FUNDAMENTALS OF REFRIGEATION & P-H DIAGRAM STUDY

- Fellow Life member ASHRAE
- Fellow member -ISHRAE
- Cell No.+9120-9822398220
- Mail: Ramesh.paranjpey@gmail.com
- Web: http://Ramesh-paranjpey.com

1

REFRIGERATION AS A UTILITY

IT'S DIFFERENT

2

2

FIELDS OF UTILIZATION

- Mobile Air-conditioning
- Office & Residential Comfort Cooling
- Process Air Conditioning
- Preservation of Fruits & Vegetables
- Meat, Fish, Poultry processing , Freezing, Storage
- Deep Freezers
- Dairy Products, ice cream, Ice plants
- Medical and Pharmaceuticals
- Industrial –Chemical/Dyestuff
- Software, Entertainment
- Laboratories, Defense and many more

3

3

THERE ARE THREE RULES TO LEARN REFRIGERATION

Rule-1. Learn the basics

Rule 2. Learn the basics

Rule 3. Learn the basics

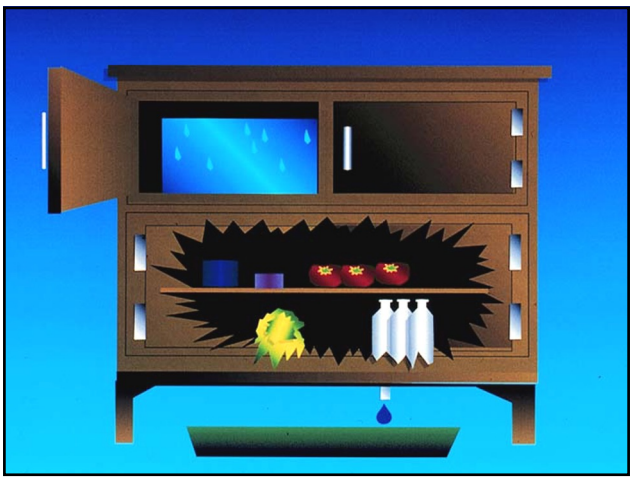
4



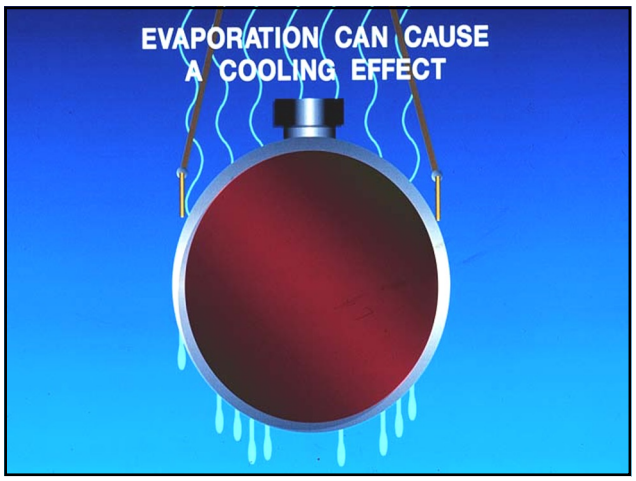
5


1918
Colored by
Dana Keller

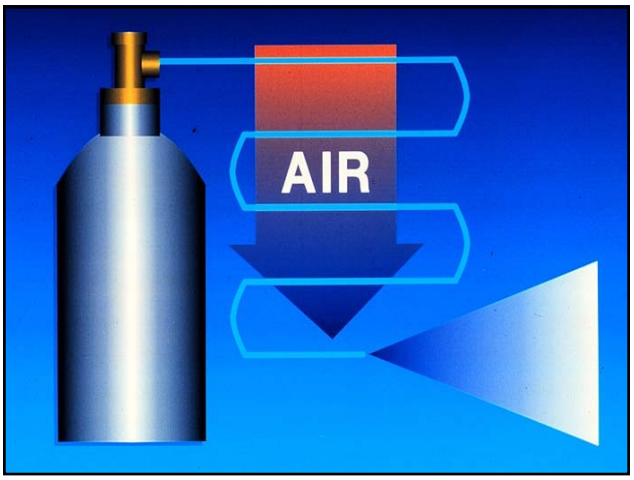
6



7


EVAPORATION CAN CAUSE
A COOLING EFFECT

8


AIR

9


BTU
British Thermal Unit
One BTU Raises One Pound of Water One Degree Fahrenheit

10

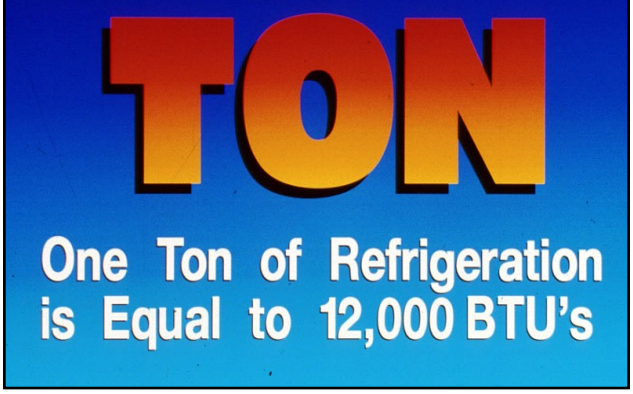

HEAT (144 BTU/LB.)
1 POUND ICE 32 F
LATENT HEAT OF FUSION (WATER) =
1 POUND x 144 BTU/LB. =144 BTU

11


1 TON ICE AT 32°
WHEN MELTED IN 24 HOUR. = 1 TON REFRIGERATION
(2000 x 144) = 288,000 BTU/DAY
(288,000 ÷ 24 HR.) = 12,000 BTU/HR.

12

1 TON of REFRIGERATION=3.517kW



13

Ton Of Refrigeration

1 Ton= 12000 Btu/hr
1 Ton = 3024 kcal/hr
1 Ton =3.517kW

14

OBJECTIVE

With the help of basic understanding of charts--it helps in

1.Designing the right equipment
2. Selecting correct specifications
3. Most energy efficient Selection
4. Consuming minimum energy and at optimum cost
5. Ease of maintenance & reduced maintenance cost

15

IMPORTANT CYCLES & DIAGRAMS

1. Carnot Cycle
2. Rankine Cycle
3. Pressure-Enthalpy diagram-King of Refrigeration- (P-H) Diagram
4. Temperature –Entropy Diagram-(T-S)diagram
5. Temperature-Enthalpy Diagram-(T-H) diagram
6. Each has some unique features which helps in understanding some basic concepts more clearly

16

WHAT IS REFRIGERATION?

Refrigeration is the process of cooling by removing/(transferring) heat from a space or substance to a lower level and maintain its temperature below the surrounding environment

17



18

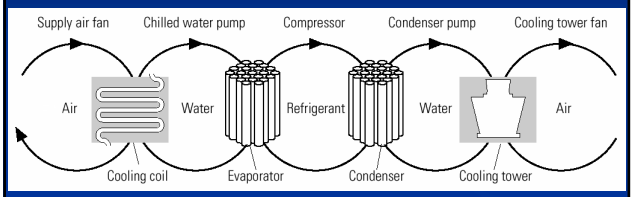
REFRIGERATION IS COOLING BY TRANSFERRING HEAT.

In reality we cannot remove heat: we can only move/transfer heat from a place where it is not wanted to a place where it is less objectionable.

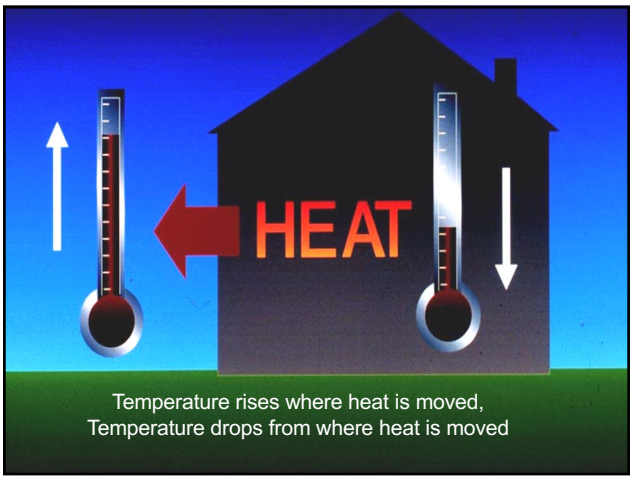
Energy cannot be created or it cannot be destroyed, we can only transfer it from one form to the other

19

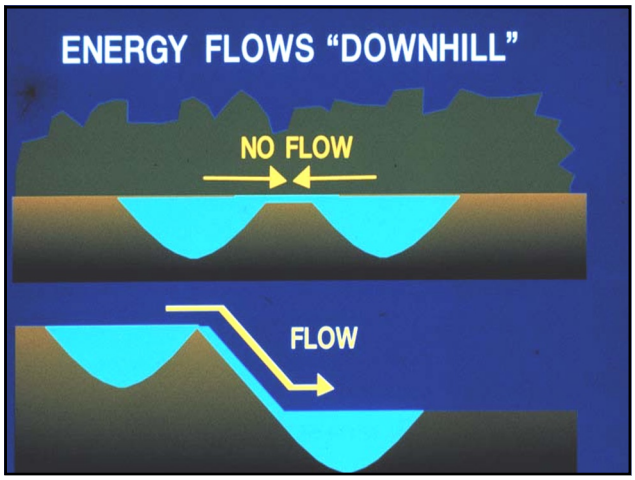
HEAT TRANSFER LOOPS IN AIR CONDITIONING & REFRIGERATION SYSTEMS



20



21



22

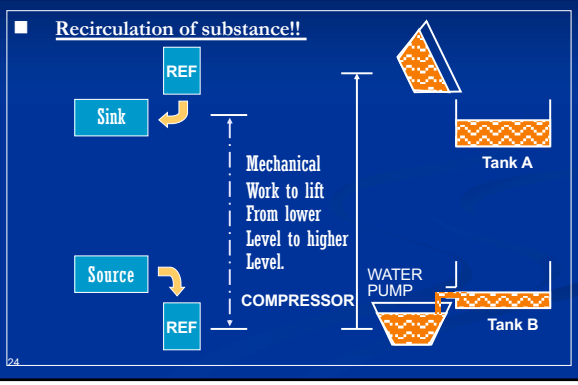
HEAT IS THE LOWEST FORM OF ENERGY

As per the law of conservation of energy, all energies finally degenerate in heat.

1. When mechanical work is done heat is generated.
2. chemical reactions generate exothermic heat.
3. electrical energy also generates heat.

23

VAPOUR COMPRESSION CYCLE



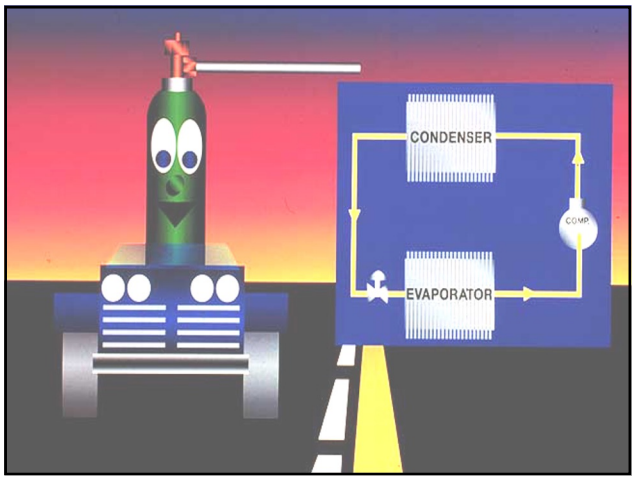
24

WHY REFRIGERANT IS NEEDED?

Since the refrigeration equipment, once installed is immovable, a medium is required to transfer the heat.

Refrigerant is the fluid which picks up the heat by evaporating at a lower temperature and pressure and rejects heat by condensing at a higher temperature and pressure.

25



26

LATENT HEAT OF REFRIGERANT- MOST IMPORTANT

Out of all properties of various refrigerants, the most important property is the **LATENT HEAT** of refrigerant.

When refrigerant evaporates it absorbs heat from surrounding medium

Hence refrigerant which has highest latent heat per kg of circulation will absorb maximum heat.

Amongst all refrigerants , Ammonia has the maximum latent heat.

27

IT IS THE **LATENT HEAT** WHICH MAKES REFRIGERATION WORK

Water has a large specific heat capacity (4.19 kJ/kg °C) The latent heat of vaporization of water is 2260 kJ/kg. Latent heat is **540** times more

For Ammonia refrigerant ,at ambient temperature specific heat it is 2.2kJ/kg.K and latent heat is 1180kJ/kg.K-**536.37** times more

28

LATENT HEAT OF VARIOUS REFRIGERANTS

Refrigerant	Boiling Point -0C At Atmospheric pressure	Latent heat at Boiling Point-kJ/kg
Ammonia - R717	-33.34	1370
R-22	-40.8	20.207
R-134a	-26.074	216.97
R 404A	-46.5	200.1
R410A	-48.5	272.97
R32	-51.7	382.0
CO2-R744	-78.4	320.5
R 507	-47.1	200.5
R407C	-43.6	173.0
R290-Porpane	-42.1	18.669
R600A-Isobutane	-11.7	21.174
R600-Butane	-0.5	22.425
R1150-Ethylene	-103.7	13.475
R1270-Propylene	-47.7	18.448
R1234yf	-30.0	180.25
R1234ze	9.8	162.9

29

CHANGING REFRIGERANT CHANGES CAPACITY

Refrigerant	Capacity kcal / hr - ton	Power Consumption kW	kW/Ton
AMMONIA	**118.8**	76.7	0.645
R12	**60.84**	53.0	0.871
R22	**101.32**	82.0	0.809
R502	**98.97**	105.3	1.0639

30

30

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

Ref: IIAR –Condenser magazine Nov 2008

31

31

CARNOT CYCLE

REVERSE CARNOT CYCLE IS REFRIGERATION

The normal Carnot cycle uses heat energy and delivers mechanical work

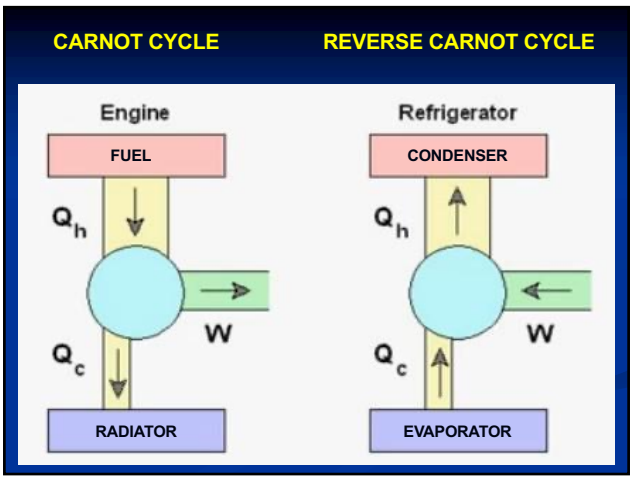
An engine operating in this cycle is called a Carnot engine.

The **Carnot cycle** is a theoretical ideal thermodynamic cycle proposed by French physicist Sadi Carnot in 1824 The Carnot heat-engine cycle described is a totally reversible cycle. That is all the processes that compose it can be reversed.

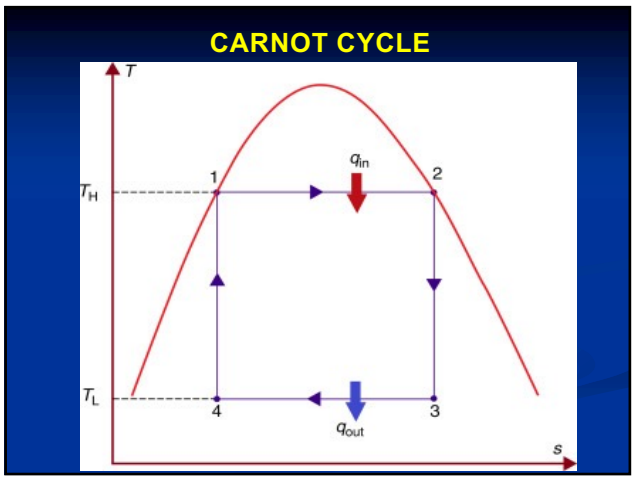
When they are reversed. it becomes the **Carnot refrigeration cycle**.

The cycle remains exactly the same except that the directions of heat and work interactions are reversed. **Heat is absorbed from the low-temperature reservoir, and heat is rejected to a high-temperature reservoir,**
And to achieve this, a work input is required.

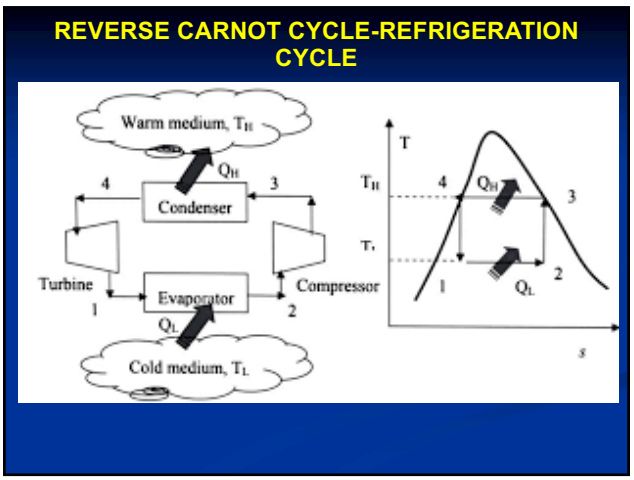
32


CARNOT CYCLE
REVERSE CARNOT CYCLE
Engine
Refrigerator
FUEL
CONDENSER
Qh
Qc
W
RADIATOR
EVAPORATOR

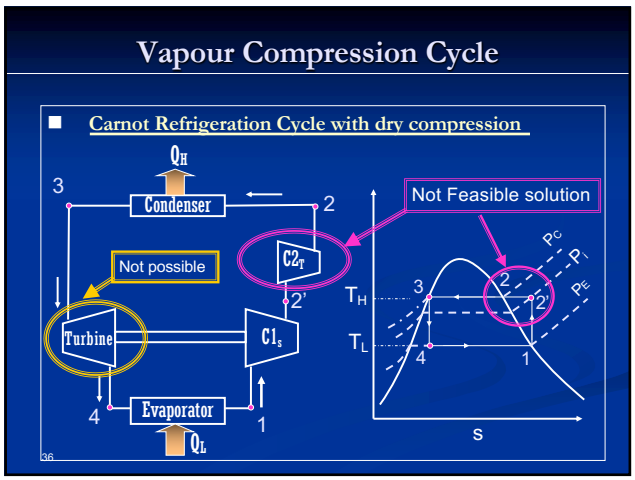
33


CARNOT CYCLE
T
TH
TL
qin
qout
1
2
3
4
s

34


REVERSE CARNOT CYCLE-REFRIGERATION CYCLE
Warm medium, TH
Cold medium, TL
Condenser
Evaporator
Turbine
Compressor
QH
QL
T
TH
TL
s

35

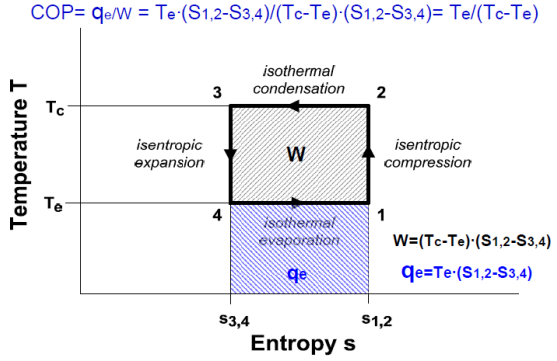

Vapour Compression Cycle
Carnot Refrigeration Cycle with dry compression
QH
QL
Condenser
Evaporator
Turbine
Not possible
Not Feasible solution
C2T
C1s
TH
TL
s

36

Calculation of COP

the ideal Carnot (Refrigeration) Cycle

COP= q_e/w = $T_e \cdot (S_{1,2}-S_{3,4})/(T_c-T_e) \cdot (S_{1,2}-S_{3,4}) = T_e/(T_c-T_e)$



37

System Efficiency: COP and "Carnot Efficiency"

Carnot COP_C is the "benchmark" for cold vapour compression cycles.

We learnt: $$COP_C = \frac{q_e}{w} = \frac{\dot{Q}_e}{P} = \frac{T_e}{T_c - T_e}$$

Carnot COP_C is a function of Tc and Te only

38

EXAMPLE

Let us assume condensing temperature as 35^{0}C and evaporating temperature as 0^{0}C

The Carnot efficiency would be (0+273/ (35+273) -(0+273)

=273/35=**7.8 COP**

Let us assume that a real refrigeration system working at 0 ^{0}C evaporating temperature and 35^{0}C condensing temperature has a refrigeration capacity of 100kW and compressor consumes 21kW power

The COP, efficiency would be output/input in the same units.

=100/21=**4.76 COP**

Thus, actual COP is 4.76/7.8= **61%** of theoretical Carnot COP

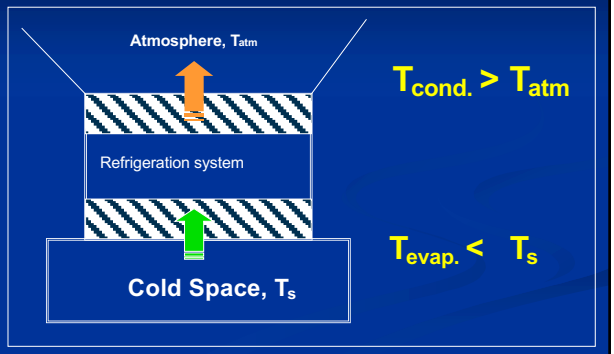
39

CARNOT REFRIGERATION CYCLE

1. Model of perfection for refrigeration cycle.
2. Most efficient cycle between temperature levels and is purely a Theoretical concept.
3. Consists of two isothermal processes and two isentropic processes.
4. Efficiency is independent of fluid properties.
5. **All real cycles are compared with the Carnot cycle.**
6. **In actual practice Carnot systems do not exist**

40

ACTUAL REFRIGERATION SYSTEM

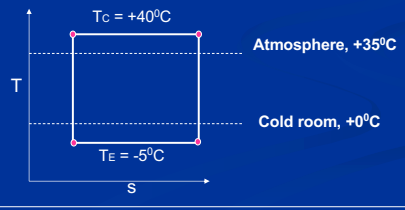


41

VAPOUR COMPRESSION CYCLE

Condition to achive high COP near the Carnot Cycle

- Maintain T_E as high as possible.
- Maintain T_C as low as possible.



42

42

LOWER TEMPERATURE MEANS MORE ENERGY

Application	Energy Consumption	Temp.
An Air conditioning plant would consume	(0.2431 W/unit output)	+10⁰C
Fruit & vegetable pre cooling would consume	(0.2635 W/W)	+5⁰C
Refrigerators	(0.3125 W/W)	0⁰C
Dairy & Milk products	(0.3866 W/W)	-5⁰C
Meat storage	(0.4348 W/W)	-15⁰C
Freezing plants	(0.6666 W/W)/	-30⁰C
ICF cream freezers	(0.8333 W/W)	-40⁰C

43

43

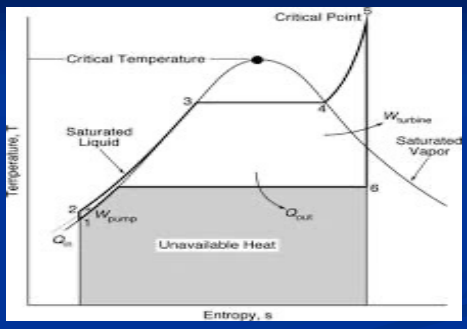
SCOTTISH ENGINEER WILLIAM J.M. RANKINE DEVELOPED THE RANKINE CYCLE IN 1859.

Since Carnot cycle is only theoretical, a more practical and realistic Rankin cycle is introduced consisting of two isobaric processes, one isentropic compression, and one adiabatic expansion.

The Rankin cycle incorporates some inevitable irreversibility's and COP of Rankin cycle is therefore lower than the COP of Carnot cycle.

44

RANKINE CYCLE

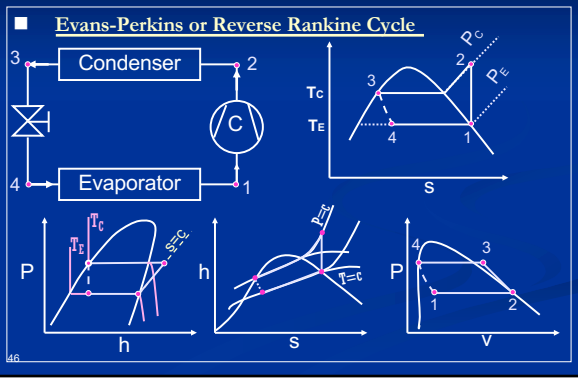


6-7- Isentropic compression
3-2- Adiabatic expansion

5-4-isobaric condensation
2-6-isobaric evaporation

45

Vapour Compression Cycle



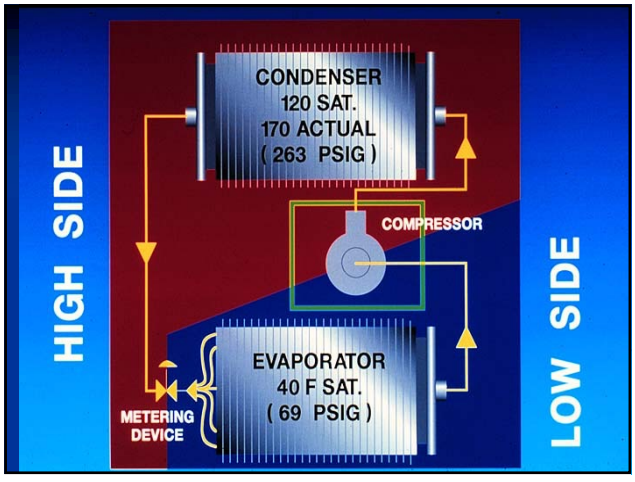
45

46

BASIC COMPONENTS OF A REFRIGERATION SYSTEM

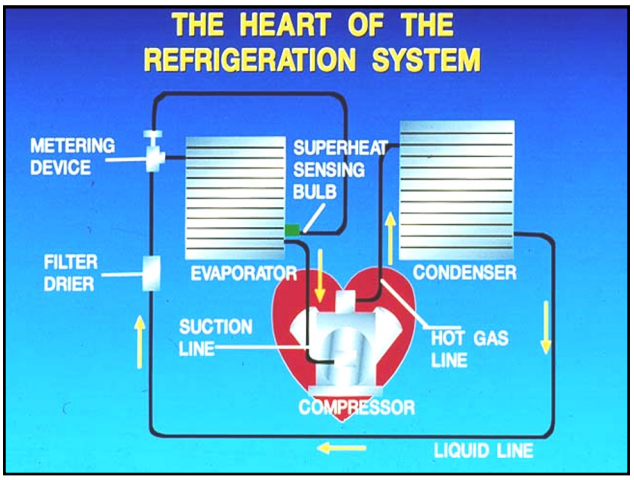
- EVAPORATOR
- CONDENSER
- COMPRESSOR
- LIQUID METERING DEVICE

47

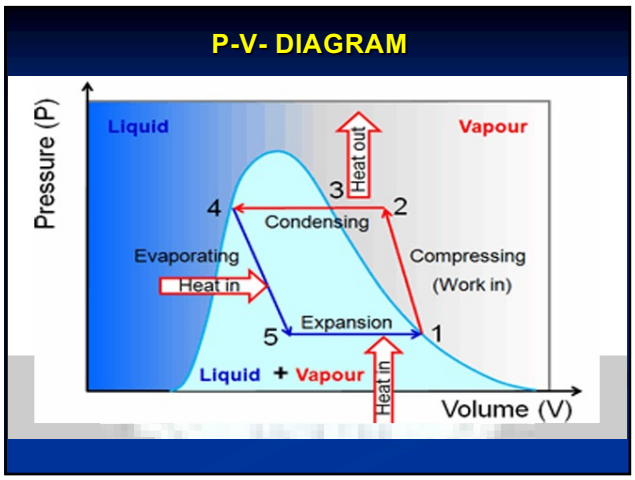


47

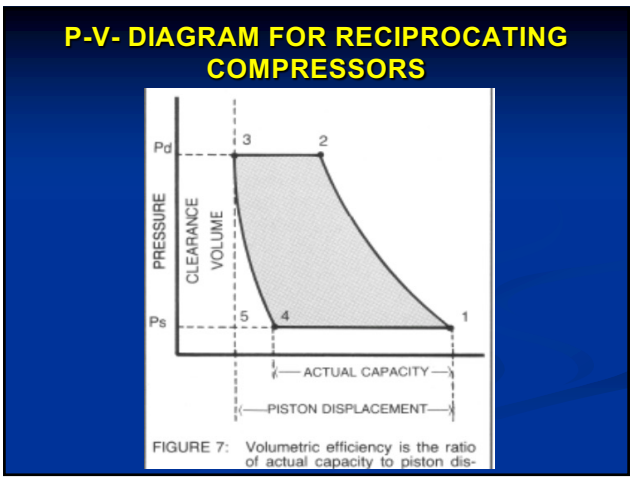
48


THE HEART OF THE REFRIGERATION SYSTEM
METERING DEVICE
SUPERHEAT SENSING BULB
FILTER DRIER
EVAPORATOR
CONDENSER
SUCTION LINE
HOT GAS LINE
COMPRESSOR
LIQUID LINE

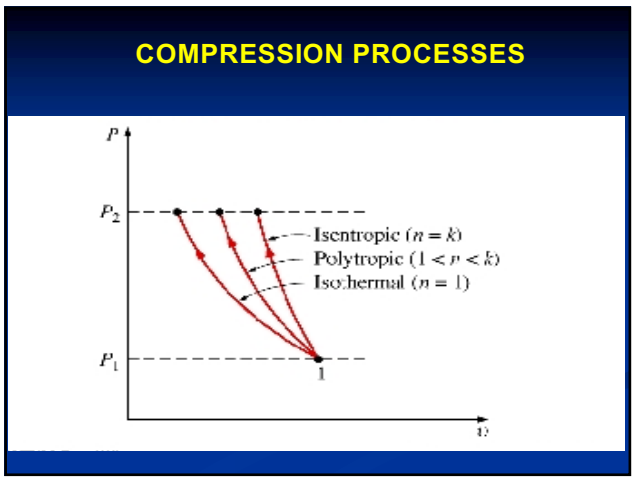
49


P-V- DIAGRAM
Pressure (P)
Liquid
Vapour
Heat out
3
2
4
Condensing
Evaporating
Heat in
Compressing
(Work in)
5
Expansion
1
Liquid + Vapour
Heat in
Volume (V)

50


P-V- DIAGRAM FOR RECIPROCATING COMPRESSORS
Pd
Ps
PRESSURE
CLEARANCE VOLUME
3
2
5
4
1
ACTUAL CAPACITY
PISTON DISPLACEMENT
FIGURE 7: Volumetric efficiency is the ratio of actual capacity to piston dis-

51


COMPRESSION PROCESSES
P
P2
P1
Isentropic (n = k)
Polytropic (1 < n < k)
Isothermal (n = 1)
1
v

52

ISENTROPIC PROCESS

An Isentropic Process is an idealized thermodynamic process that is both adiabatic and reversible. It implies that there is no transfer of heat or matter and no change in entropy.

In real-world applications, the isentropic process is an approximation or idealization because total isolation of a system is not possible. However, the concept is instrumental in simplifying the analysis and calculation of various thermodynamic processes.

an isentropic process occurs when the entropy of the system remains constant. This translates to no energy being lost as heat, and no work is done externally.

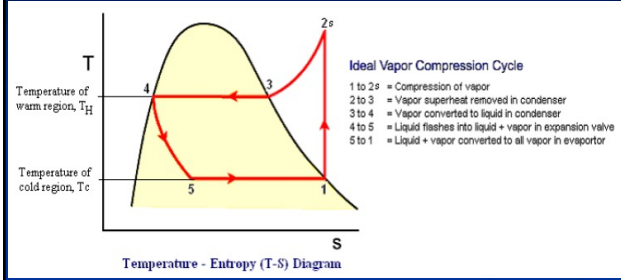
$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} \quad \text{Equation 1}$$

53

TEMPERATURE –ENTROPY DIAGRAM

T-S DIAGRAM

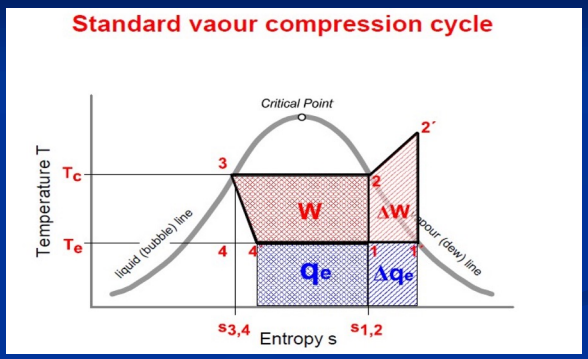
54



1. SHOWS MORE CLEARLY ISENTROPIC COMPRESSION(1-2)
2. SHOWS MORE CLEARLY IRREVERSIBLE EXPANSION (4-5)
3. SHOW MORE CLEARLY SUPERHEAT REMOVAL(2-3)

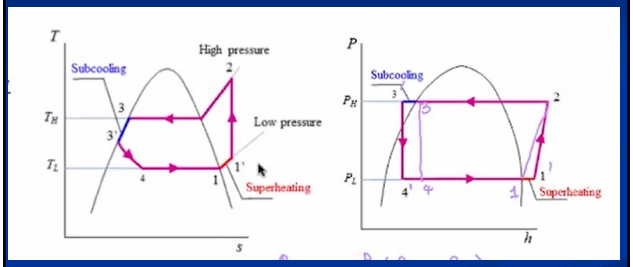
55

TEMPERATURE- ENTROPY DIAGRAM



56

T-S DIAGRAM WITH SUPERHEAT AND SUB-COOLING



57

Usefulness of Temperature Entropy diagram

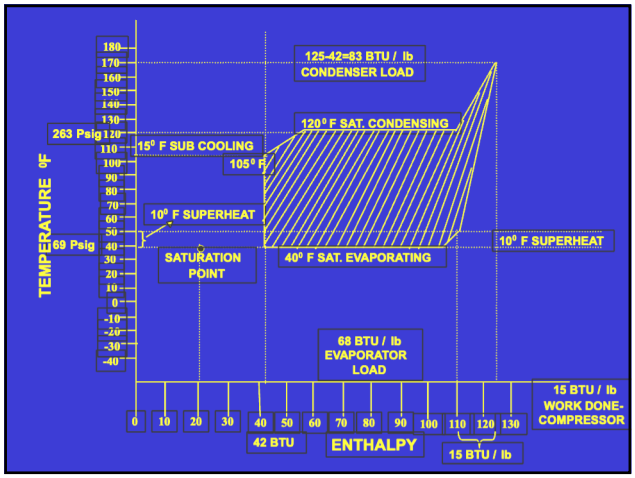
1. It shows more clearly the superheat horn
2. It show more clearly the subcooling Zone
3. It shows irreversibility in the expansion valve
4. It shows loss of capacity due to expansion device

58

TEMPERATURE-ENTHALPY DIAGRAM

T-H Diagram

59



60

USEFULNESS OF TEMPERATURE-ENTHALPY DIAGRAM

1. Shows superheating and sub-cooing process more clearly
2. Shows effect of sub cooling and superheating on enthalpy
3. Shows compression process with temperature rise during compression
4. Shows enthalpy remains constant during expansion-adiabatic process
5. Shows constant pressure and temperature during condensation and evaporation process

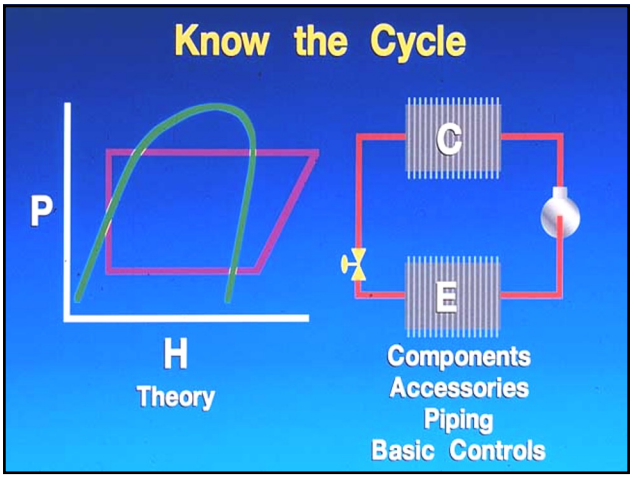
61

P – H DIAGRAMS CAN :

- Find Pressure That Matches Any Saturation Temperature
- Allows You to Find All Refrigerant Conditions
- Use One Diagram to Plot the Performance of All Components
- Show How Each Component Works and Effects Other Components of a System

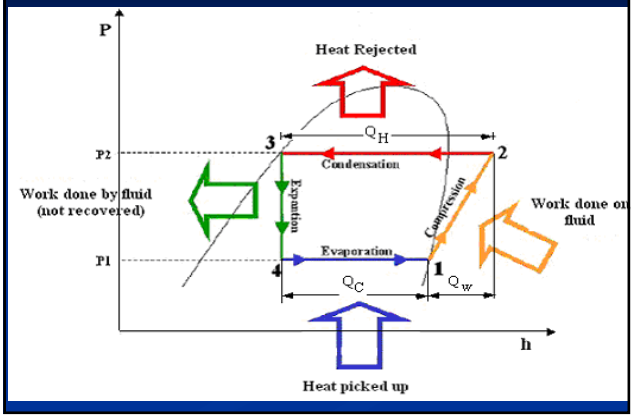
62

Know the Cycle

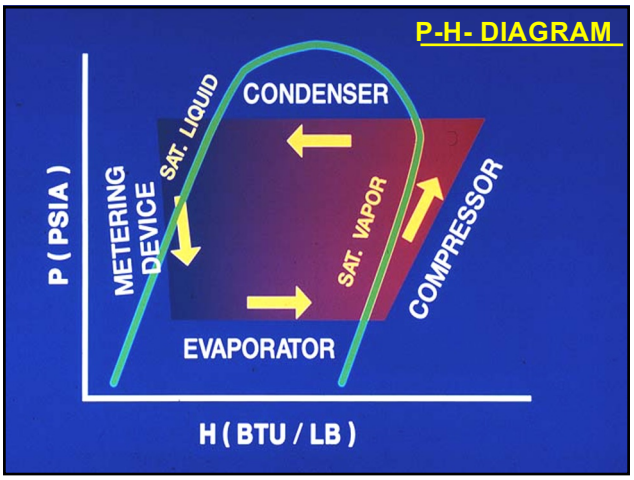


63

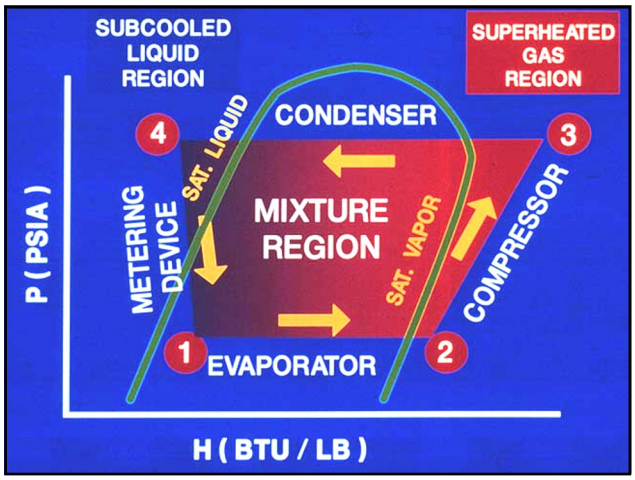
P-H DIAGRAM



64



65



66

Coefficient of Performance

COP

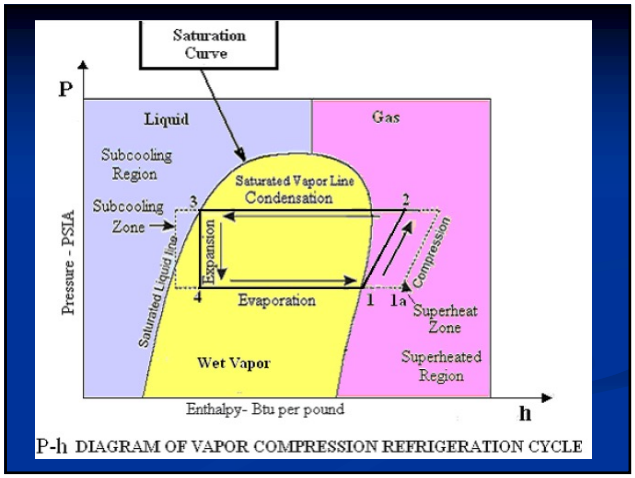
The COP is NOT an "efficiency" BUT an energy characteristic.

It describes:

$$COP = \frac{\text{what you get}}{\text{what you spend}} = \frac{\text{cooling(refrigeration)}}{\text{energy demand}}$$

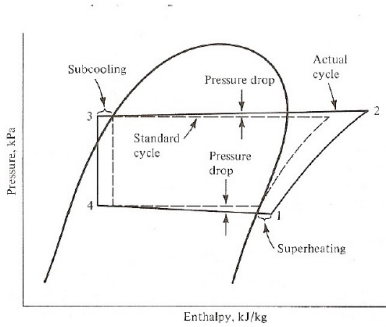
COP IS DIMENSIONLESS

67



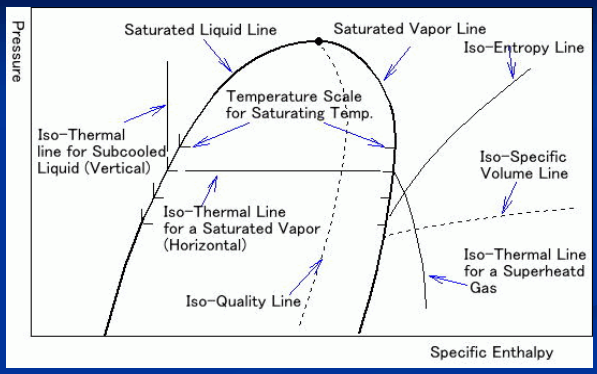
68

Actual vapor-compression cycle compared with standard cycle



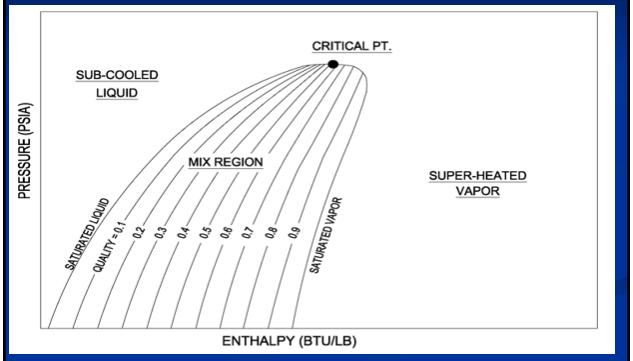
69

P-H DIAGRAM



70

P-H DIAGRAM-CRITICAL POINT



71

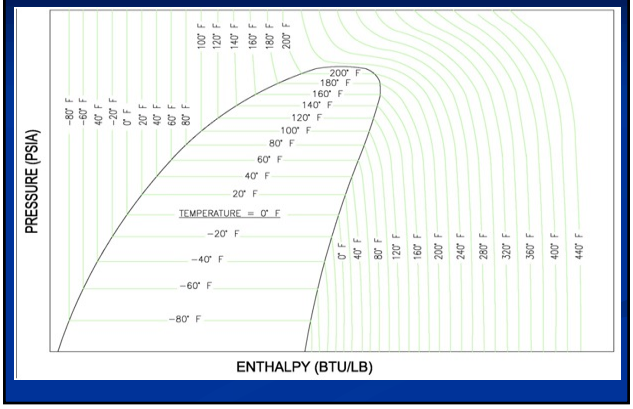
CRITICAL TEMPERATURE OF VARIOUS REFRIGERANTS

Refrigerant	Critical Temperature-^{0}C	Critical pressure -MPa
R717 -Ammonia	**132.25**	11.333
R134a	100.06	4.0593
R22	96.15	4.99
R1234yf	94.7	3.3822
R32	78.11	5.782
R404A	72.05	3.729
R410A	71.36	4.903
R744	30.98	7.377

1. At critical Point Liquid & vapour are indistinguishable
2. Operating near critical point makes cycle less efficient

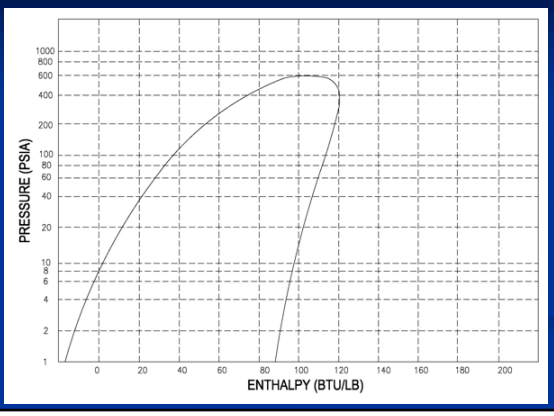
72

P-H DIAGRAM-CONSTASNT TEMPERATURE LINES



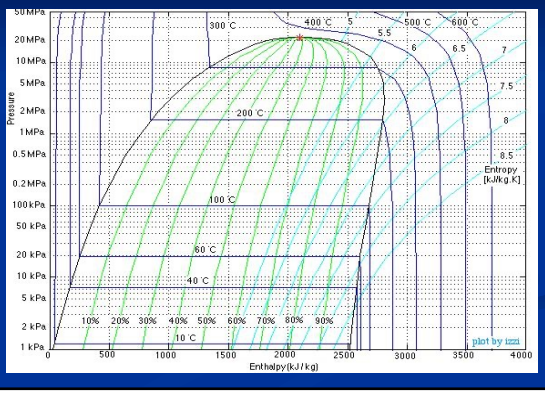
73

P-H DIAGRAM-CONSTANT ENTHALPY LINES



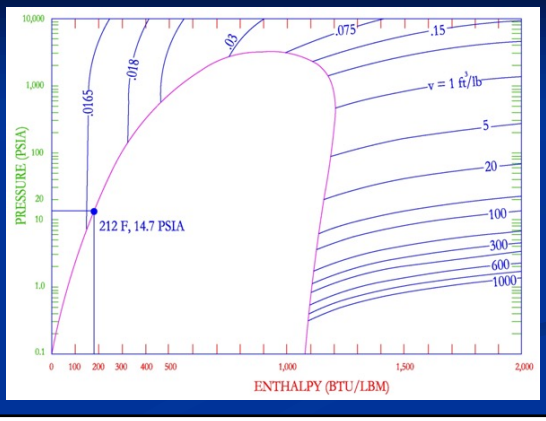
74

P-H DIAGRAM-CONSTANT ENTROPY LINES

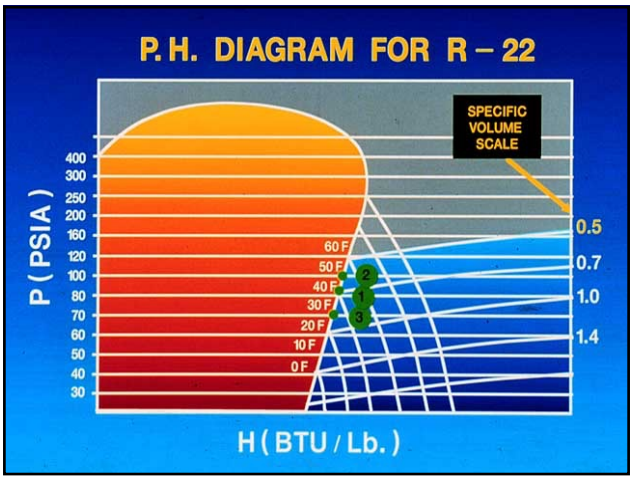


75

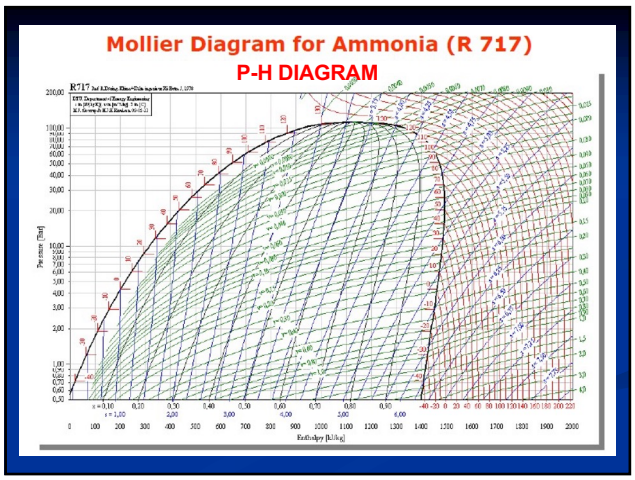
P-H DIAGRAM-CONSTANT SPECIFIC VOLUME LINES



76



77



78

COMPRESSION PROCESS-ADIABATIC PROCESS

P-H diagram shows constant entropy lines in the vapour region and we use these lines to follow compression process as we use constant entropy compression. The process is also called adiabatic compression.
The compression in compressor occurs very quickly. There is little time for significant heat transfer to take place between the refrigerant vapor and the surrounding environment or the compressor walls. In an ideal model, this heat transfer is assumed to be zero.

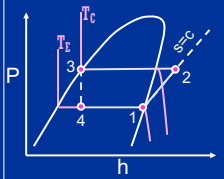
In isentropic process, the change in entropy (dS) is related to heat transfer (dQ) and entropy generated due to irreversibility is (I)

Th equation is dS=dQ/T +I
For adiabatic process dQ is zero as explained above
For reversible process I=0
Therefore, for reversible adiabatic process dS=0 indicating that the **entropy remains constant and hence it can be also called as isentropic process.**

79

Vapour Compression Cycle

- Formulae of VCRS



COMPRESSOR

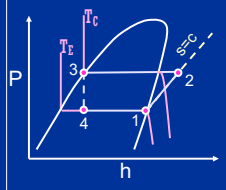
1. Compressor work,
$W_r = \dot{m}_r \times (h2 - h1)$

Units:
1 W = 1 J/s
1 kW = 1000 W = 1.341 hp
1 hp = 745.7 W
1 kWh = 1 kW × h

80

VAPOUR COMPRESSION CYCLE

- Formulae of VCRS



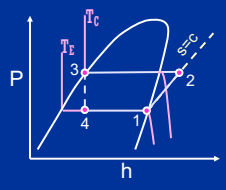
CONDENSER

1. Condenser capacity,
$Q_h = \dot{m}_r \times (h2 - h3)$

81

VAPOUR COMPRESSION CYCLE

- Formulae of VCRS



EXPANSION DEVICE

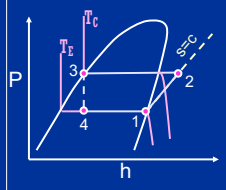
h3 = h4

NO HEAT TRANSFER

82

Vapour Compression Cycle

- Formulae of VCRS



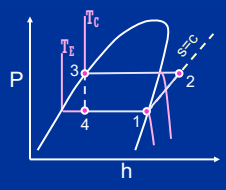
EVAPORATOR

1. Refrigeration capacity,
$Q_r = m_r \times (h1 - h4)$

83

Vapour Compression Cycle

- Formulae of VCRS



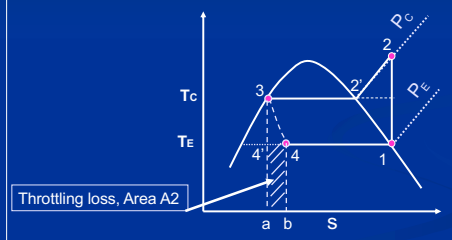
COEFFICIENT OF PERFORMANCE

$$COP = \frac{\dot{Q}_e}{\dot{W}_c} = \frac{(h1 - h4)}{(h2 - h1)}$$

84

VAPOUR COMPRESSION CYCLE

Comparison with Carnot Cycle



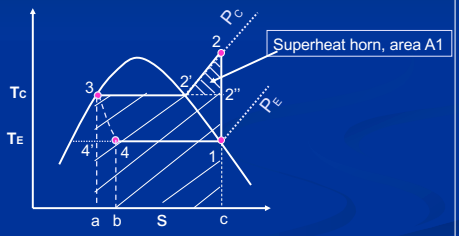
Throttling loss = area b-4-4'-a-b = area A2

85

85

VAPOUR COMPRESSION CYCLE

Comparison with Carnot Cycle



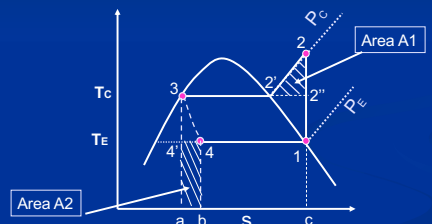
Increased heat rejection rate = superheat horn = area 2'-2"-2

86

86

VAPOUR COMPRESSION CYCLE

Comparison with Carnot Cycle



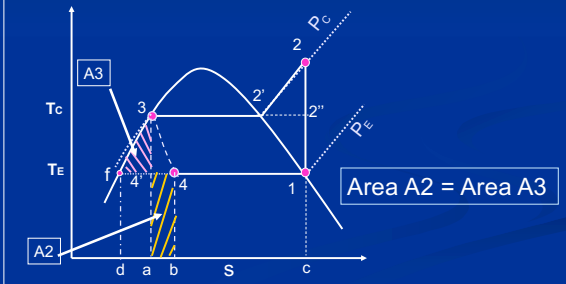
Increase in Net Work Output = area A1 + area A2

87

87

VAPOUR COMPRESSION CYCLE

Comparison with Carnot Cycle



88

88

VAPOUR COMPRESSION CYCLE

- Comparison with Carnot Cycle

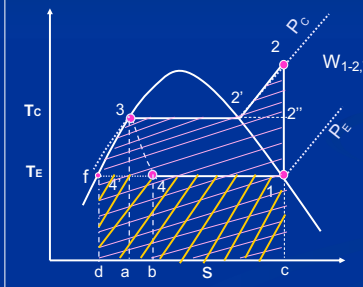
  - The losses due to superheat (area A1) and throttling (A2 ≅ A3) depends very much on the shape of the vapor dome (saturation liquid and vapour curves)
  - The shape of the saturation curves depends on the nature of the refrigerant.

89

89

VAPOUR COMPRESSION CYCLE

- Comparison with Carnot Cycle

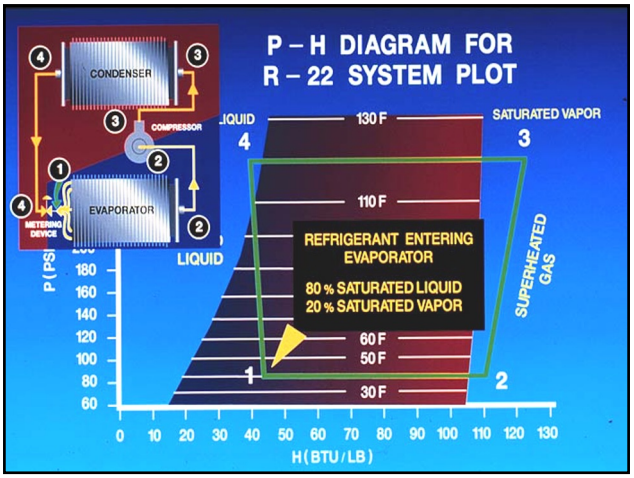


$W_{1\text{-}2,VCRS}$ = (h2-hf) – (h1-hf)

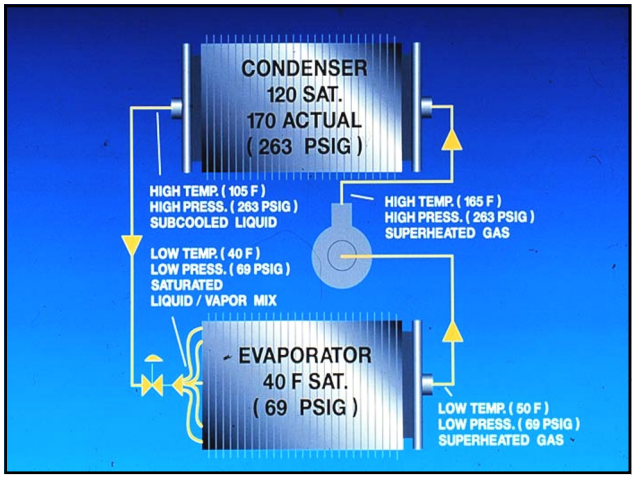
= area 1-2-3-f-1

90

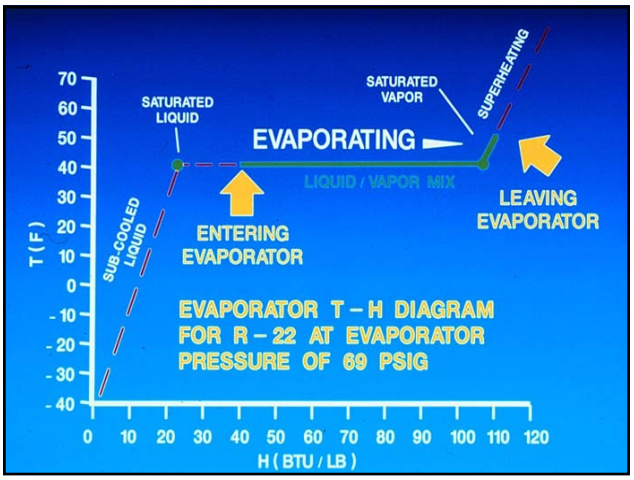
90



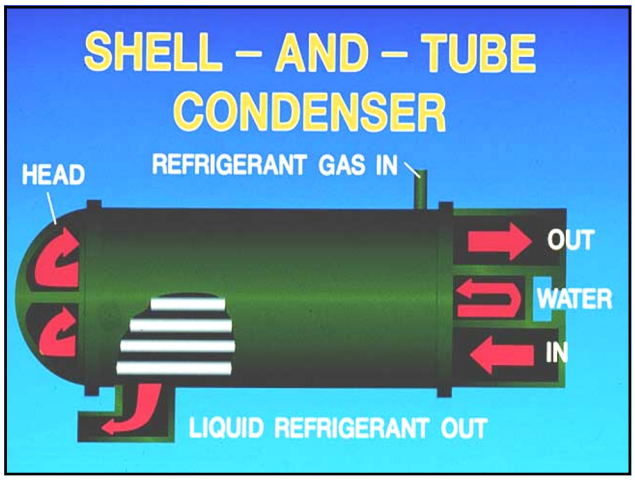
91



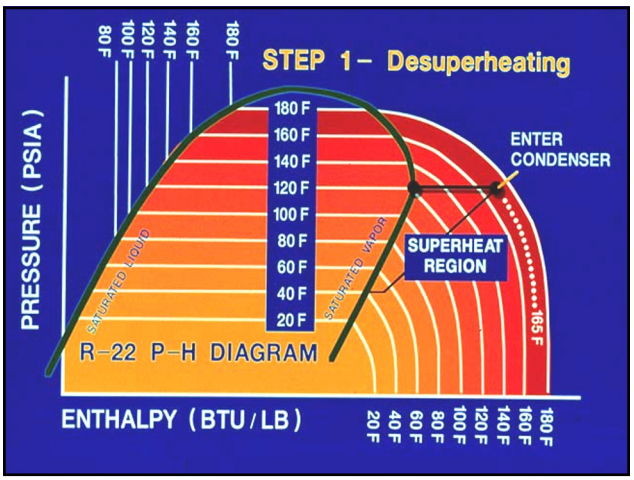
92


SATURATED LIQUID
SATURATED VAPOR
SUPERHEATING
EVAPORATING
LIQUID / VAPOR MIX
SUB-COOLED LIQUID
ENTERING EVAPORATOR
LEAVING EVAPORATOR
EVAPORATOR T – H DIAGRAM FOR R – 22 AT EVAPORATOR PRESSURE OF 69 PSIG
T (F)
70 60 50 40 30 20 10 0 - 10 - 20 - 30 - 40
0 10 20 30 40 50 60 70 80 90 100 110 120
H (BTU / LB)

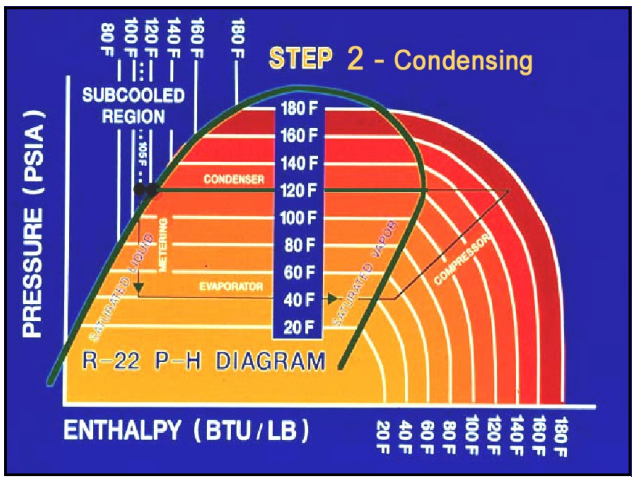
93


SHELL – AND – TUBE CONDENSER
HEAD
REFRIGERANT GAS IN
OUT
WATER
IN
LIQUID REFRIGERANT OUT

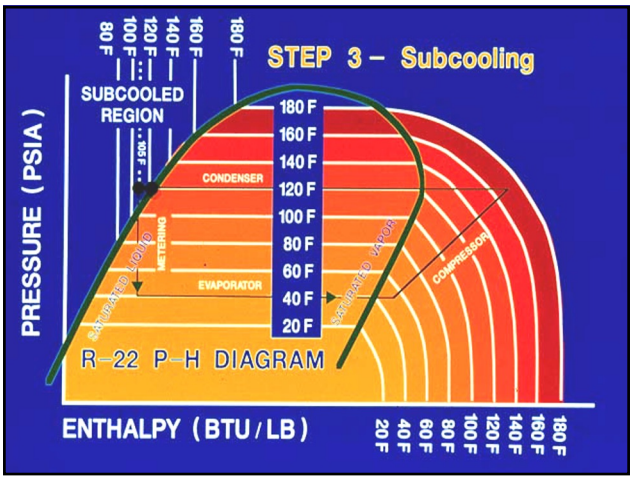
94


STEP 1 – Desuperheating
80 F 100 F 120 F 140 F 160 F 180 F
180 F 160 F 140 F 120 F 100 F 80 F 60 F 40 F 20 F
ENTER CONDENSER
SUPERHEAT REGION
SATURATED LIQUID
SATURATED VAPOR
165 F
R–22 P–H DIAGRAM
PRESSURE (PSIA)
ENTHALPY (BTU / LB)
20 F 40 F 60 F 80 F 100 F 120 F 140 F 160 F 180 F

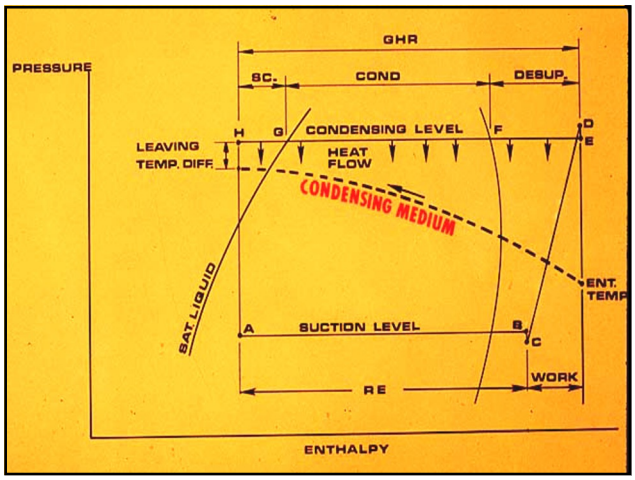
95


STEP 2 - Condensing
80 F 100 F 120 F 140 F 160 F 180 F
SUBCOOLED REGION
165 F
CONDENSER
METERING
EVAPORATOR
SATURATED LIQUID
SATURATED VAPOR
COMPRESSOR
180 F 160 F 140 F 120 F 100 F 80 F 60 F 40 F 20 F
R–22 P–H DIAGRAM
PRESSURE (PSIA)
ENTHALPY (BTU / LB)
20 F 40 F 60 F 80 F 100 F 120 F 140 F 160 F 180 F

96



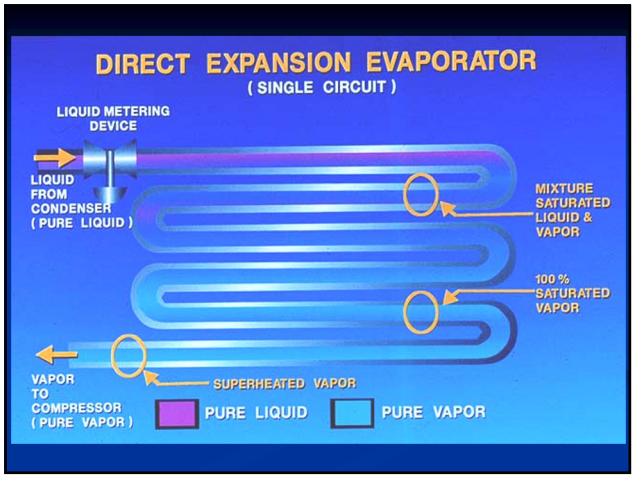
97



98

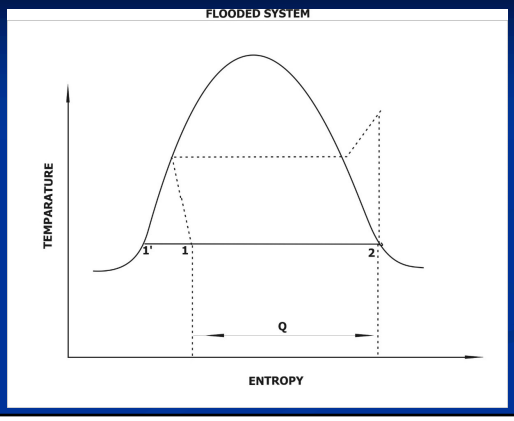
Direct Expansion Air Coil

99



100

T-S- DIAGRAM-FLOODED EXPANSION

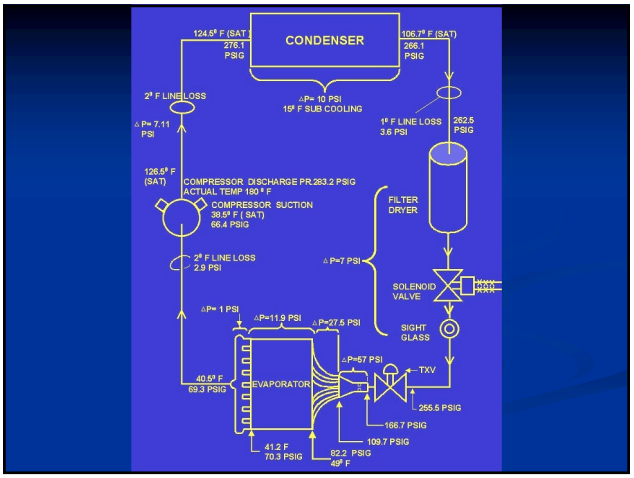


101

FLOODED COOLER IS MORE EFFICIENT THAN DX COOLER

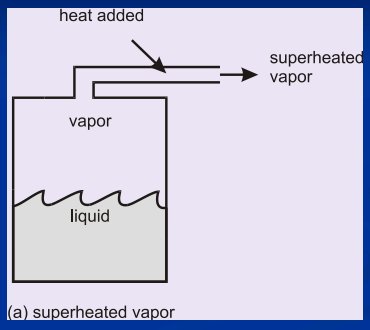
Flooded Air Coil

102

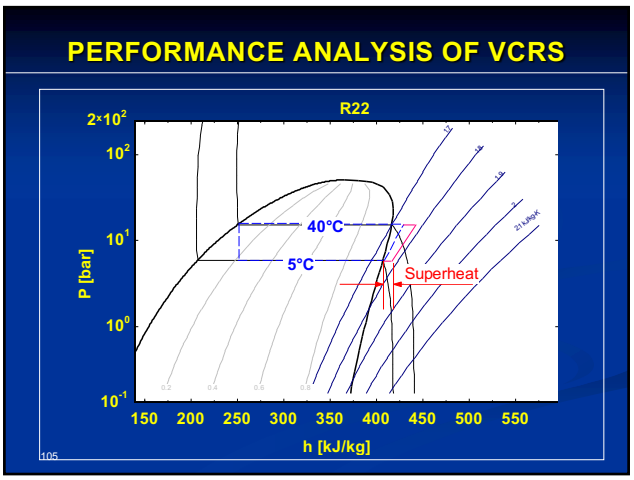


103

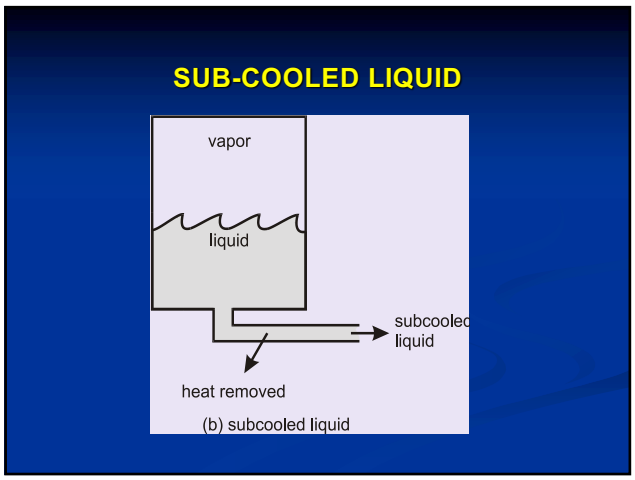
SUPERHEATED VAPOR



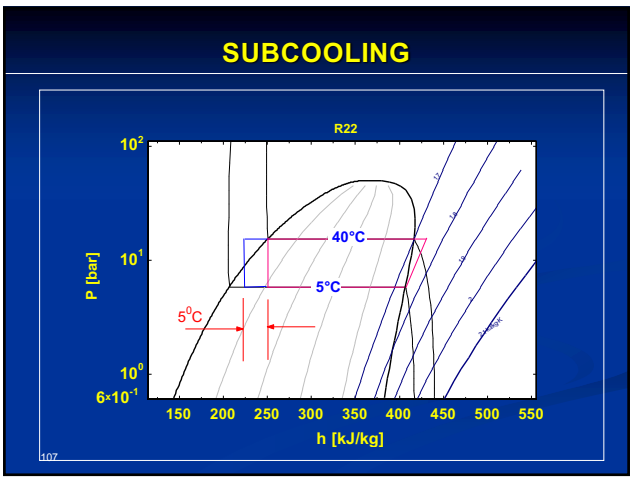
104



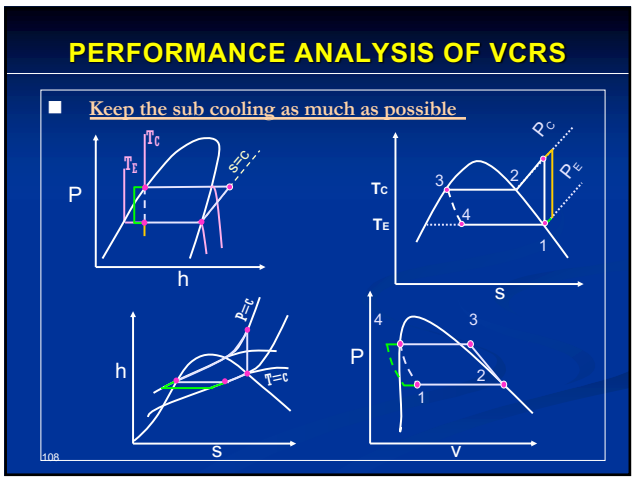
105



106

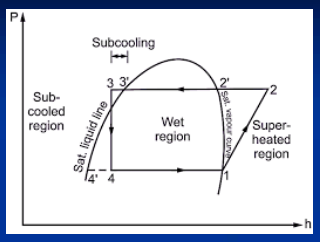


107



108

Sub cooling increases capacity

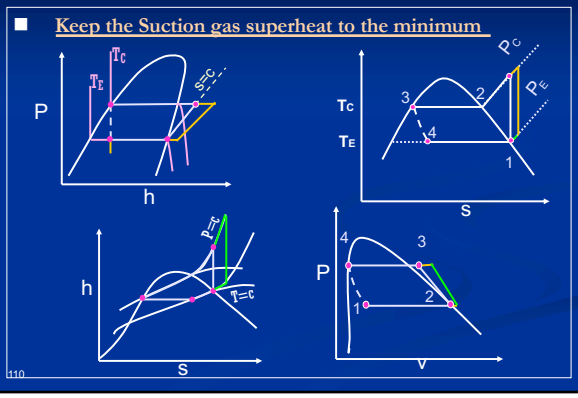


For every degree Celsius (or Fahrenheit) of subcooling achieved in a system, the refrigeration capacity increases by approximately 0.5% to 1% depending on the specific refrigerant and operating conditions. The capacity increase without any increase in power consumption. It also helps in ensuring that only liquid enters expansion valve and reducing vapour bubble formation leading to stable operation of expansion valve.

109

PERFORMANCE ANALYSIS OF VCRS

- Keep the Suction gas superheat to the minimum



110

SUPERHEAT REDUCES CAPACITY

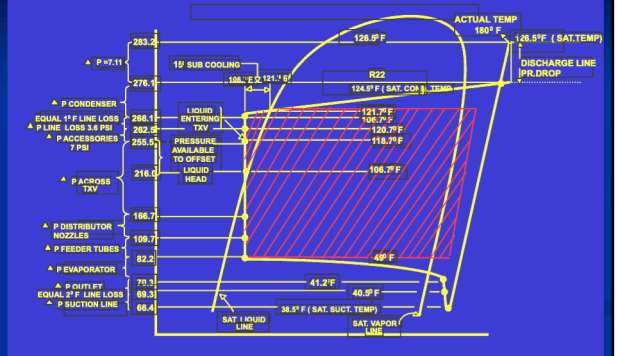
+ 40⁰ C / +5⁰ C , Ammonia

Superheat	CAPACITY kcal/hr
0 K	359400
5 K	350700
10 K	342600

111

111

R22 PRESSURE -ENTHALPY DIAGRAM - PRESSURES SHOWN IN PSIG



112

COMPARISON OF VARIOUS REFRIGERANTS

ASHRAE Fundamentals –Ammonia has highest COP

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, ft³/lb	Compressor Displacement, gal/min	Power Consumption, hp	Coefficient of Performance	Compressor Discharge Temp., °F
170	Ethane	233.2	672.8	2.88	69.5	0.81	0.35	0.541	3.27	0.489	2.7	121.73
744	Carbon dioxide	326.9	1041.4	3.19	57.3	0.51	0.10	0.269	1.03	0.257	2.69	157.73
1270	Propylene	51.9	189.1	3.64	123.0	0.46	0.11	2.081	7.12	0.295	4.5	107.33
290	Propane	41.5	155.9	3.76	119.5	0.47	0.12	2.502	8.73	0.292	4.5	96.53
502	R-22/115 (48.8/51.2)	49.7	190.3	3.83	45.6	1.25	0.13	0.814	7.59	0.306	4.38	100.13
507A	R-125/143a (50/50)	55.0	211.6	3.85	47.4	1.20	0.14	0.814	7.31	0.321	4.18	94.73
404A	R-125/143a/134a (44/52/4)	52.9	206.0	3.89	49.1	1.16	0.14	0.860	7.45	0.318	4.21	96.53
410A	R-32/125 (50/50)	69.3	271.5	3.92	72.2	0.77	0.09	0.873	5.04	0.298	4.41	123.53
125	Pentafluoroethane	58.5	226.4	3.87	36.7	1.51	0.16	0.631	7.12	0.327	3.99	87.53
22	Chlorodifluoromethane	42.8	172.2	4.02	69.9	0.81	0.08	1.248	7.58	0.287	4.66	127.13
12	Dichlorodifluoromethane	26.3	107.5	4.09	50.3	1.12	0.10	1.479	12.43	0.284	4.7	100.13
500	R-12/152a (73.8/26.2)	31.0	127.1	4.09	60.1	0.94	0.10	1.504	10.54	0.284	4.66	105.53
407C	R-32/125/134a (23/25/52)	41.8	182.7	4.38	70.2	0.81	0.09	1.289	7.80	0.298	4.5	118.13
600a	Isobutane*	12.8	58.5	4.58	113.5	0.50	0.11	6.524	24.30	0.288	4.62	85.73
134a	Tetrafluoroethane	23.6	111.2	4.71	63.6	0.89	0.09	1.945	12.90	0.290	4.6	98.33
124	Chlorotetrafluoroethane*	12.8	64.3	5.03	50.7	1.11	0.10	2.741	22.81	0.287	4.62	85.73
717	Ammonia	34.1	168.5	4.94	474.3	0.12	0.02	8.197	7.34	0.282	4.76	209.93
600	Butane*	8.1	41.0	5.05	125.6	0.47	0.10	10.325	36.04	0.292	4.74	85.73
11	Trichlorofluoromethane	2.9	18.1	6.25	67.0	0.84	0.07	12.317	77.52	0.264	5.02	109.13
123	Dichlorotrifluoroethane	2.3	15.8	6.81	61.2	0.93	0.08	14.279	99.21	0.274	4.9	91.13
113	Trichlorotrifluoroethane*	1.0	7.8	7.71	52.7	1.04	0.08	26.940	209.02	0.268	4.81	85.73

*Superheat required.

113

MEASURING EFFICIENCY OF REFRIGERATION SYSTEM

$$C.O.P. = \frac{\text{Capacity in kW}}{\text{Power Consumption in kW}}$$ (Tonx3.517÷kW power consumption)

C.O.P. value is dimensionless

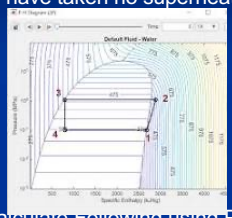
$$EER = \frac{\text{BTU per hr.}}{\text{Watt}} \qquad \frac{\text{Ton Refrigerationx12000}}{\text{kWx1000}}$$

SEER=Seasonal Energy Efficiency Ratio

$$= \frac{\text{Total heat removed Over A Period}}{\text{Total Energy input in Watt during same period}}$$

114

Let us Design an Ammonia Refrigeration system of 150kW capacity with saturated evaporating temperature as 0^0C and Condensing temperature as 40^0C, for purpose of ease of calculations we have taken no superheat or no sub cooling



Let us Calculate Following using P-H diagram

1. Evaporating pressure –kg/cm2
2. Condensing pressure –kg/cm2
3. Enthalpies at point 1,2,3,4 in kJ/kg

115

4. Compressor Discharge temperature-^{0}C
5. Mass flow rate of Refrigerant circulating in the system –kg/s
6. Volume flow rate required for compressor at point -1in m^3/s
7. Power required for getting 150kW output in kW
8. Condenser heat rejection in kW
9. C.O.P.

Calculations

1. Evaporating pressure at 0^0C-4.3barx1.01972=4.384kg/cm^2.
2. Discharge pressure at 40^0C-15.5barx1.01972=15.85kg/cm^2
3. Enthalpy at point -1 1462.0kJ/kg
4. Enthalpy at point -2-1655kJ/kg
5. Enthalpy at point 3-390.64kJ/kg
6. Enthalpy at point 4- Same as point 3- 390.64kJ/kg
7. Specific Volume at point 1-0.29m^3/kg
8. Refrigeration Effect=Point (1- 4)
9. =(1462.25-390.64)=1071.61kJ/kg

116

10. Mass flow rate for 150kW= 150÷1071.61=0.1399kg/s
11. Volume Flow rate=mass flow rate x sp. volume @ point 1
10. Volume Flow rate=0.1399kg/sx0.29m3/kg=0.0405m^3/s or145.8m^3/hr÷0.8h=182.25

11. Compressor power required =(h2-h1)x mass flow rate
= 0.1399kg/sx3600 x(1655-1462.0)=193.0x0.1399=27.0kW

12. Assuming compressor efficiency as 80%- the actual power would be **33.75kW**
13 Discharge temperature-96^{0}C
14. COP=150/27=5.55
14. KCX2 compressor at 700RPM gives 158.4kW consuming 34.86kW, so for 150kW it would consume **32.96kW**
14 KCX2 swept volume at 700 RPM is 185.78m^3/hr, against calculated 182.25m^3/hr

117

KIRLOSKAR PNEUMATIC COMPANY LTD
A Kirloskar Group Company

Enriching Lives

Selection Program for Air-conditioning & Refrigeration Compressors – [SPARC]

Reference Name: Training Date :17-09-2024

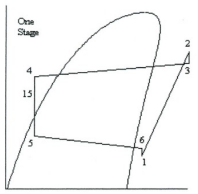
Input Data	Output Data
Compressor Group: Single Stage	
Compressor Model : KCX2	Compressor Capacity: 158.64 kW
Refrigerant: NH3	Compressor Speed: 700 rpm
Required Capacity: 150 kW	Compressor Shaft Power: 34.86 kW
Compressor Speed: AUTO	
Sat.Suction Temp: 0 °C	
Sat. Suc. Pressure: 3.35 kg/cm2 (g)	
Sat. Cond. Temp: 40 °C	
Sat. Cond. Pressure:14.82 kg/cm2 (g)	
Suction Super Heat:0 °K	

* It is recommended to select driver power approximately 10% (for Single Stage) or 20% (for Two Stage and Booster) above full load power.

118

P-H DIAGRAM COORDINATES FOR AMMONIA

Refrigerant: R717
Values at points 1-6,15 for the selected one stage cycle



Point	T [°C]	P [bar]	v [m^3/kg]	h [kJ/kg]	s [kJ/(kg K)]
1	-5.000	2.908	0.427680	1461.848	5.7987
2	118.949	15.549	0.115999	1715.167	5.7987
3	118.949	15.549	0.115999	1715.167	5.7987
4	40.000	15.549	N/A	386.426	N/A
5	-10.000	2.908	N/A	386.426	N/A
6	-5.000	2.908	0.427673	1461.848	5.7987
15	N/A	15.549	N/A	386.426	N/A

119

P-H DIAGRAM USEFULNESS

1. You can find pressure to match saturation temperatures
2. Allows you to find all refrigerant conditions in the operating system
3. Only one diagram is sufficient to plot the performance of all the components
4. Shows conditions and working of each component and its effect on other components in the system
5. Gives you idea whether you are operating is safe region or near or over the critical point
6. Helps in deciding whether to go in for single stage or two stage or cascade system
7. Shows which system is best for interstage cooling
8. Indicates danger points like discharge temperature exceeding the limits,
9. Shows effects of subcooling and superheating and how to control the same
10. Shows advantage of flooded system over D-X system
11. Indicates advantage of pump circulation system

120

CONCLUSION
(Try using natural refrigerants where ever possible)

1. Keep discharge Pressure as Low as possible
2. Keep Suction Pressure as High as possible
3. Keep Superheat Minimum
4. Maximize Subcooling
5. Use VFD, where ever possible
6. Use Water Cooled/Evaporative Condenser
7. Electronics - Continuous Response and Modulation to Load Fluctuations

121

CONCLUSION

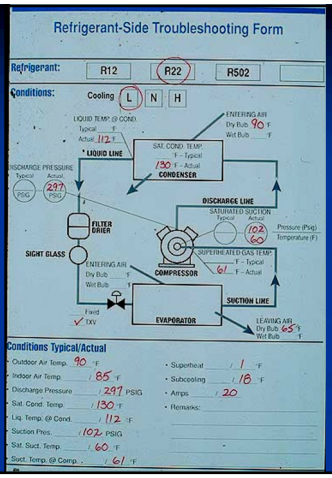
8. Keep Layout Compact
9. Do Not Over Design Equipment
10. Size Refrigerant Piping –With Minimum pressure Drop
11. Ensure Proper Oil Management
12. Do Not Over Select Pumps/Motors
13. Keep Water side Pressure Drops Minimum
14. Remove Non Condensable Periodically
15. Keep Water Lines Clean-Descale
16. Keep Filters/Coils Clean
17. Ensure daily /Weekly/Monthly/Yearly Maintenance Schedule
18. Follow Preventive Maintenance Practices & maintain log book

SAVE 20%-30% POWER

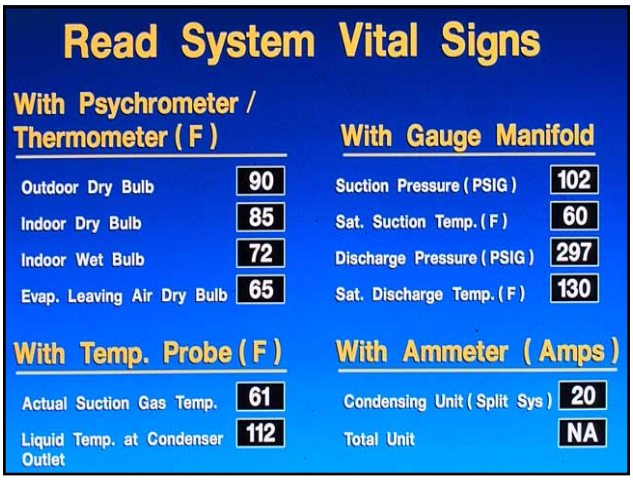
122

TROUBLE SHOOTING

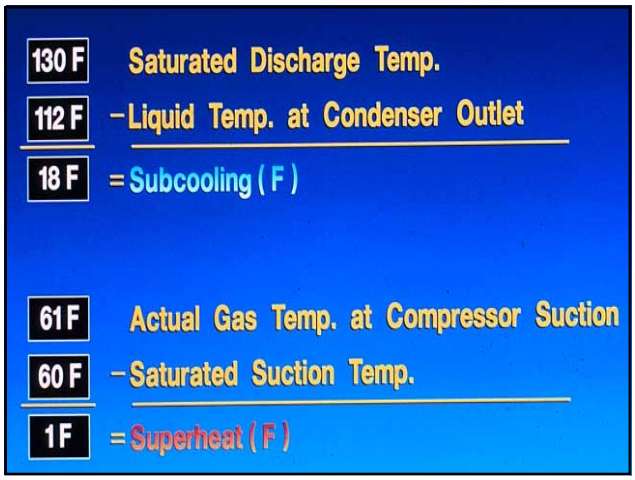
123



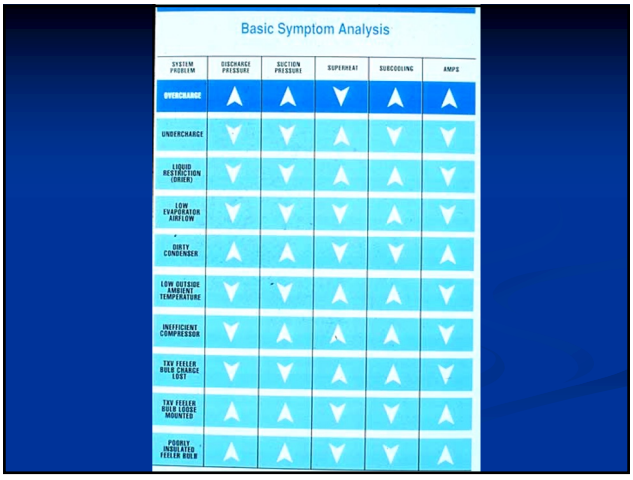
124



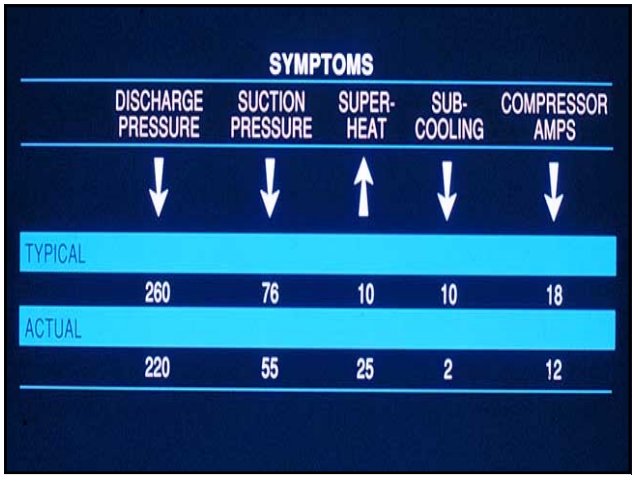
125



126



127



128



129

TRUST YOU ENJOYED THE PRESENTATION



130



Thank you for listening

131

Thank you

Any Questions ?

Ramesh Paranjpey

Fellow Life member ASHRAE

Website:-http://ramesh-paranjpey.com

Contact: + 91 98223 98220

ramesh.paranjpey@gmail.com

132