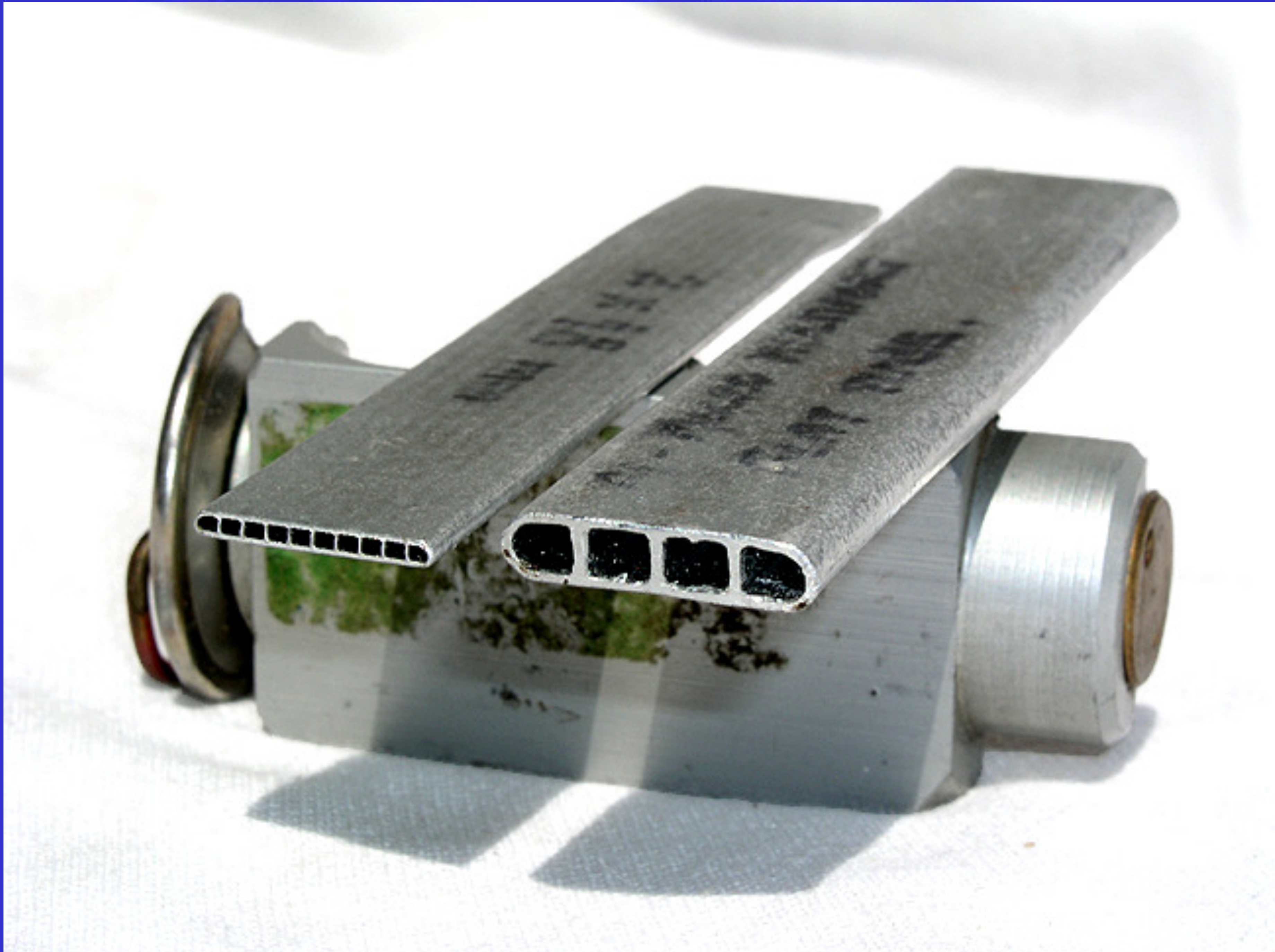


Ammonia Reciprocating Compressor Package

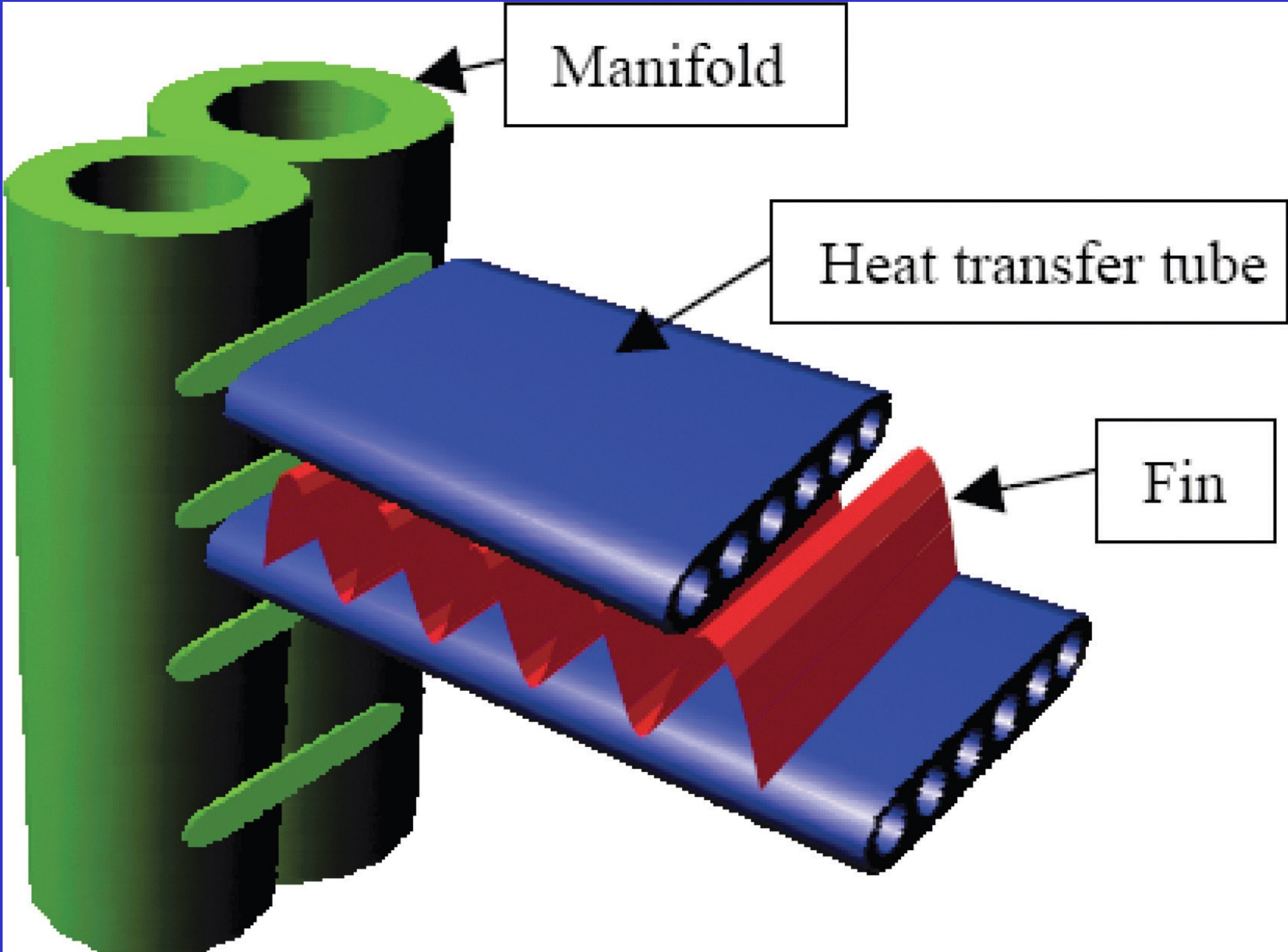
ECO Mesh Ammonia Air cooled condenser

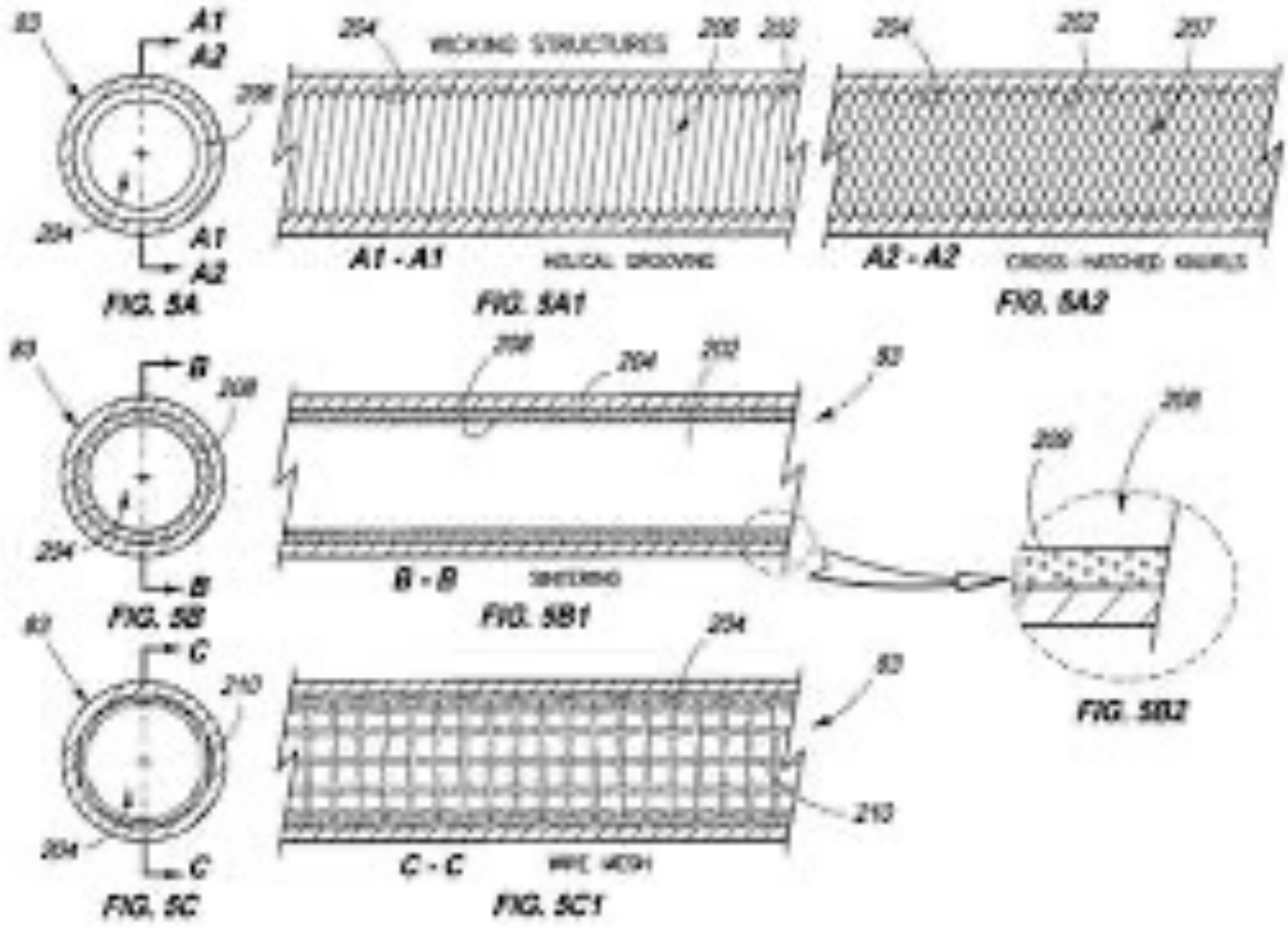
HYBRID EVAPORATIVE CONDENSER



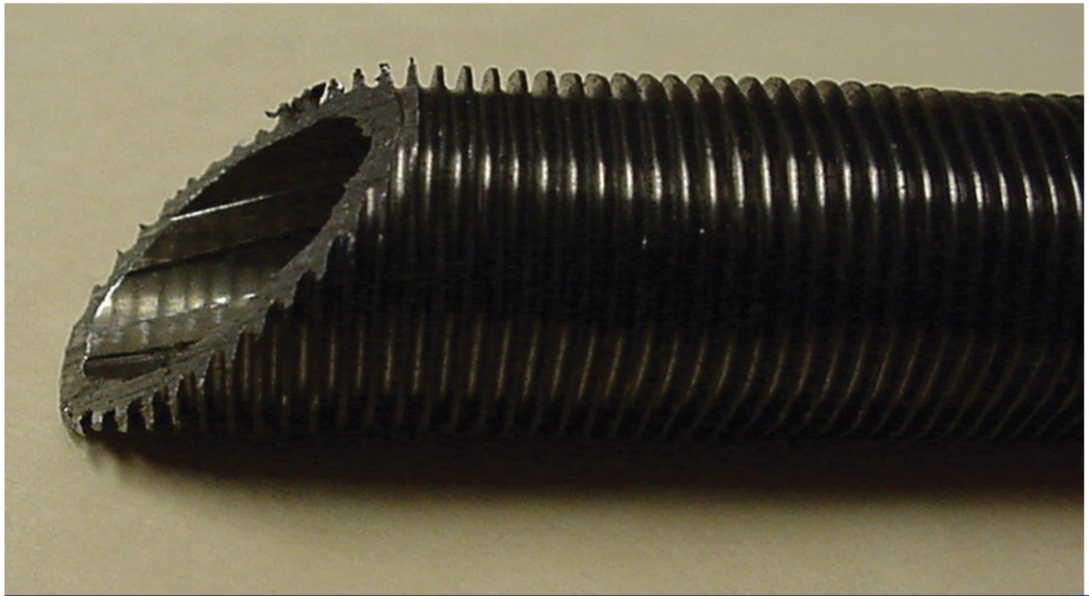


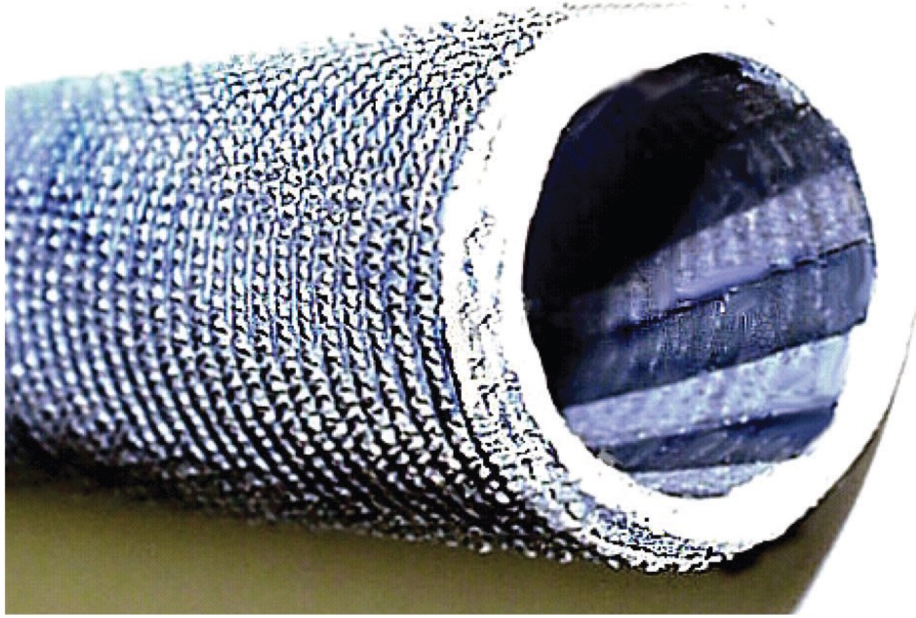
Micro Channel Heat Exchanger Tubes




A1
A2
A1
A2
FIG. 5A
WICKING STRUCTURES
A1 - A1
HELICAL GROOVING
FIG. 5A1
A2 - A2
CROSS HATCHED KNURLS
FIG. 5A2
B
B
FIG. 5B
B - B
SINTERING
FIG. 5B1
FIG. 5B2
C
C
FIG. 5C
C - C
WIRE MESH
FIG. 5C1

External/Internal fin tubes for heat exchangers





Aluminum Coolers For Ammonia

Aluminum and Stainless Steel Tubing comparison
Ref ASHRAE Journal Feb 13 Page 18

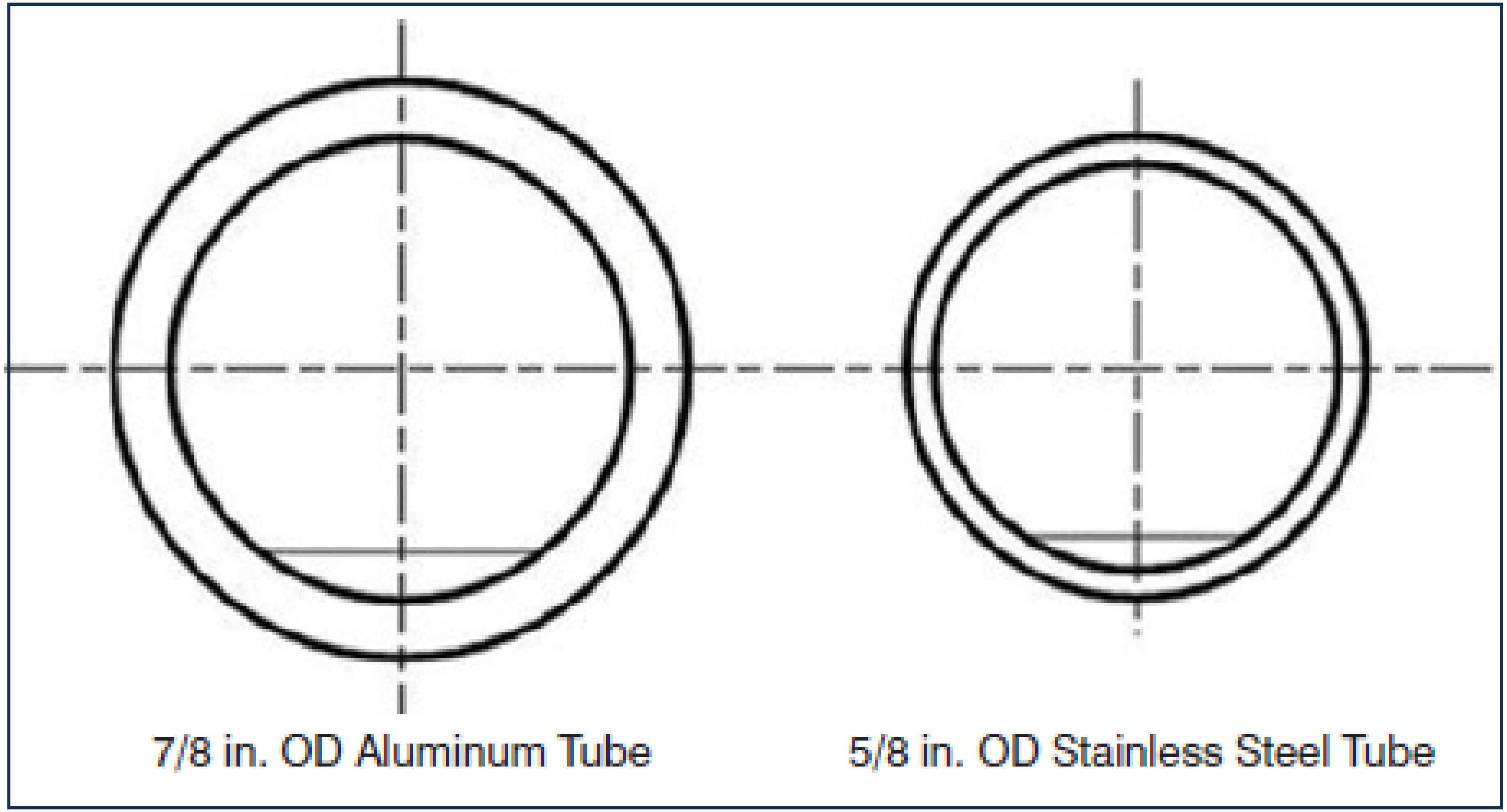


Figure 2: Relative proportions of aluminum and stainless steel tubing used in comparative tests in an operating cold store.

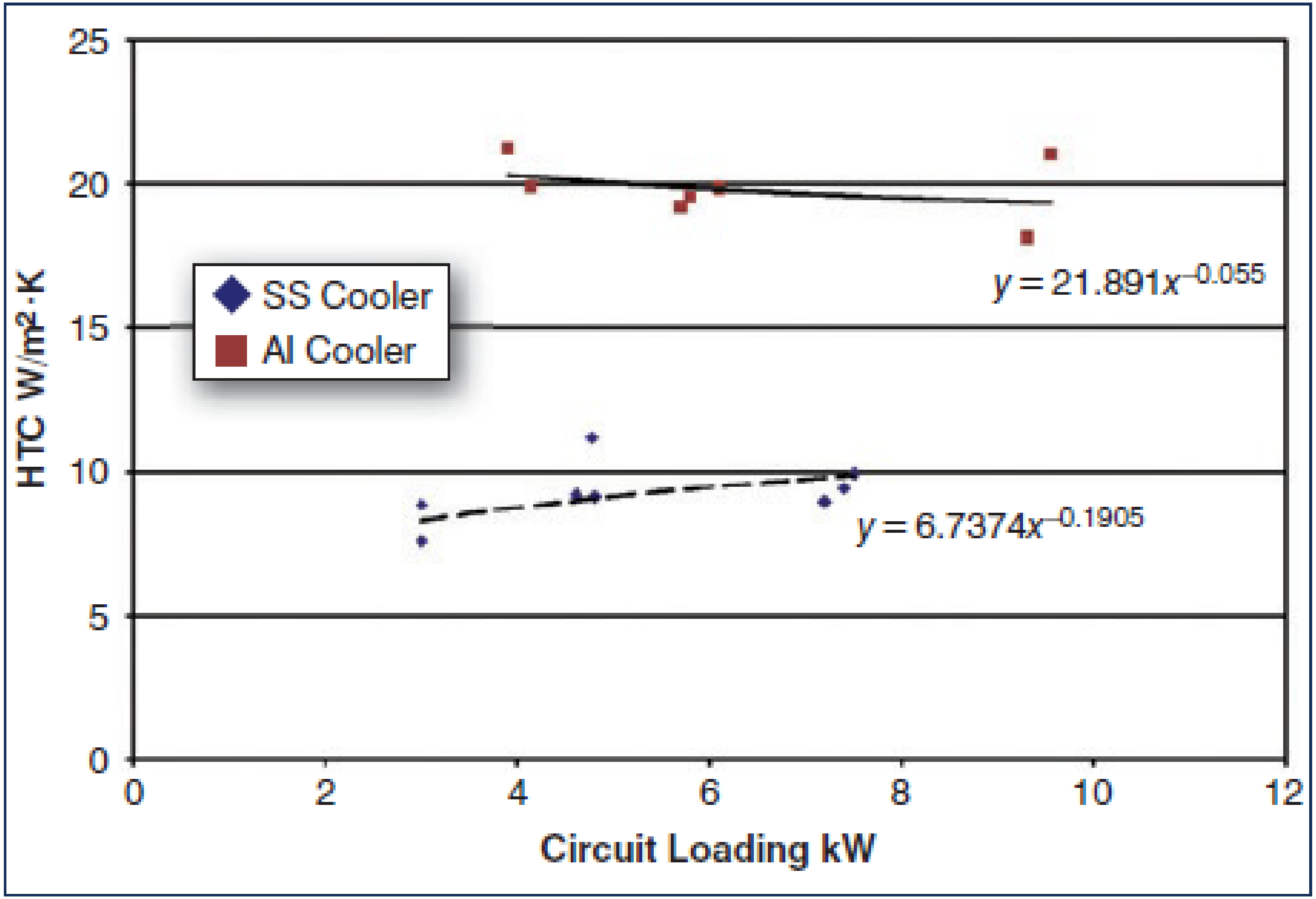
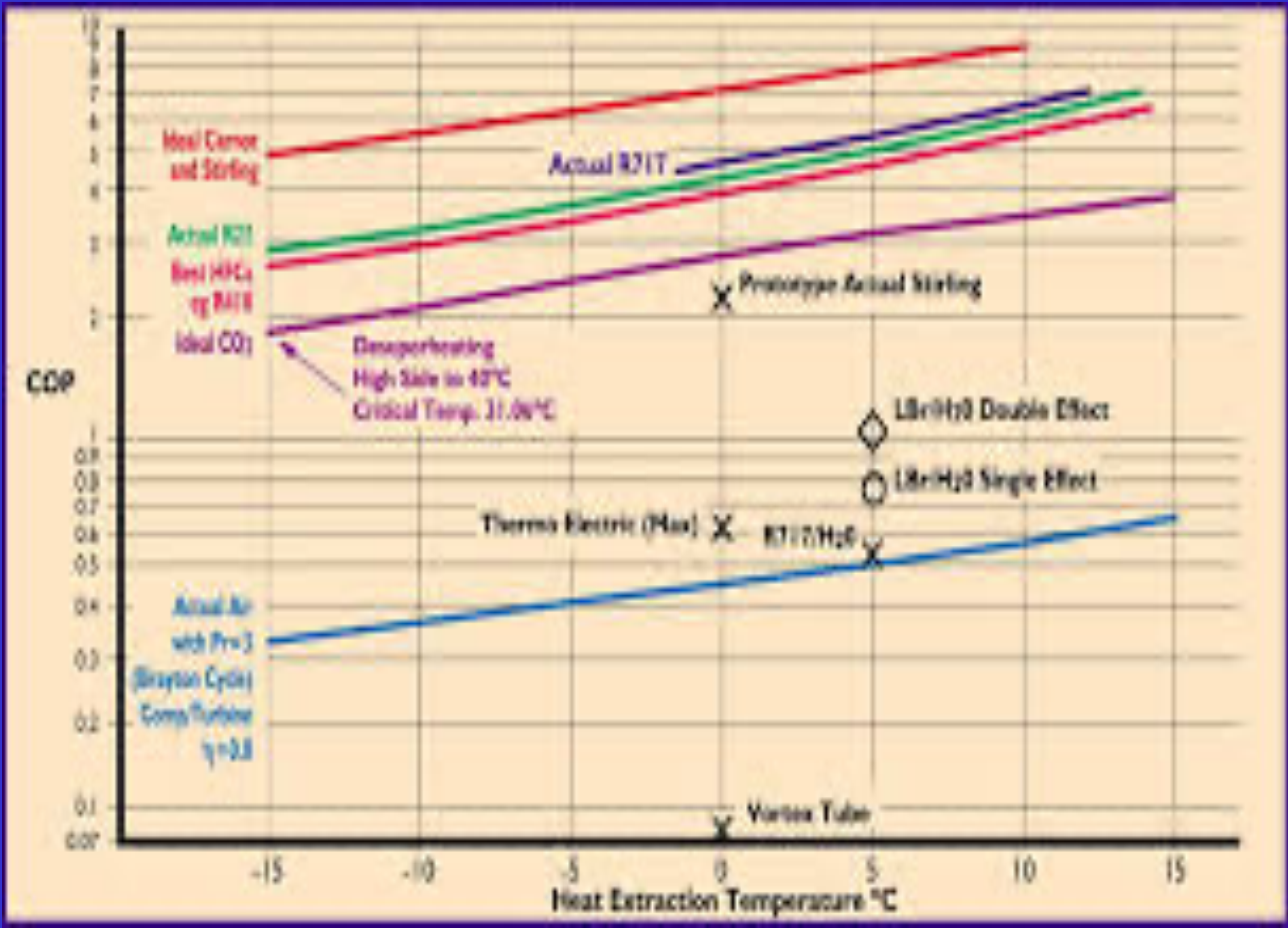


Figure 3: Finned air cooler test (2009); heat transfer coefficient vs. circuit loading.

Ref. ASHRAE Journal Feb 13 Page 18


COP
Ideal Carnot and Stirling
Actual R717
Actual R22
Ideal CO2
Prototype Actual Stirling
Desuperheating
High Side to 40°C
Critical Temp. 31.06°C
LiBr/H2O Double Effect
LiBr/H2O Single Effect
Thermo Electric (Max)
R717/H2O
Vortex Tube
-15
-10
-5
0
5
10
15
Heat Extraction Temperature °C

Aluminum Coolers

Innovation: Aluminum Coil

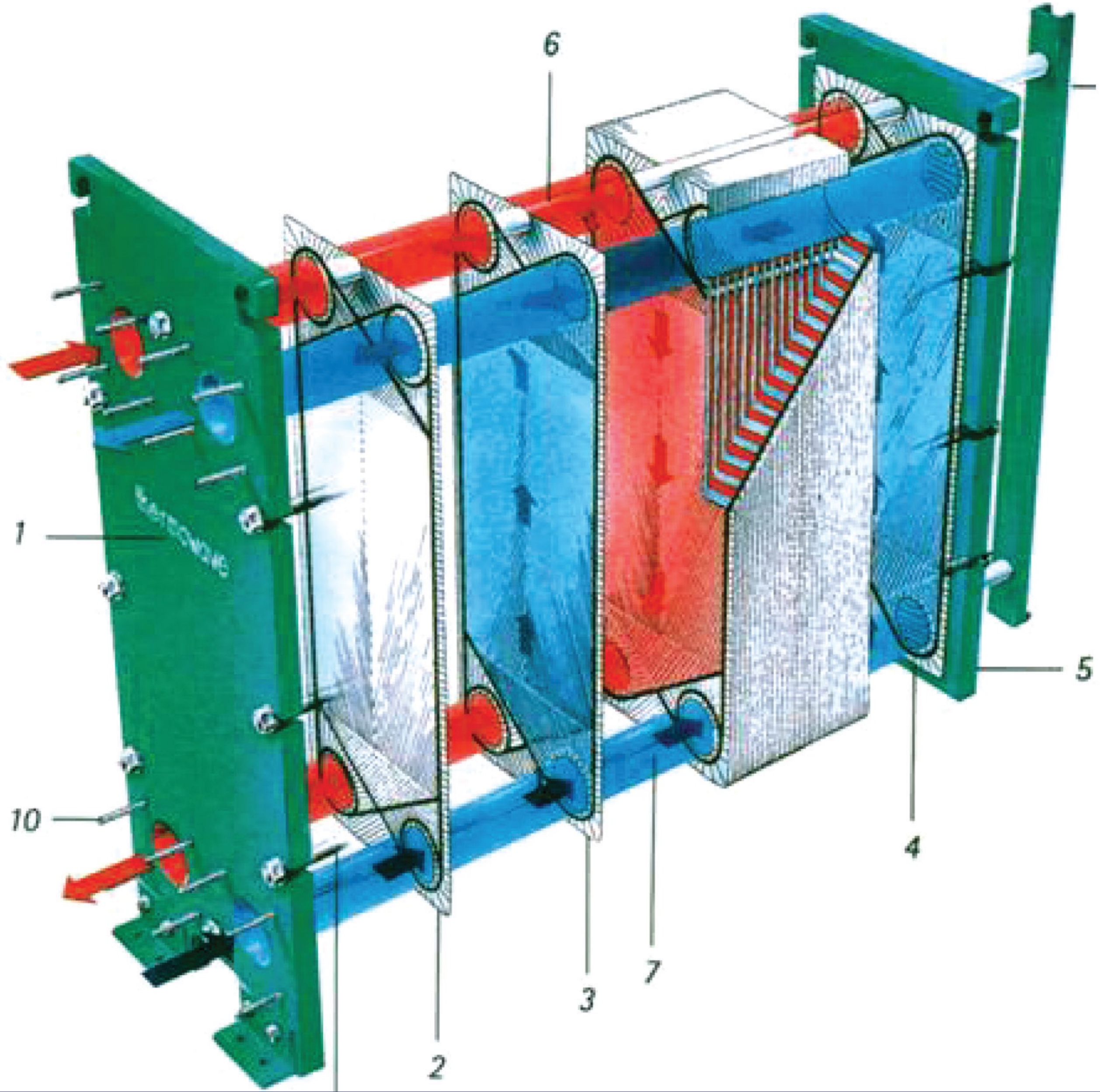
STAR REFRIGERATION

Metal	Density lb/ft^3	Thermal Conductivity Btu/h ft^2 °F
Aluminum	165	117
Carbon Steel	489	26
Zinc	440	65
Stainless Steel	501	9.4

ATMOsphere America the Business Case natural refrigerants
June 12-13 2012 | Washington DC

Ammonia chiller packaged unit with a hermetic scroll compressor

Plate Heat Exchangers



AIR COOLED AMMONIA PACKAGE CHILLER

Low Ammonia Charge Systems

Andy Pearson-IIAR presentation

Optimum-charge systems have become very common, and the generally accepted benchmark is to achieve a specific charge of about 0.1 kilogram/kilowatt (0.8 pounds/TR). As an example, a project at Welwyn Garden City in England involved such a standard. The system was designed to be quite large, with a cooling capacity of 7,500 kW (2,160 TR), and was to use plate evaporators and condensers. The job specifications stipulated that the charge was to be less than 250 kilograms (550 pounds) per chiller. The eventual solution we developed was to use three water chillers, each 2,500 kilowatts (720 TR) in capacity, and each requiring 238 kilograms (524 pounds) of ammonia upon commissioning.

WATER COOLED PACKAGE CHILLER-SCREW COMPRESSORS & PHE CONDENSER/COOLER-856 kW-86 kg

0.353kg/TR

WATER CHILLER USING RECIPROCATING COMPRESSOR
& ENCLOSED PHE CONDENSER/COOLER

PACKAGE MILK CHILLER WITH 'U' TUBE ACCUMULATOR

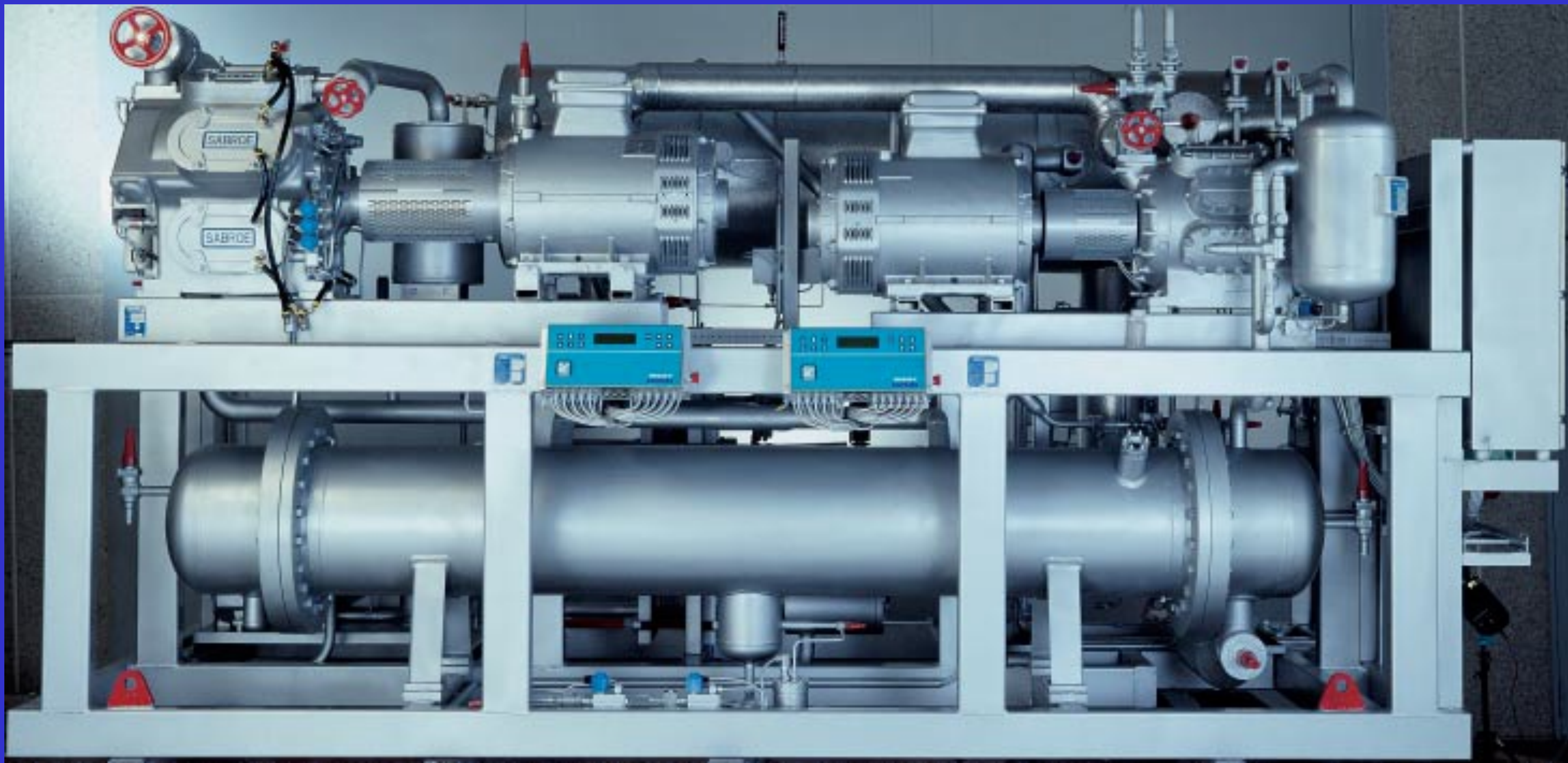
Non-Azeotropic Liquid Gas Blends-Advantage

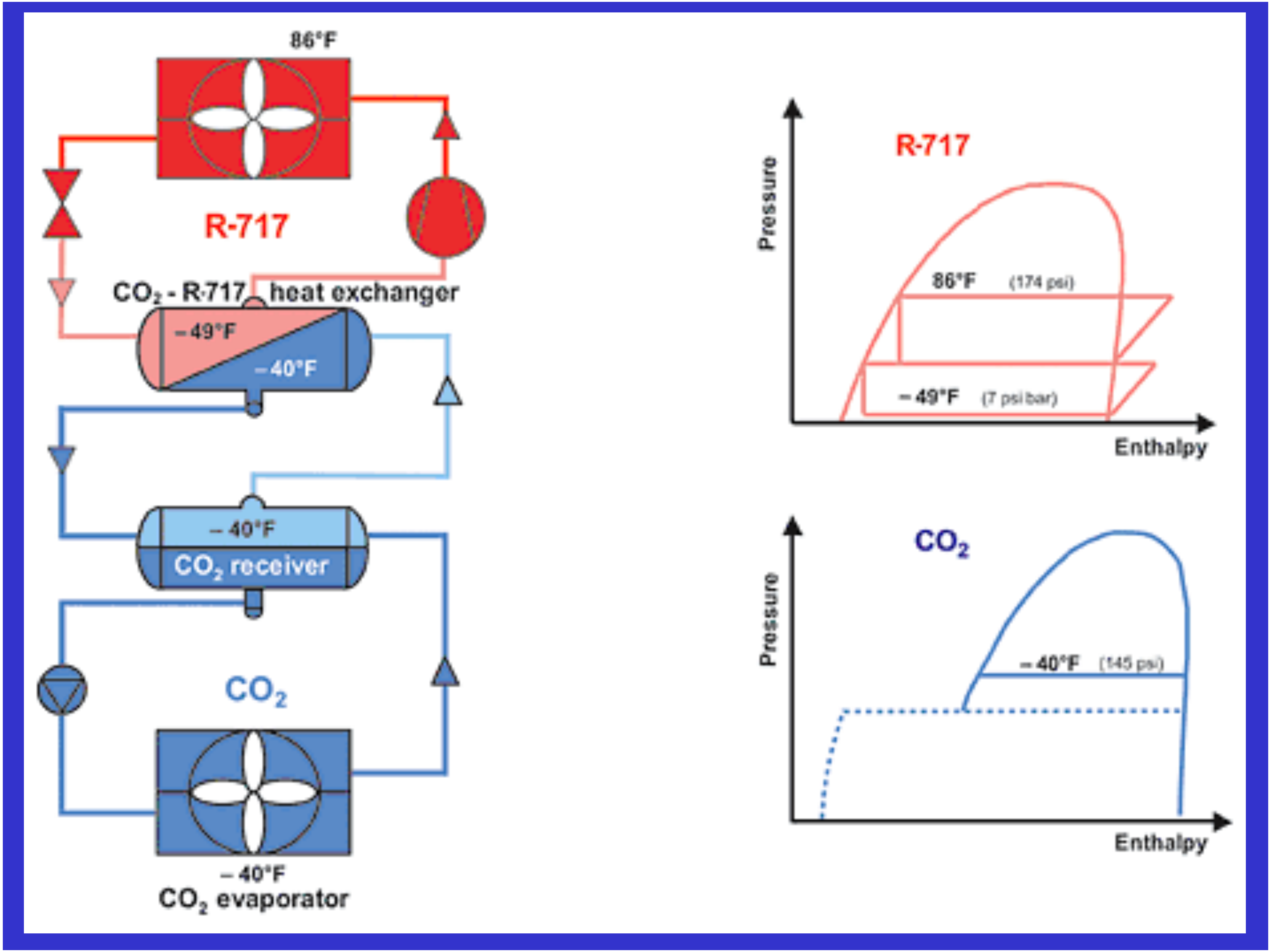
1. Ammonia with Propane(290)
2. Ammonia with Octafluoropropane(R218)
3. Ammonia with Octafluorocyclobutane(R318)
4. Ammonia with isobutane(R600a)
5. 60% Ammonia and 40% dimethyl ether(R723)

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

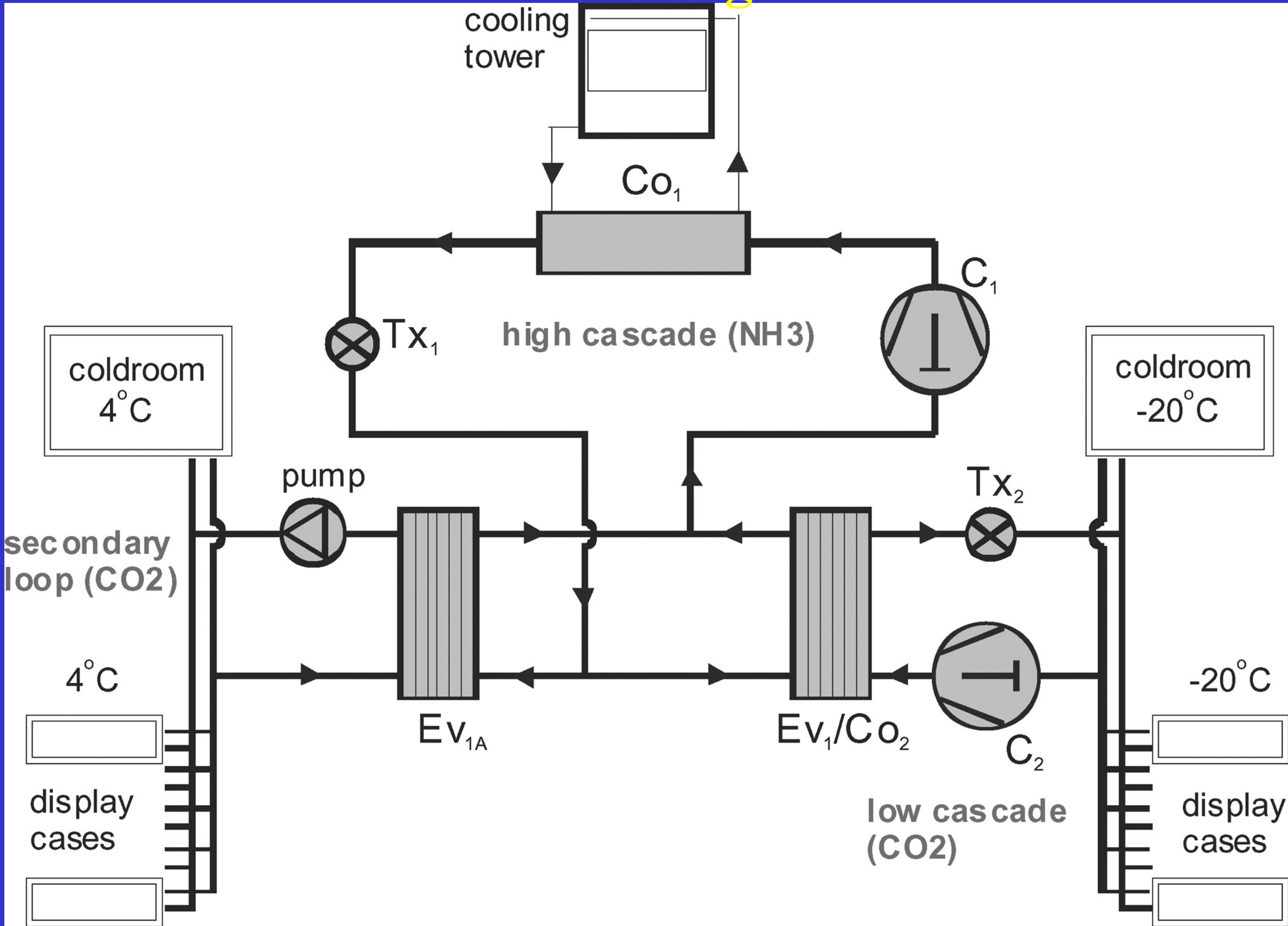
CO2 Ammonia Cascade





86°F
R-717
CO_2 - R-717 heat exchanger
−49°F
−40°F
−40°F
CO_2 receiver
CO_2
−40°F
CO_2 evaporator
Pressure
R-717
86°F (174 psi)
−49°F (7 psi bar)
Enthalpy
Pressure
CO_2
−40°F (145 psi)
Enthalpy

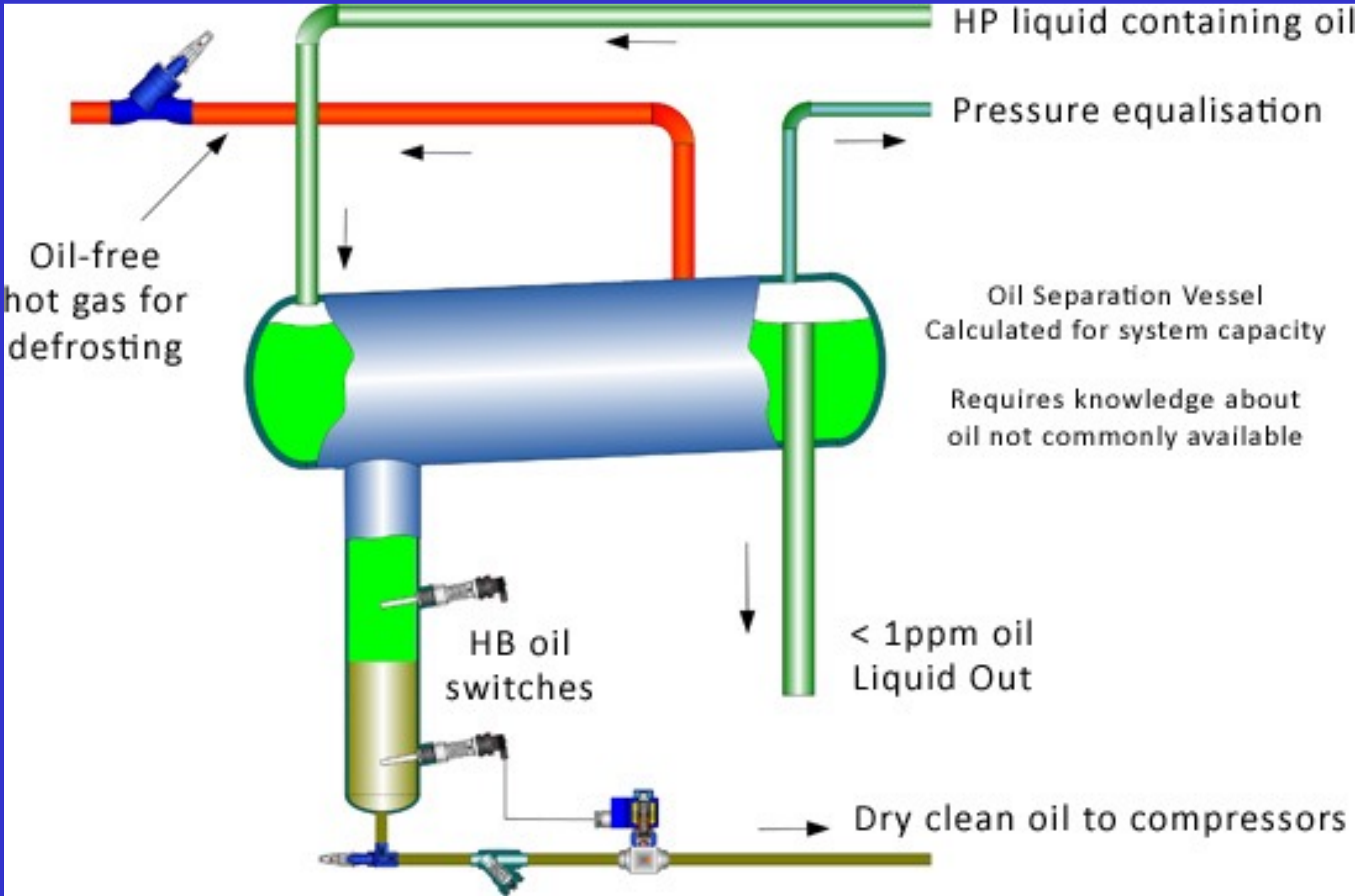
Cascade refrigeration system NH3/CO2 and indirect cooling



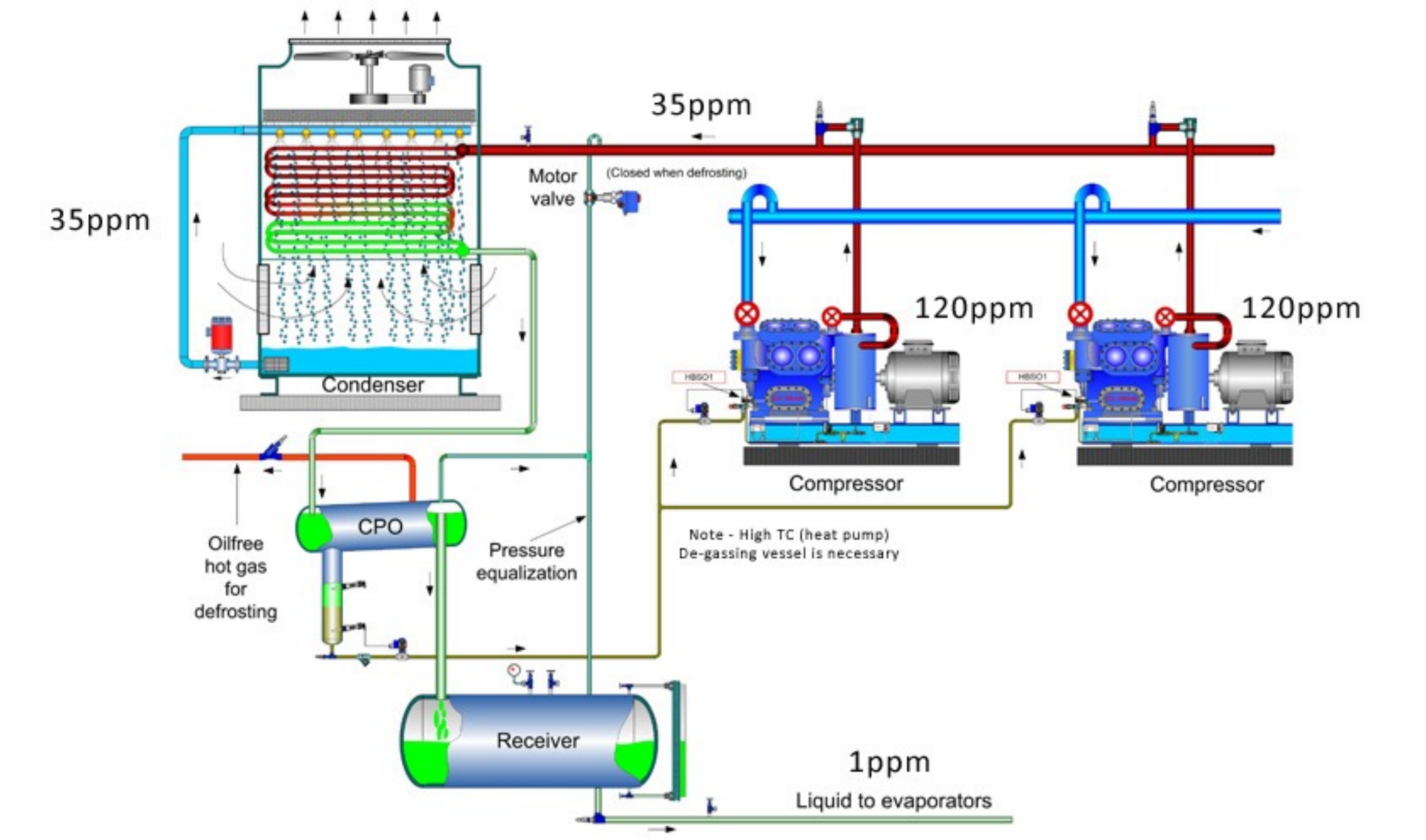
AMMONIA-CO2 BRINE SYSTEM –FRUIT STORAGE-HOLLAND

AMMONIA -CO2 CASCADE

Oil Recovery System-The first installation of this vessel saved over 237 litres of oil in the first year, plus countless man hours in maintenance and draining of waste oil.



Oil Management System



The Ozeaneum In Stralsund Gernmany:Underwater world

KOREAN SHIP

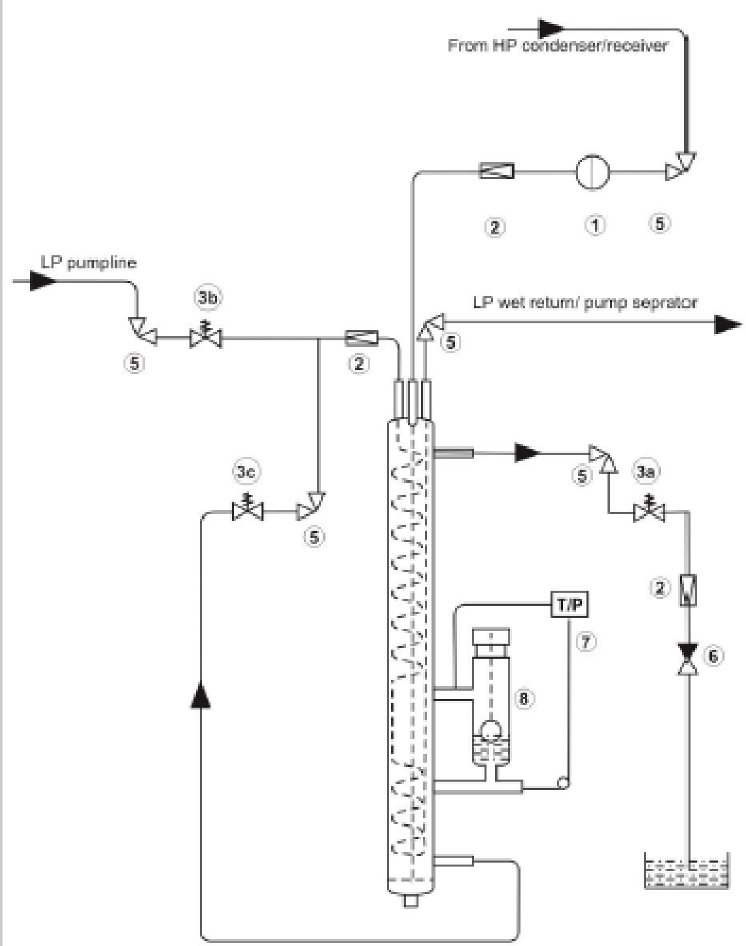
Strength and Weakness of Fuels

Type	MGO	LNG	Bio gas	Bio diesel	Methanol	Ammonia	Hydrogen
Fuel type	Fossil fuel		Carbon-neutral fuel				
Storage condition	Ambient temperature and pressure	−162°C	−162°C	Ambient temperature and pressure	Ambient temperature and pressure	−34°C or 10 bar	-253°C
Relative Fuel Tank size	1	2.3	2.3	1	2.3	4.1	7.6
Relative CAPEX	1	~ 1.3	~ 1.3	1	~1.15	~1.2	Very expensive
Fuel cost & Availability	Less expensive and rich reserves		Difficult to mass produce due to the fuel sourcing problem	Difficult to forecast the price due to unstable supply and demand and the food security problem	High cost of CO_2 capture* (when capturing CO_2 from air)	Expensive but relatively low priced for carbon-neutral fuel	Reasonable fuel production cost but high storage and transport costs

* Although it is possible to lower the cost by capturing carbon dioxide from combustion gas (exhaust gas from power plants), it is not the carbon-neutral fuel since it uses carbon dioxide produced by fossil fuel.

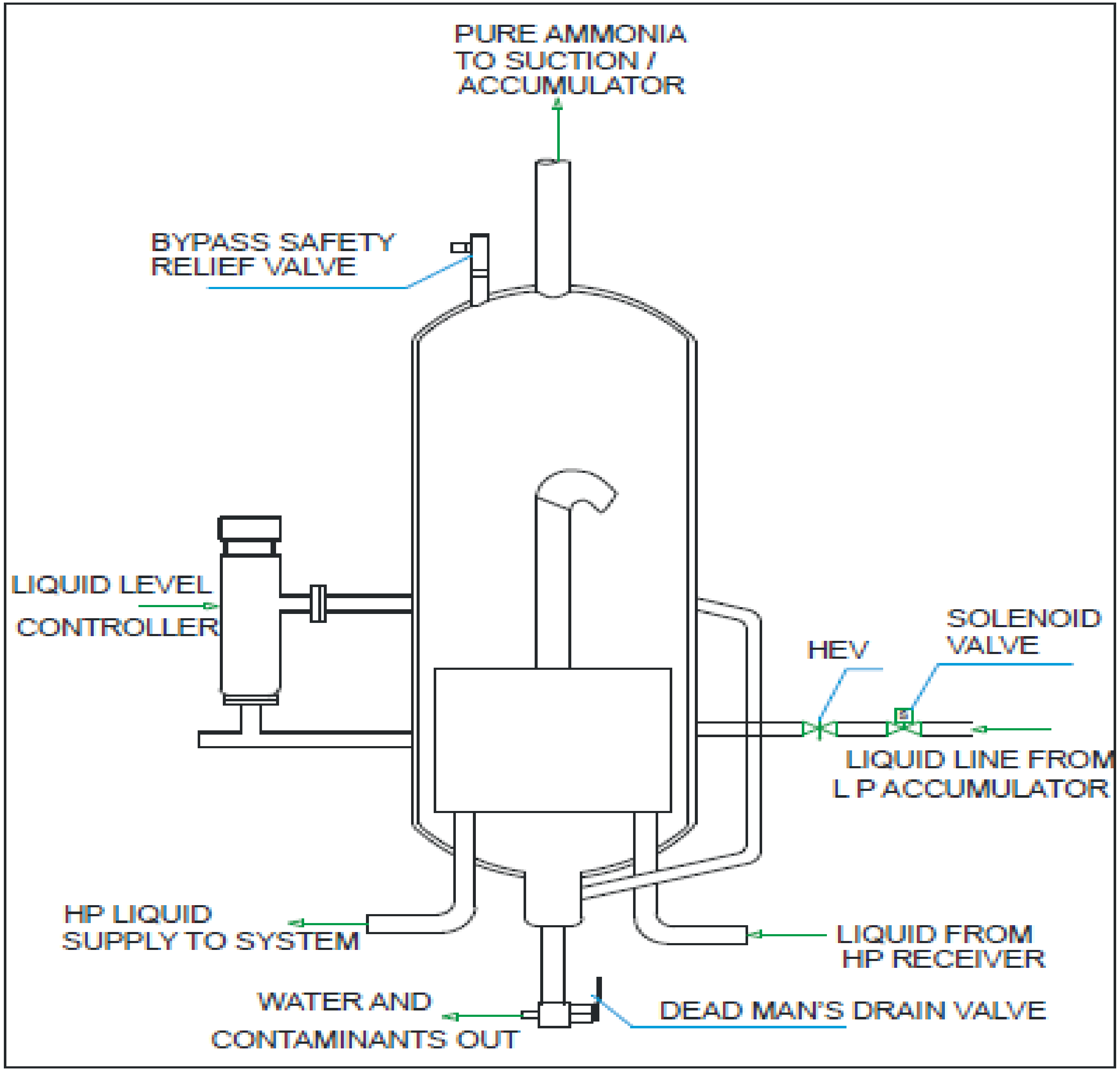
Source: Korean Register

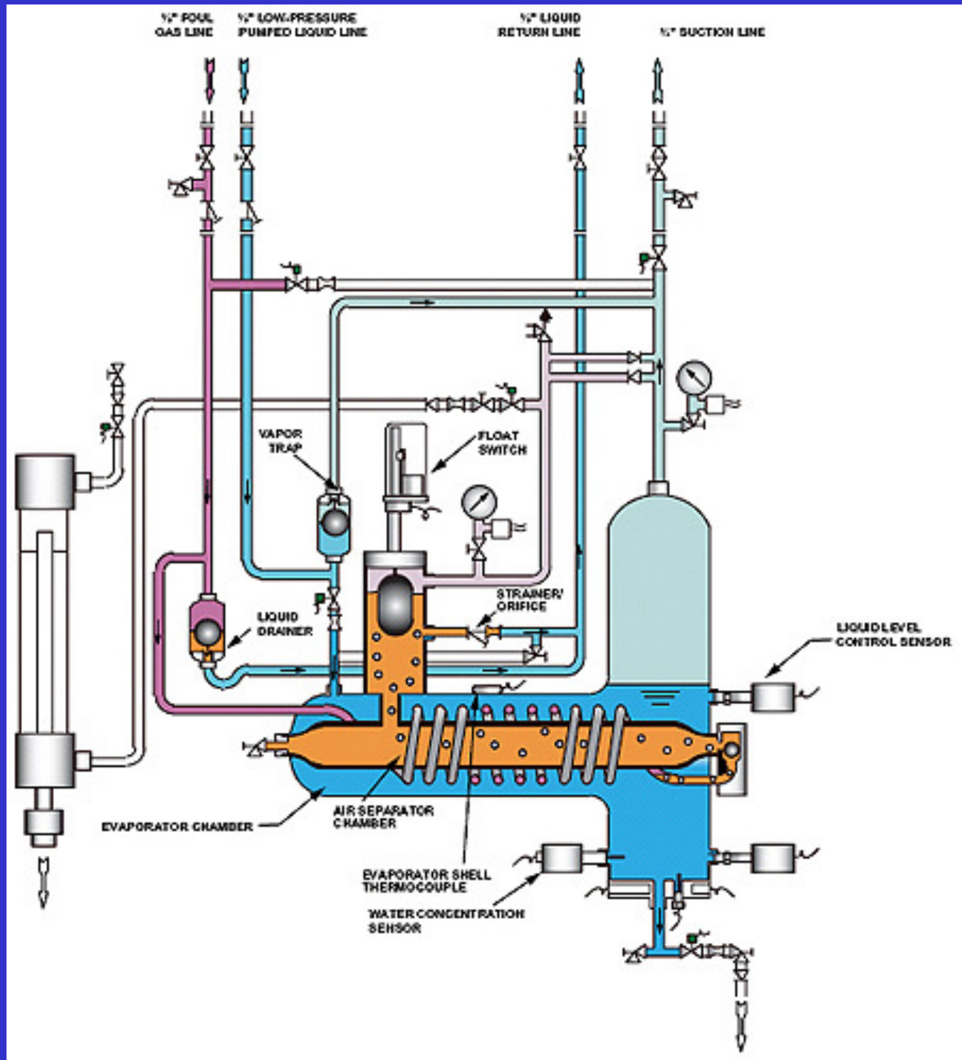
Excellent Acceptable. Undesirable



Pump Re-cerculation System

Water Remover




½" FOUL GAS LINE
½" LOW-PRESSURE PUMPED LIQUID LINE
½" LIQUID RETURN LINE
½" SUCTION LINE
VAPOR TRAP
FLOAT SWITCH
STRAINER/ ORIFICE
LIQUID DRAINER
LIQUID LEVEL CONTROL SENSOR
EVAPORATOR CHAMBER
AIR SEPARATOR CHAMBER
EVAPORATOR SHELL THERMOCOUPLE
WATER CONCENTRATION SENSOR

Water Dehydrator

AMMONIA DEHYDRATOR (WDO)

Thank you

Any Questions ?

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