Advances in Compressors, condensers, coolers and controls and comparisons

By
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Chairman AAR standards committee
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CURRENT SITUATION

It is predicted that Refrigeration Industry would grow faster than Comfort Air Conditioning Industry

ASHRAE Journal statement

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ADVANCES IN REFRIGERATION TECHNOLOGY IN LAST 50 YEARS

DRIVING FORCES- THEY ARE NEED BASED

1.FOOD

2. SHELTER

3.COMFORT

4.TECHNOLOGY

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ADVANCES IN REFRIGERATION TECHNOLOGY IN LAST 50 YEARS

TECHNOLOGY

1.Efficiency-Energy Savings-First Priority
2.Environmental concerns-Top Priority
3.Reliability-Safety
4.Compactness-space constraints
5.Reduced maintenance-Human dependability
6.Automation-Electronics-Controls

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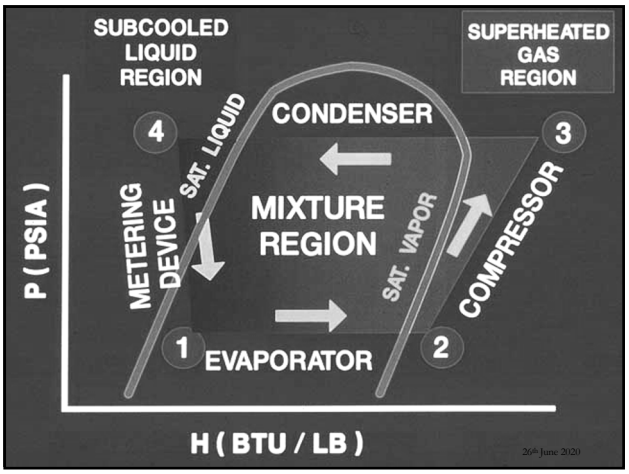

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ADVANCES IN REFRIGERATION TECHNOLOGY LAST 50 YEARS

Advances in Technology

1. Refrigerants -Alternate Refrigerants
2. Refrigeration compressors
3. Condensers
4. Evaporators
5. Controls

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1. COMPRESSORS

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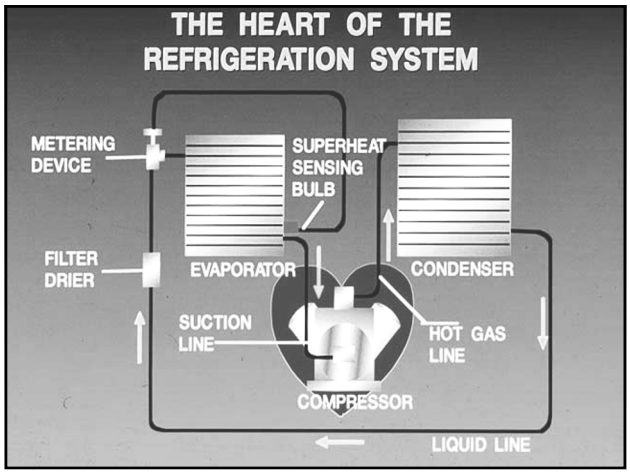

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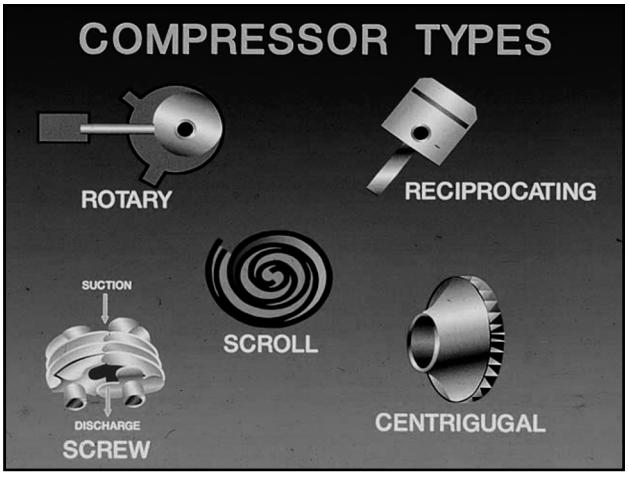

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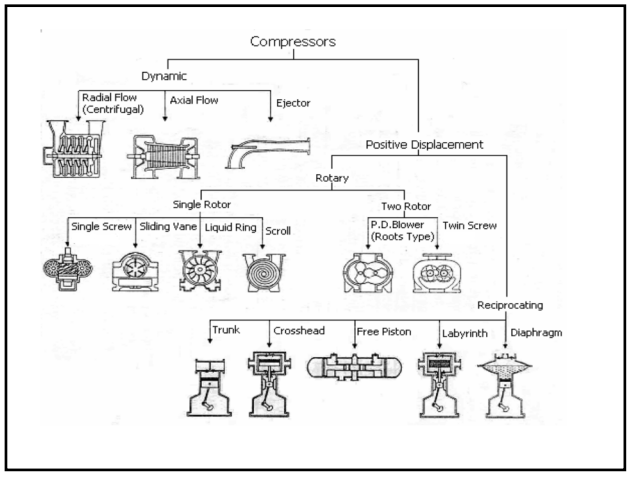

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Type of compressors

1. Reciprocating- Pistons travelling back and forth
2. Rotary- Out of center rotor rotating within cylinder
3. Scroll- Two spiral shaped parts, one remains fixed while the other orbits (without spinning) against it.
4. Screw-Two helical rotors male and female mesh with each other as they turn same way as bolt is turned into a threaded opening., or mono screw with two star wheels
5. Centrifugal compressors- High speed impeller with many blades

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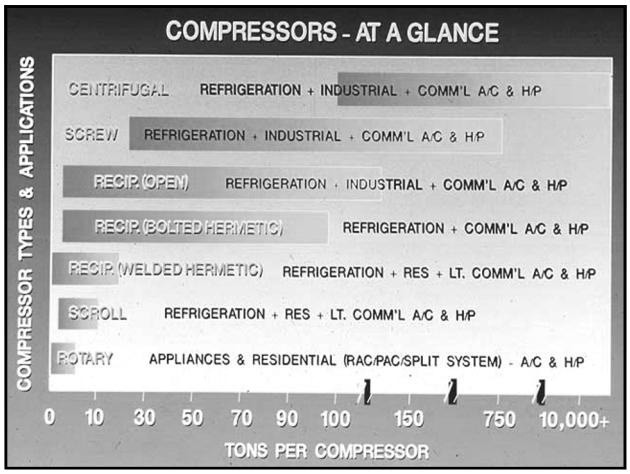

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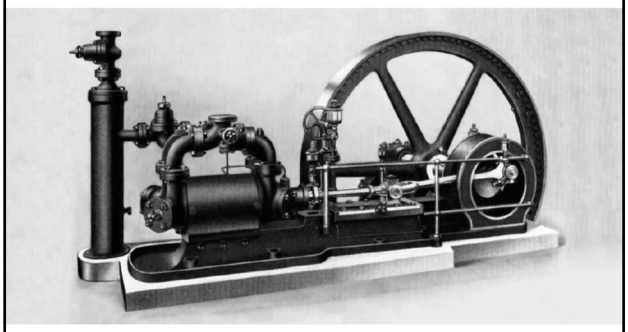

FIRST Horizontal Ammonia Two stage compressor By Linde Group around 1900

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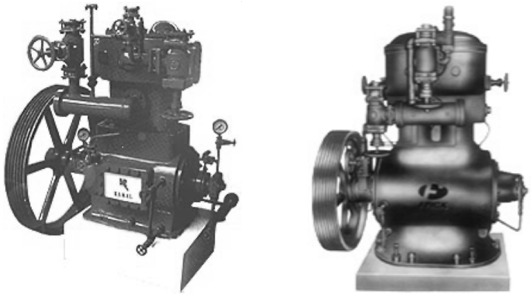
AMMONIA SLOW SPEED COMPRESSORS-
SLOW SPEED COMPRESSORS-UP TO 400 RPM TILL 1970



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MEDIUM SPEED AMMONIA COMPRESSORS-
UP TO 750 RPM

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MEDIUM SPEED AMMONIA COMPRESSORS-
UP TO 1000 RPM

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MEDIUM SPEED AMMONIA COMPRESSORS-
UP TO 1200 RPM

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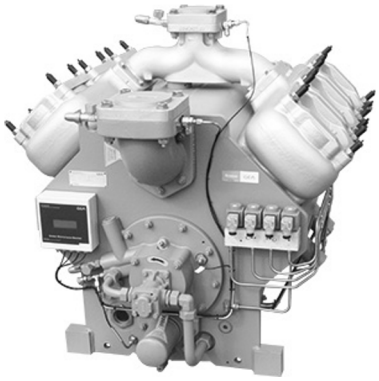
HIGH SPEED AMMONIA COMPRESSORS-UP TO 1450RPM



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SEMI HERMETIC COMPRESSORS-for HFC/HCFC refrigerants

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SEMI HERMATIC RECIPROCATING COMPRESSORS-NOT FOR AMMONIA REFRIGERANT

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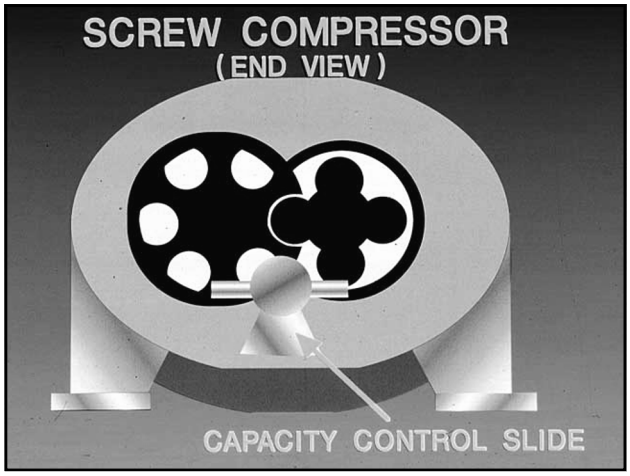

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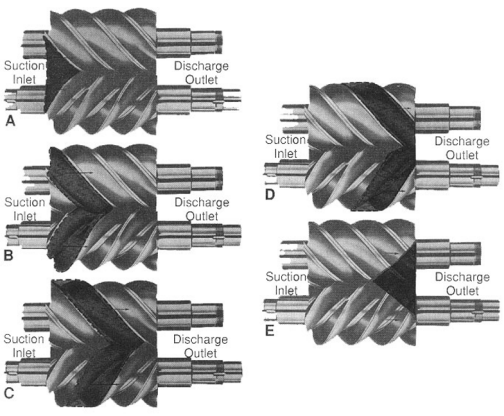

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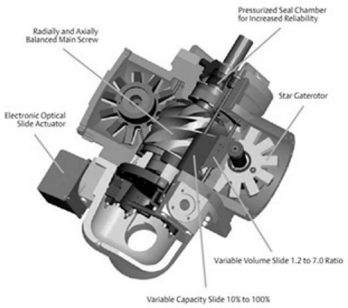
MONO SCREW COMPRESSORS



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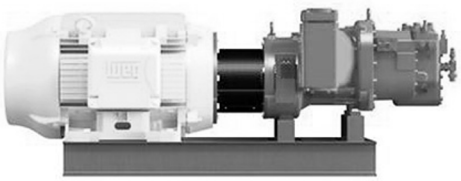
HIGH SPEED AMMONIA SCREW COMPRESSORS- 3000 /3600 RPM



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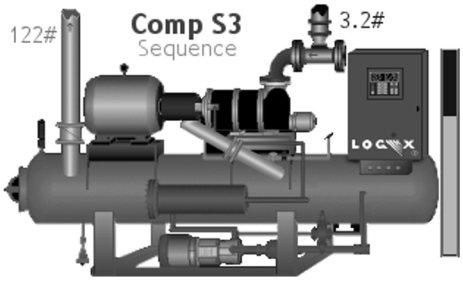
COMPRESSOR-MOTOR SET



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ADVANTAGES OF SCREW COMPRESSOR-AMMONIA APPLICATIONS

1.More rugged, reliable, less number of parts, less to go wrong
2.Fully balanced, no vibrations
3.Does not require foundation, load bearing slab is adequate
4. Rotors fully immersed in oil, no rubbing parts or friction, roller bearings
5.Speeds higher than reciprocating-more compact
6. VFD can increase speed up to 3600 RPM for initial fast cool down
7.Large capacity single compressor is available, less number of compressors for large plants
8.External oil pump, hence lubrication not affected by speed reduction
9.External oil cooler-oil temperature can be controlled bet. 60-65^{0}C
10.No suction or discharge valves needed
11.MTBO -MTBF higher than reciprocating compressors

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Advantages of Reciprocating compressor over screw compressors

1. Variable compression ratio, makes automatic adjustments to atmospheric temperature variations, screw compressor is fixed internal compression due to construction, hence there is over or under compression
2. Consumes 10 to 15 % lower power
3. Part load performance of multi step-unloading better compared to slide valve or VFD
4. Published values of screw are with economizer, at part load with slide valve, economizer port likely to get bypassed and loose power saving benefits.
5. Reciprocating compressor system requires substantially less quantity of oil

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Hermetic Reciprocating Compressor

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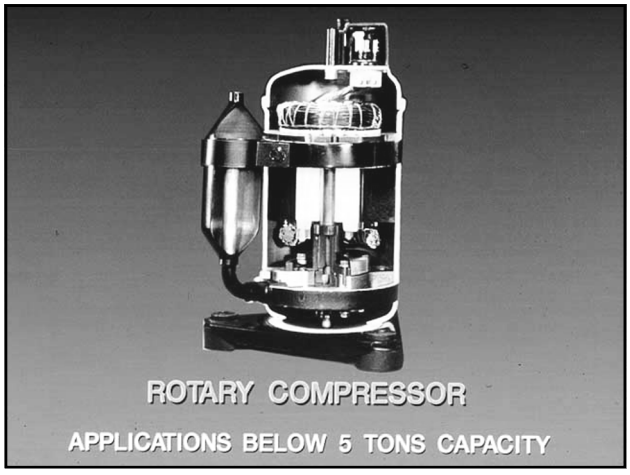

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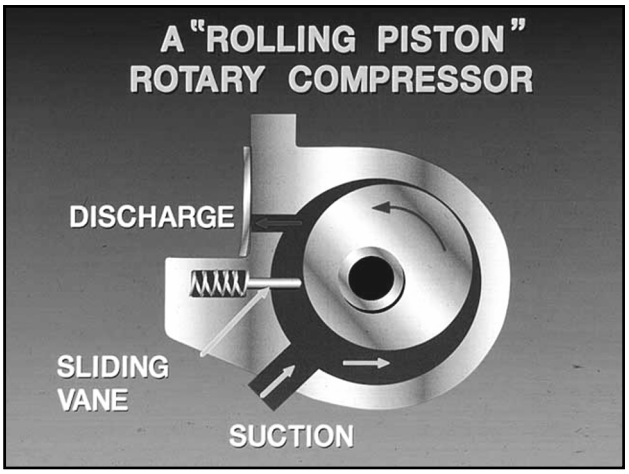

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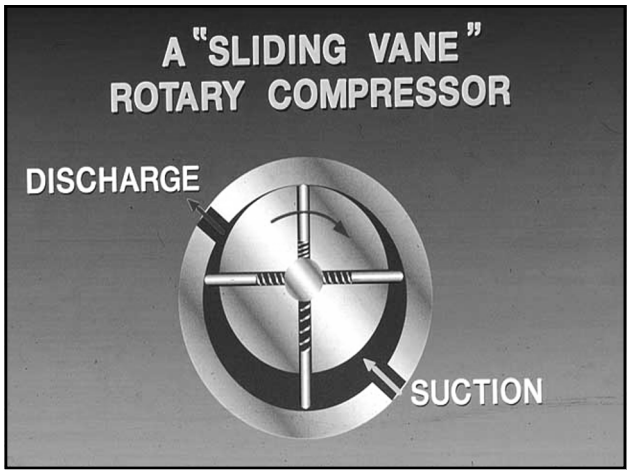

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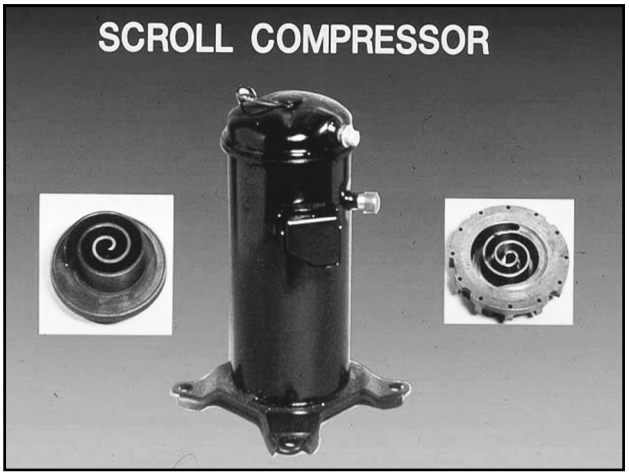

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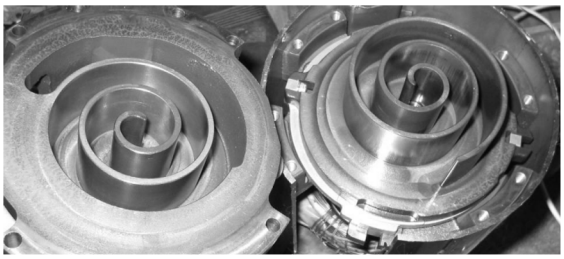
SCROLL COMPRESSORS-STATOR/ROTOR



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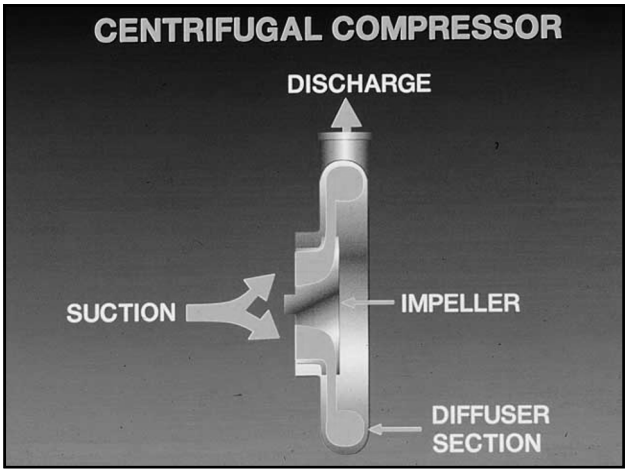

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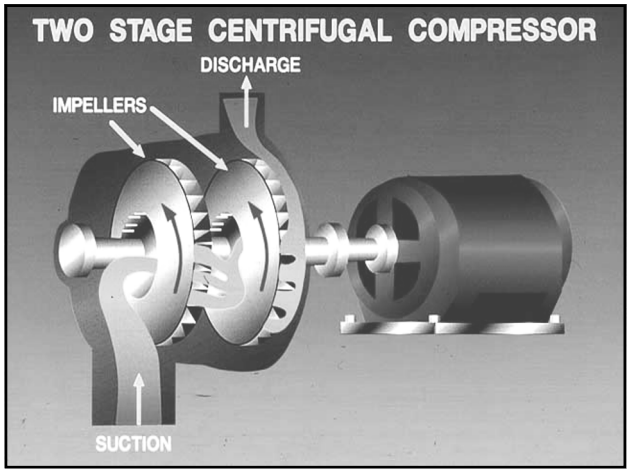

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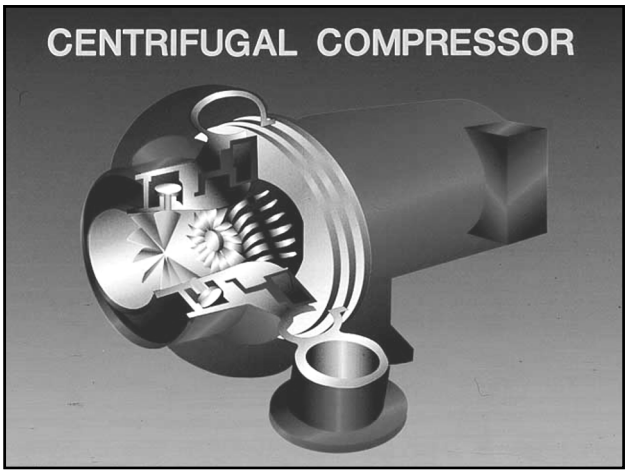

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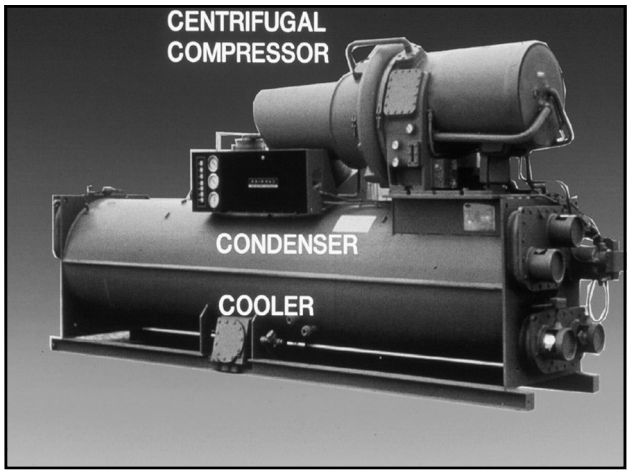

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CENTRIFUGAL CHILLER EFFICIENCY PROGRESS

EFFICIENCY - kW/TON

YEAR	AVERAGE	GOOD
1979	0.80	0.72
1980	0.72	0.68
1990	0.65	0.62
1991	0.64	0.60
1993	0.63	0.55
1995	0.61	0.52
1997	0.60	0.50
1999	0.59	0.49
2000	0.58	0.48
2002/2006	0.56	0.45
2012-2013	0.45	0.32 IPLV

0.1 kW/TON = 9.9 billion kg of CO_2+ 6.3 grams SO_2,
+ 3.5 billion gms NOx OR = 3 MILLION CARS OFF ROAD
OR = PLANTING 600 MIL. TREES

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ADVANCES IN TECHNOLOGY -LAST 50 YEARS

COMPRESSORS SPEEDS

1. Reciprocating-Ammonia Slow Speed 300 RPM –now up to 1500 RPM
2. Screw Compressors- 3600 RPM
3. Cetntrifugals-6000 RPM -40000 RPM
4. Rotary/Scroll Technology-1500RPM

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LATEST DEVELOPMENTS

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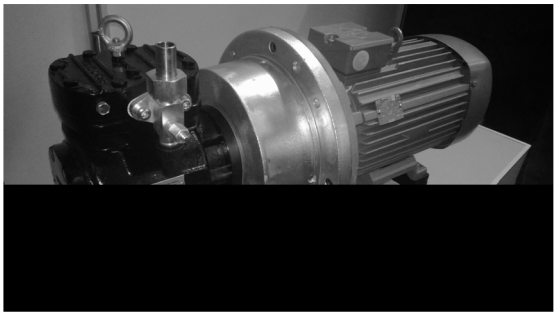
Small capacity -7kW Ammonia Reciprocating Compressor - HKT –GOELDNER-GERMANY



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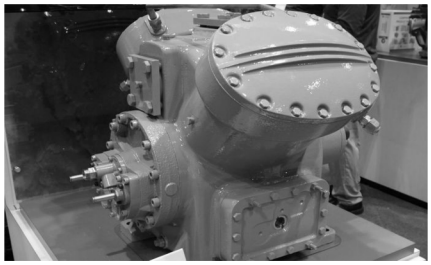
Carrier Corporation has developed new Ammonia compressor



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HERMETIC AMMONIA SCROLL COMPRESSOR

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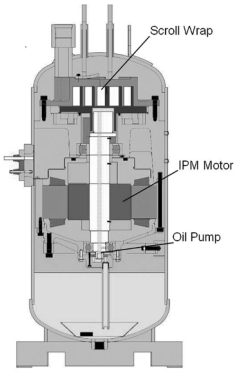
HERMETIC AMMONIA SCROLL COMPRESSOR



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Semi Hermetic Ammonia Compressor with aluminum winding motor

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CO2 COMPRESSOR-(Car Air conditioning)

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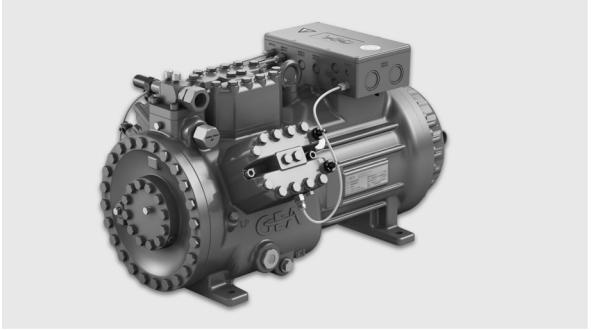
CO_2 COMPRESSOR-(Industrial applications)



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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

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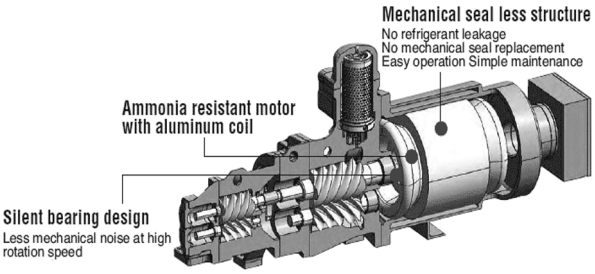
AMMONIA SEMI HERMETIC COMPRESSORS-KOBELCO-MYCOM



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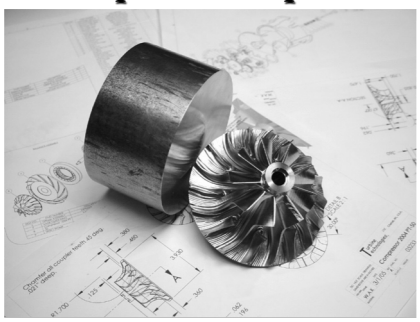
Finished Titanium Centrifugal compressor impeller



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1.In addition to Titanium rotors,
2.The development of magnetic bearings allows no lubrification for centrifugal machines and new relatively small centrifugal compressors have been appearing on the market since last five years.
3. This trend is also associated with significant increase in RPMs of those centrifugal compressors. Velocities higher than 25,000 rpm are foreseen.
4. The development of new software enables rapid design of wheels and possible new developments of high speed non-lubricated centrifugal compressors seem a new opportunity.

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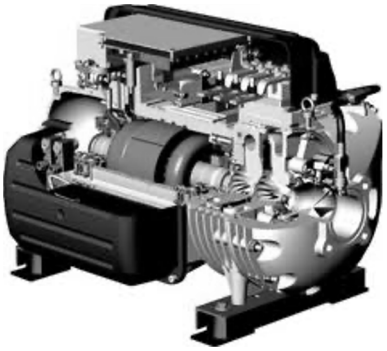
TERBOCOR CENTRIFUGAL COMPRESSOR WITH MAGNETIC BEARINGS-OIL FREE AND HIGH SPEED UP TO 40000 RPM



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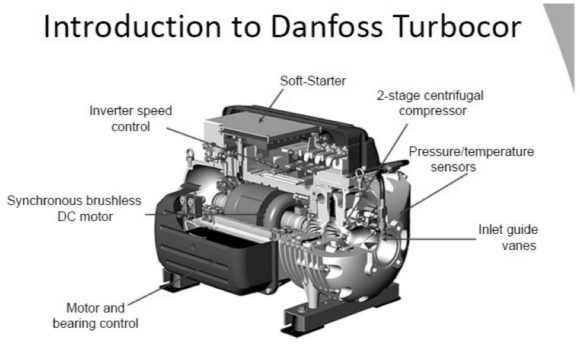
Turbocor compressor Introduced in 2016 sitable for refrigerant 1234ze-upto 150 TR



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TERBOCOR CHILLER

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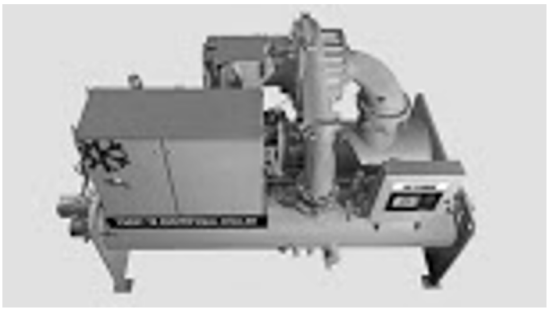
Johnson Controls YZ Centrifugal Chiller with magnetic bearings & R1233Zd Refrigerant-Winner AHR EXPO Award 2018



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TEKO AMMONIA SCREW CHILLERS

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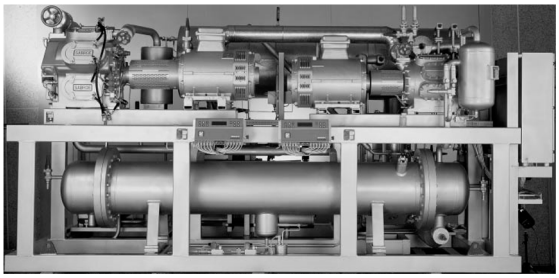
CO2 Ammonia Cascade



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PROPANE CO2 CASCADE

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2. CONDENSERS

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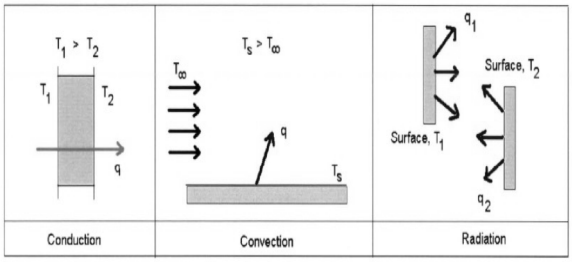
HEAT TRANSFER METHODS



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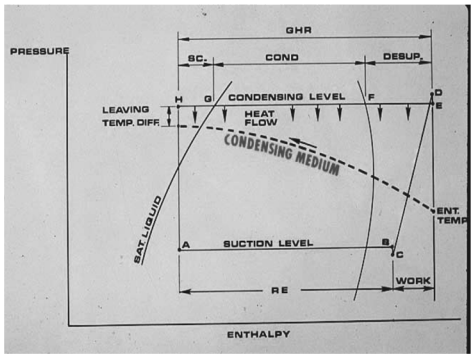
Heat Rejection in Condensers



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TYPES OF CONDENSERS

1. **WATER COOLED- ATMOSPHERIC- NATURAL DRAFT CONDENSER**
2. **WATER COOLED- SHELL AND TUBE CONDENSER**
3. **WATER COOLED- EVAPORATIVE CONDENSER**
4. **WATER COOLED- PLATE HEAT EXCHNGER TYPE– PHE CONDENSER**
5. **AIR COOLED CONDENSERS FOR ALL REFRIGERANTS INCLUDING AMMONIA**

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Important points - for use in Ammonia plants

1. Air cooled condensers, Natural draft condensers, vertical condensers and evaporative condensers do not require additional cooling tower and its allied equipment
2. Quality of water more important for PHE, shell and tube condensers
3. Most compact condenser is PHE condenser compared to shell and tube and evaporative condenser
4. In condenser design we need three parameters to optimize-
   1. A. air quantity
   2. B, Water quantity
   3. C. heat transfer area
5. Evaporative condenser and natural draft condenser has both heat and mass transfer at one place, whereas shell and tube and PHE condensers do only sensible-water heat transfer and then water is evaporated in cooling tower.
7. Most energy efficient condenser is Evaporative condenser

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Water cooled Atmospheric condenser

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VERTICAL CONDENSER

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Shell and Tube Ammonia Condenser

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Evaporative Condensers

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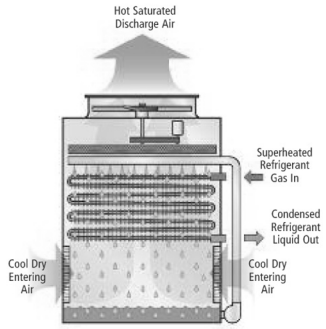
Evaporative Condensers



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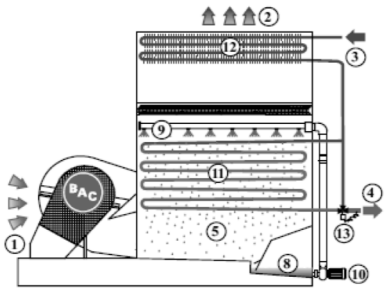
Evaporative condenser with desuperheater



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Evaporative condenser with de-superheater

-A **desuperheater** is an air-cooled finned coil usually installed in the discharge airstream of an **evaporative condenser**. ... Its primary function is to increase the **condenser** capacity by removing some of the superheat from the discharge vapor before the vapor enters the wetted **condensing** coil.

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ECO Mesh Ammonia Air cooled condenser

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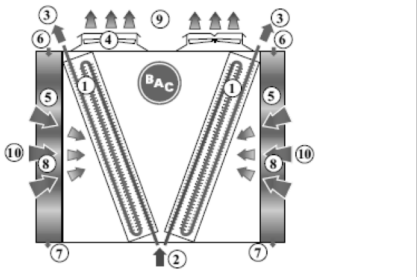

Dry coolers equipped with an adiabatic pre-cooler cool the liquid by sensible heat transfer only. Before the air is drawn through the high density finned coil however, it is pre-cooled adiabatically as it passes through an evaporative pad where water is evaporated in the air

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Importance of L/G ratio

$$L(T_1 - T_2) = G(h_2 - h_1)$$

$$\frac{L}{G} = \frac{h_2 - h_1}{T_1 - T_2}$$

where:

L/G = liquid to gas mass flow ratio (lb/lb or kg/kg)
T_1 = hot water temperature (^{0}F or ^{0}C)
T_2 = cold water temperature (^{0}F or ^{0}C)
h_2 = enthalpy of air-water vapor mixture at exhaust wet-bulb temperature (same units as above)
h_1 = enthalpy of air-water vapor mixture at inlet wet-bulb temperature (same units as above)

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EVAPORATIVE CONDENSR OPERATION

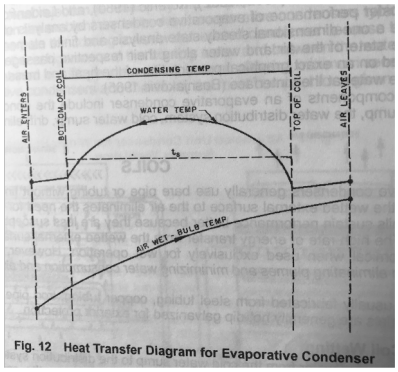

Fig. 12 Heat Transfer Diagram for Evaporative Condenser

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Type	Evaporative condenser	Shell & Tube condenser
Dry Bulb Temeprature-^{0}C	40	40
Wet bulb Temperature -^{0}C	28	28
Water Tank Temperature-^{0}C	32	32
Water spray Temperature-^{0}C	32	36
Condensing Temperature-^{0}C	38	40
Compressor capacity kW(TR)	201.1(57.17)	198.4 (56.39)
Power consumption-kW	45.14	46.88
Power consumption –kW/TR	0.7896	0.831
C.O.P.	4.45	4.23

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The evaporative condenser offers a number of important advantages over other condensing systems:

1. Low system operating costs. Condensing temperatures within 15°F of design wet-bulb are practical and economical, resulting in compressor horsepower savings of 10% or more over cooling tower/condenser systems and more than 30% over air-cooled systems. With 29^{0}C wet bulb+38^{0}C condensing possible
2. Fan horsepower is comparable to cooling tower/condenser systems and is about one-third that of an equivalent air-cooled unit,because of the low pumping head and reduced water flow
3. water pumping horsepower is approximately 25% of that required for the normal cooling tower/condenser installation.

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The evaporative condenser offers a number of important advantages over other condensing systems:

4. The evaporative condenser combines the cooling tower, condenser surface, water circulating pump, and water piping in one assembled piece of equipment. This reduces the cost of handling and installing separate components of the cooling tower/condenser system.

5. Since the evaporative condenser utilizes the efficiency of evaporative cooling, less heat transfer surface, fewer fans, and fewer fan motors are required resulting in an initial material cost savings of 30 to 50% over a comparable air-cooled condenser.

6. Space saving The evaporative condenser saves valuable space by combining the condensing coil and cooling tower into one piece of equipment, and eliminating the need for large water pumps and piping associated with the cooling tower/condenser system.

78

PHE Semi Welded Condenser

79

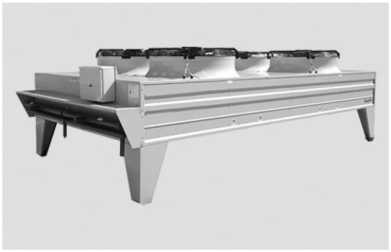
Advantages of plate type evaporative condenser

1. Unique design of plates for superior performance
2. Designed to withstand high condensing pressures
3. Excellent heat transfer
4. Lower ammonia charge compared to tubes
5.Lower water quantity requirements
6. Smaller foot print , compact design
7. Easily accessible plate bank
8. Lower operational and maintenance cost

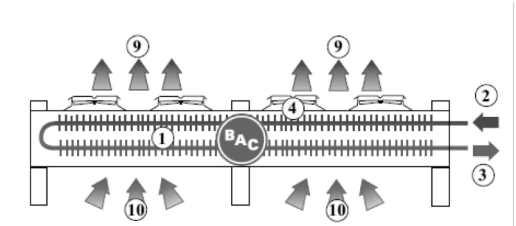
Requires additional cooling of water in cooling tower

80

Air Cooled Ammonia Condenser



81

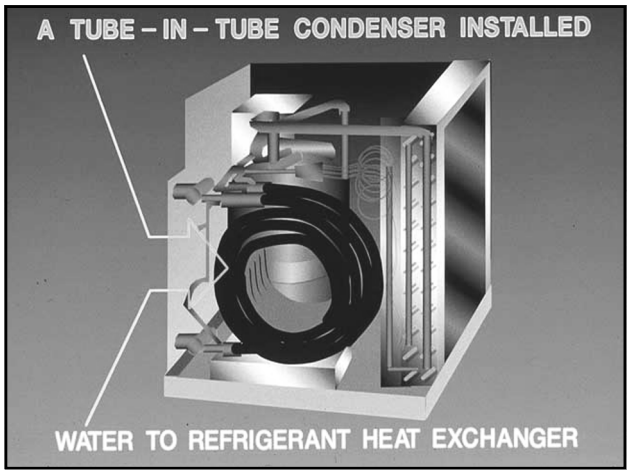


Dry fluid coolers cool the liquid in a closed circuit by means of sensible heat transfer using a high-densifty finned coil block

82

Tube in Tube water cooled condenser for HFC/HCFC refrigerants

83



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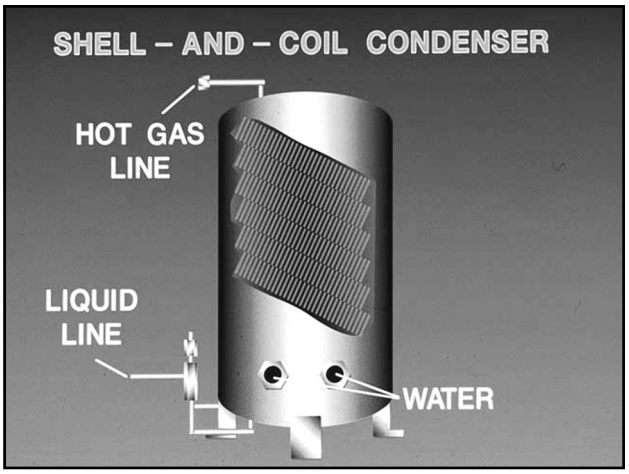
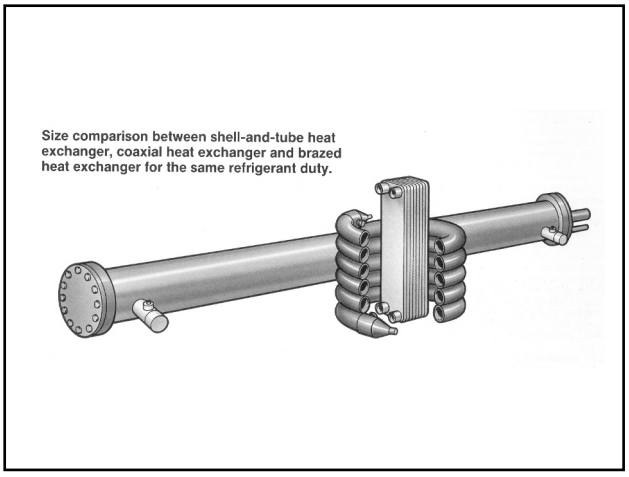


85

Water Quality Requirements

Parameter	Units	Stainless Steel	Galvanized Steel
pH	NA	6.5 to 8.5	6,5 to 8,0
Total Alkalinity	ppm of $CaCO_3$	< 300	100 to 300
Calcium Hardness	ppm of $CaCO_3$	< 300	100 to 300
Chlorides	ppm of Cl	< 100	< 250
Soluble Silica	ppm of SiO_2	< 150	< 150
Sulphates	ppm of SO_4	< 250	< 250
Total Iron	ppm of Fe	< 3.0	< 3.0
Conductivity	uS/cm	< 3,000	< 3,000

86

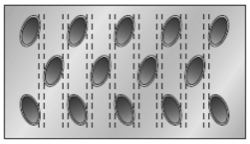


87

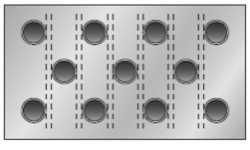
LATEST ADVANCES

88

Evaporative condenser Tube Arrangement



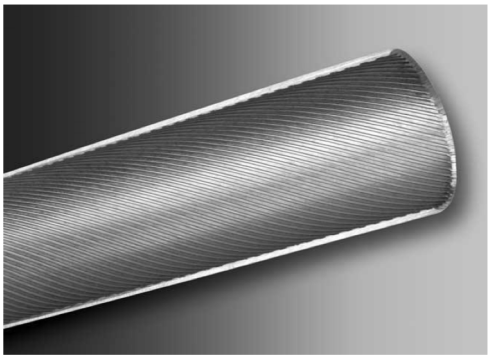
Thermal-Pak® Coil by EVAPCO



Round Tube Coil by Others

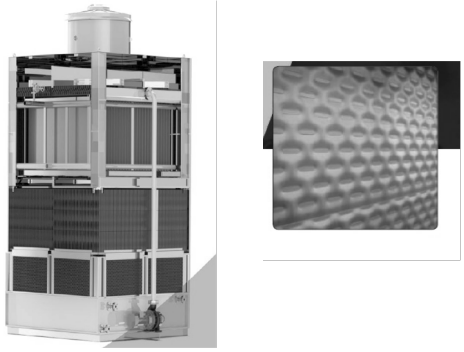
89

Latest Addition-Internally Enhanced evaporative condenser tube-EVAPCO



90

Evaporative condenser using plate type heat transfer medium



91

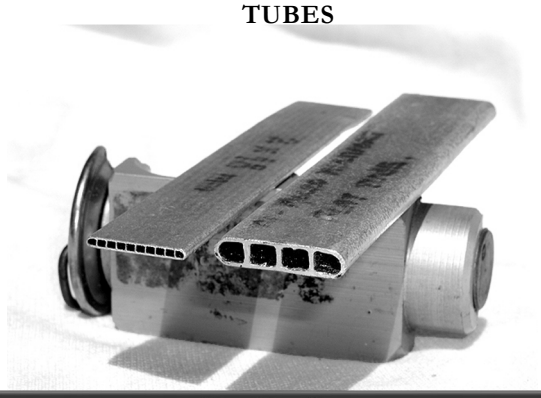
Plate and Frame Evaporative condenser

92

Guntner Evaporative condenser with EC fans& speed control. Fully automatic controller

93

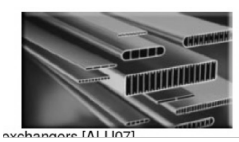
MICRO CHANNEL HEAT EXCHANGER TUBES



EXIT

94

Condensers have been designed with extruded micro-channel aluminium tubes. Those tubes are brazed with accordion louvered fins, leading to a significantly higher surface ratio of fins compared to stationary application. For equivalent air velocity, the heat exchange coefficients are higher of nearly a factor 2 compared to stationary condensers. For evaporators, design of plate fin heat exchangers has been the leading technology for the last twenty years, and due to the constraints of pressure associated with CO2, new designs for evaporators has been realized with the same technology as for condensers using micro-channel tubes organized in different circuitry.



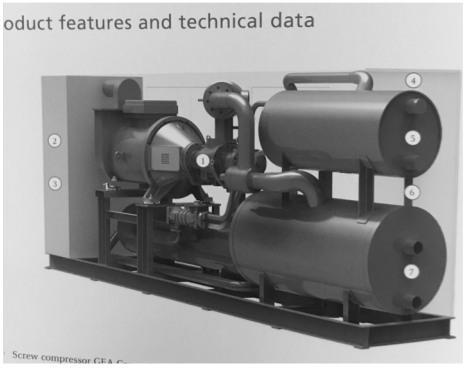
Photos 2. Micro-channel heat exchangers [ALU07].
The high compacity the lower cost of aluminum compared to copper has led to the beginning of the transfer from the automotive industry to the stationary industry

95

UNIT USING MICRO CHANNEL CONDENSER

96

SHELL & PLATE CONDENSER/CHILLER-SABROE AMMONIA PACKAGED CHILLER



97

3. EVAPORATORS

98

Three types of evaporator construction using these metals are in common use and are widely available from a number of manufacturers:

1. Hot Dip Galvanized Steel (Stl/Zn)

2. Stainless Steel Tubes with Aluminium Fins(SST/Al)

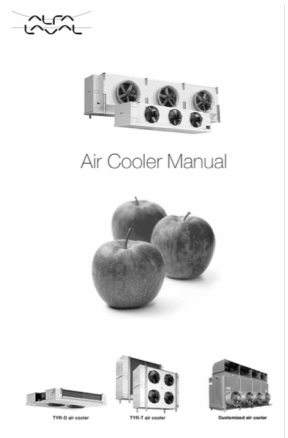
3. Aluminum Tubes with Aluminum Fins(Al/Al)

99

COMPARISON OF PRPPERTIES

Metal	Density, lbm/cu ft	Thermal Conductivity, Btu/sq ft h F ft	Specific Heat Capacity, Btu/lbm F	Tensile Strength, ksi
Carbon Steel	490	26	0.107	47
Zinc	445	65	0.094	21
304L Stainless Steel	501	9.4	0.120	70
3003 Aluminum	165	117	0.215	14

100



101

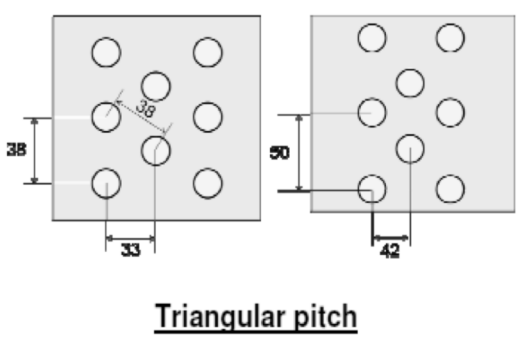
Key Points for selecting right size evaporator

1. **Flooded or Direct expansion**
2. **Pump circulation or Gravity Flooded preferred**
3. **Fin Pitch-Square or Triangular**
4. **Coil capacity selection-Based on TD1 or MTD**
5. **Air cooler total surface area or coil internal volume/length of coil without headers?**
6. **Air Quantity-Based on capacity or size and shape of room**
7. **Air Flow Direction-Blow Through or Draw Through**
8. **Material of Construction**
9. **Tube diameter/fin thickness/Fin Pitch**
10. **Coil face velocity at the air outlet**
11. **External static pressure available**
12. **No of rows deep more or coil face area more ?-inlet/out connection sizes**
13. **Defrost system-Hot gas/water/electrical heaters/reverse cycle or on/off**

102

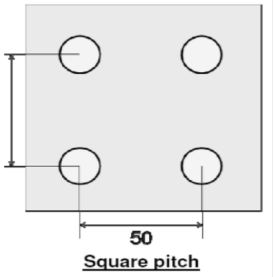
- **TRIANGULAR PITCH OR SQUARE PITCH ?-**
- **WHICH IS BETTER**

103



Triangular pitch

104



Square pitch

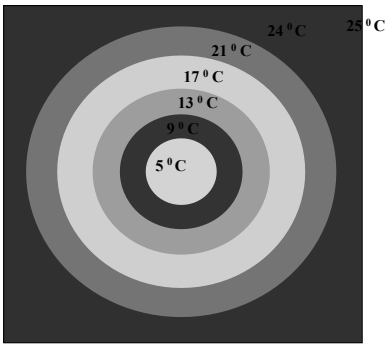
Advantages-

1. **Lower defrost Build up**
2. **Easy and quicker defrost**
3. **Lower Air resistance**
4. **Lower motor power**

Disadvantages-

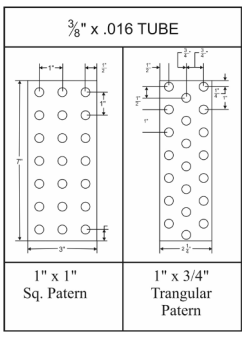
1. **Lower air side heat Transfer coefficient**
2. **Higher fin Temperature**
3. **Larger Air cooler compared to Triangular fin pitch air cooler**
4. **More expensive**

105



CROSS SECTION OF FIN & TUBE

106



1. **Square Pattern: 21 Tubes**
2. **Triangular Pattern-21 Tubes**
3. **Square Pattern-Fin area to Tube area ratio more**
4. **External surface Area more than Triangular Pitch, although tube area and volume same.**
5. **Surface area is not as effective as tube area**
6. **Triangular Pitch more compact-2.25" v/s 3"**

107

TD1
=Air on Temp.(Room Temp.)-Saturated Evaporating temp. at coil outlet

Application		$TD1=T_{air,in}-T_{refrig.}$
Positive temperature above freezing	High Humidity	2.2 to 4.4 deg. C
Positive Temperature	Low Humidity	5 deg. C(Preferred)
Negative temperature storage	-	5.5 deg. C to 6 deg. C

Ref: Stocker-Industrial Refrigeration-Page 207

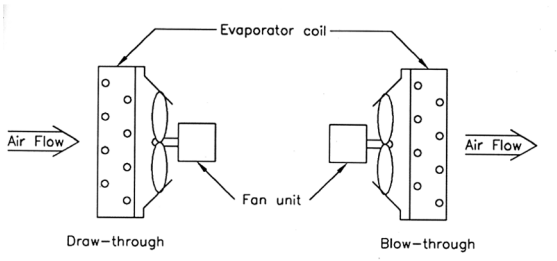
108

- **AIR FLOW DIRECTION**
- **DRAW THROUGH OR BLOW THROUGH**

109

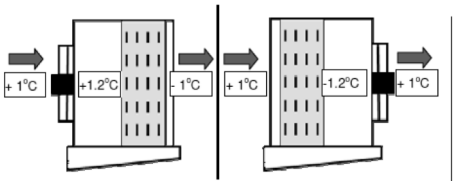
- **Q= U * A * LMTD**
- **TD1 is method is based on the difference between the air temperature entering the evaporator coil (room Temperature)and the corresponding temperature of the saturated suction pressure of the refrigerant measured at the outlet of the evaporator.**
- **-Selection by TD1 gives adequate and bigger air cooler compared to TM and hence should always be used.**
- **High humidity requirements will require coils with large surface areas and must be run at low TD's.**
- **Low humidity requirements will require coils with smaller surface areas and greater TD's.**

110



Draw through or blow through evaporator – fan configurations

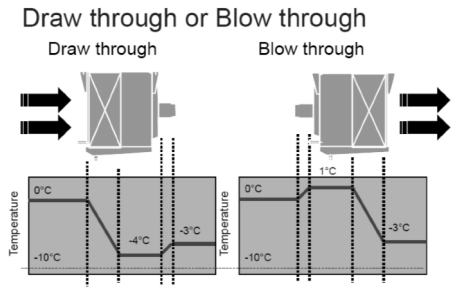
111



Blow through Draw through

Now, we assume a similar coil surface area of 284 m^2 for both the above fan executions. Due to higher Log ΔT across the coil in the ***blow through*** execution, we get a ***higher cooler capacity than draw through*** type for the same air flow.

112



LMTD=10-4/loge10/4=7.83 LMTD-11-7/Loge11/7=8.85

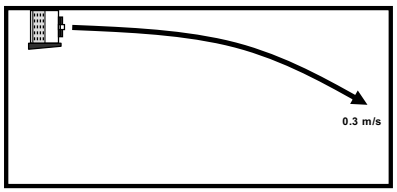
For same area of air coolers Blow through gives more capacity,

Q='U' x A x LMTD

BLOW THROUGH GIVES MORE CAPACITY

113

How is Air Throw defined

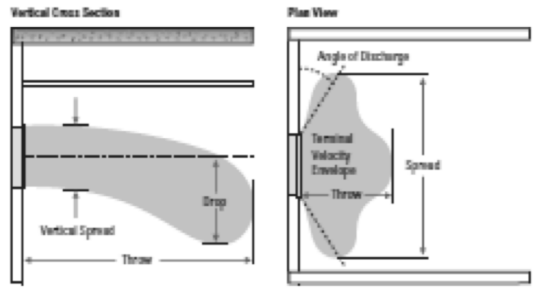


Most sources recommend a theoretical air speed of 0.3 m/s at the end of the room. This is pure theory, however, because any airflow of less than 0.5 m/s is dispersed and becomes impractical to measure.

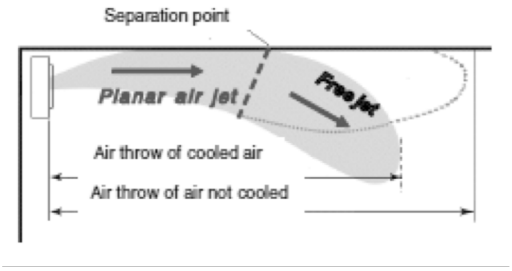
Slide 114

114

AIR THROW & AIR SPREAD



115



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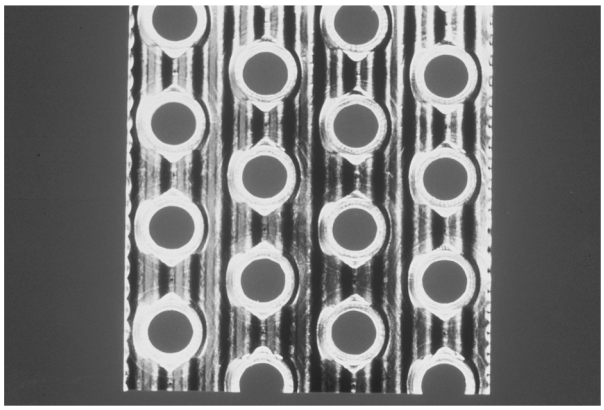

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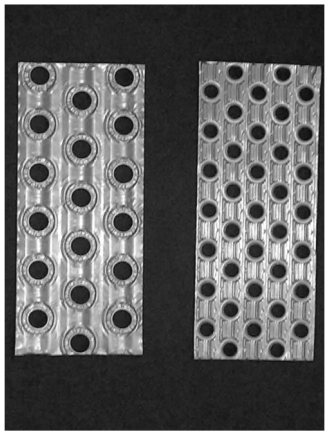

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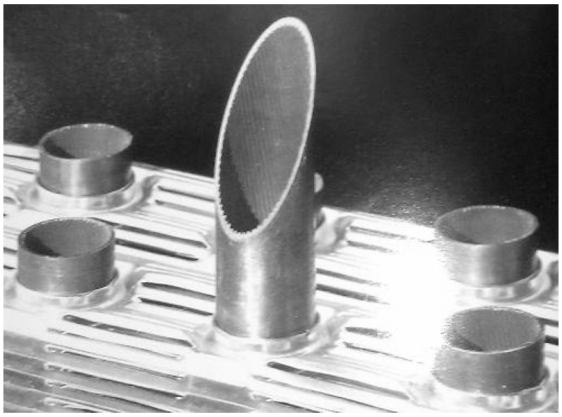
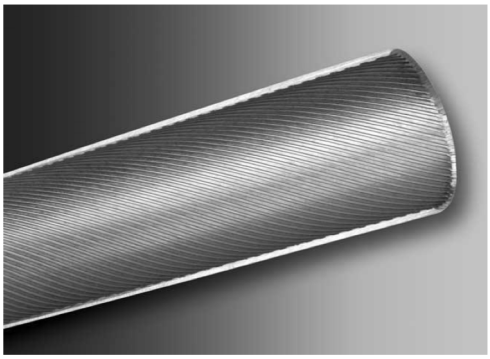


119

Latest Addition-Internally Enhanced evaporator Tube



120

A recent development in recirculated ammonia applications is the use of internal surface enhancement of stainless steel evaporator tubes as shown in earlier slide. Such enhancement allows liquid ammonia to settle into depressions in the internal surface and migrate via helical grooves around the inner periphery of the tube.

The migration occurs at a significantly lower velocity than a smooth tube and minimizes the performance differences between a top feed and a bottom feed coils.

The improved wetting achieves greater design performance at lower overfeed rates.
Laboratory testing has shown that the optimum overfeed rate for a 5/8" diameter internally enhanced tube is **1.2:1 and for 1 in**. diameter internally enhanced tube is **1.8:1.**
This is significantly lower than typical accepted industry rates discussed earlier.

121

Old – Bunker System

122

Coil Arrangement - Bunker

123

COLD STORAGE AIR COOLERS

124

New Cold Storage With Air Units

125

Aluminum Coolers

126

127

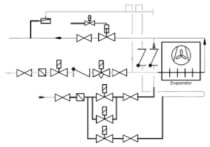
Air cooler with a flap which closes during defrosting

128

HOT GAS DEFROST WITH SEPARATE TAY CIRCUIT

Danfoss

Separate hot gas defrost line for defrost pans



Having a separate valve station for the defrost pan:

- Reduces the energy consumption since a smaller solenoid valve is necessary to heat the pan during the length of the defrost sequence
- Main hot gas solenoid valve will only be active for 10 minutes reducing the amount of heat added to the refrigerated space.

Danfoss Automatic Controls September 2013 | 5

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Direct Expansion Evaporator-(DX)

130

CO2 AIR COOLERS-ROXTAair

131

GAS COOLERS-CO_2

Capacities.

Qo_{min} 31 kW at 25 db(A) in 10 m

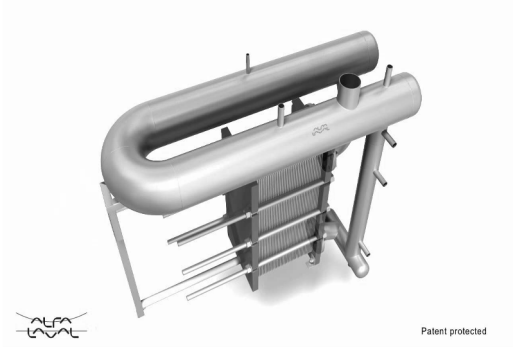
Qo_{max} 230 kW at 40 db(A) in 10 m

132

SURGE DRUM ON FLOODED AMMONIA CHILLER

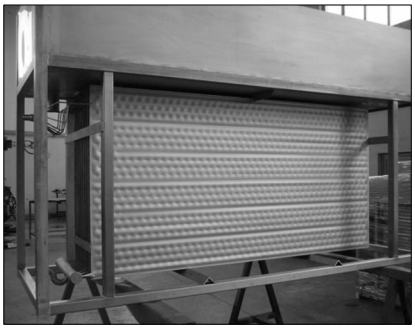
133

ALFA LAVAL PHE WITH "U" TURN ACCUMULATOR



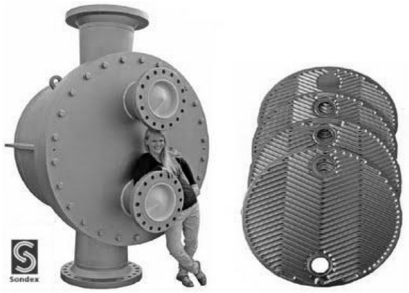
134

FALLING FILM COOLER



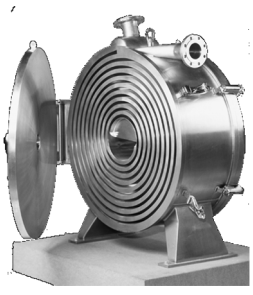
135

SHELL & PLATE HEAT EXCHANGER



136

SPIRAL HEAT EXCHANGERS



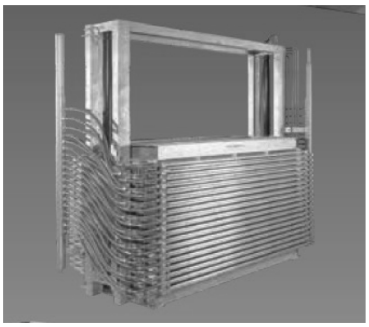
- A fully welded heat exchanger for tough process duties

137

AMMONIA PLATE FREEZER

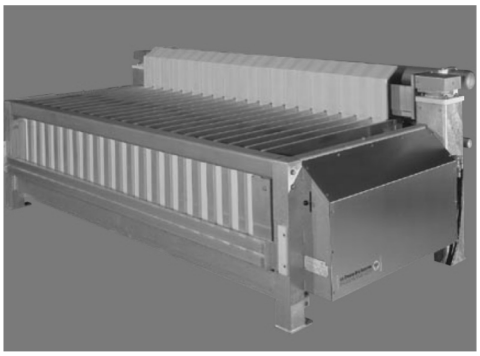
138

DSI DENMARK CO_2 PLATE FREEZER



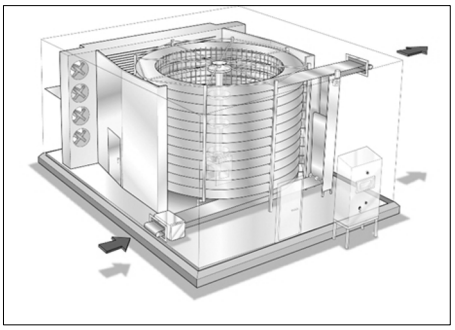
139

Vertical plates Freezer



140

SPIRAL FREEZER



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THANK YOU
Questions?

Ramesh Paranjpey
Fellow Life member ASHRAE
ramesh.paranjpey@gmail.com
Cell No. 9822398220
Web: http://ramesh-paranjpey.com

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CONTROLS

Controls are one of the most critical elements for improving efficiency/reliability/Safety of any Refrigeration system.

A good control system can make a marginally designed installation operate satisfactorily while a poor control system cannot make the best designed installation operate satisfactorily.

143

Automatic Liquid Flow Regulating Valve

26th June 2020

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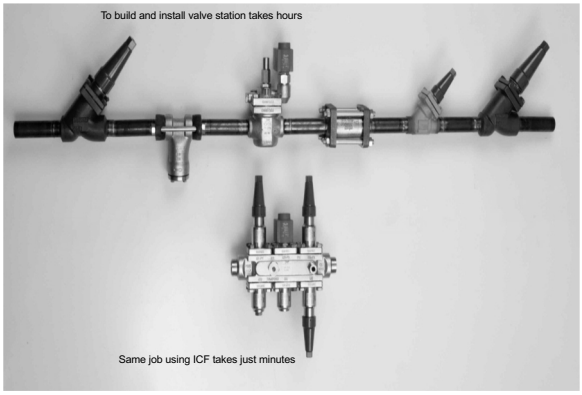
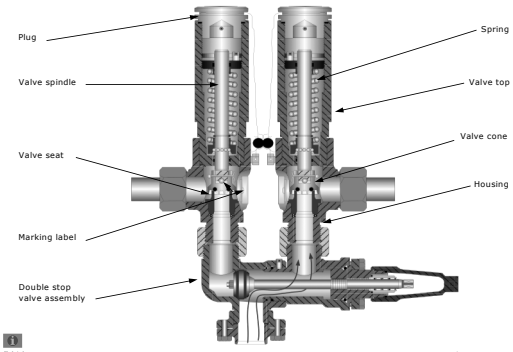
Ammonia liquid Feed module



145

Double Stop Valve - type DSV and Double Safety Valve - type SFV



26th June 2020

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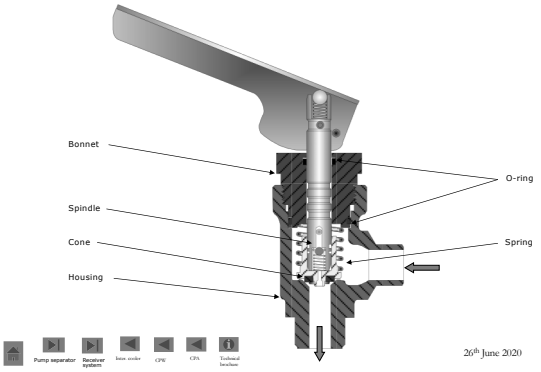
Quick closing oil drain valve – type QDV 15



26th June 2020

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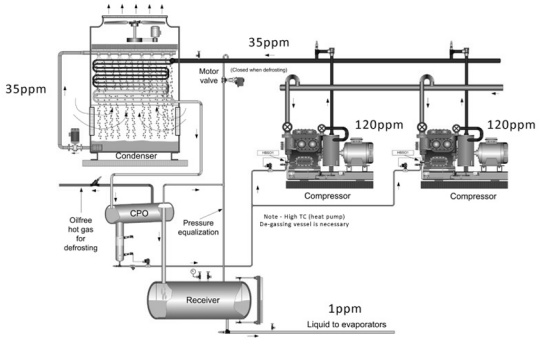
Oil Management System



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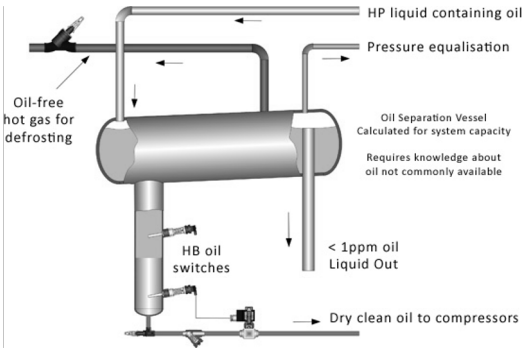
Oil Recovery System-The first installation of this vessel saved over 237 litres of oil in the first year, plus countless man hours in maintenance and draining of waste oil.



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