Ammonia Refrigeration Systems

By
Ramesh Paranjpey
Fellow Life Member ASHRAE
ASHRAE Distinguished fifty year service award-2020
Chairman ISHRAE Technical group –Refrigeration
Chairman AAR standards committee
Session-3 17th July 2020

1

Refrigeration As a Utility

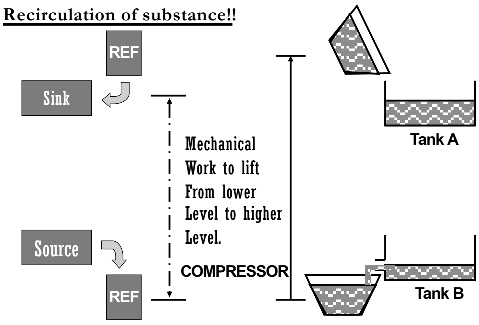
■ ***IT'S DIFFERENT***

2

2

Vapour Compression Cycle

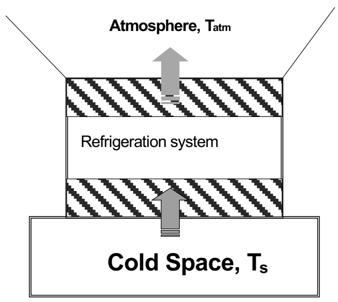
■ <u>Recirculation of substance!!</u>



3

3

Actual Refrigeration System



$T_{cond} > T_{atm}$

$T_{evap} < T_s$

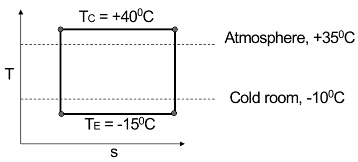
4

Vapour Compression Cycle

■ <u>Condition for high COP of the Carnot Cycle</u>

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

T_E and T_C are constrained by application temperature (source) and temperature of coolant (sink).

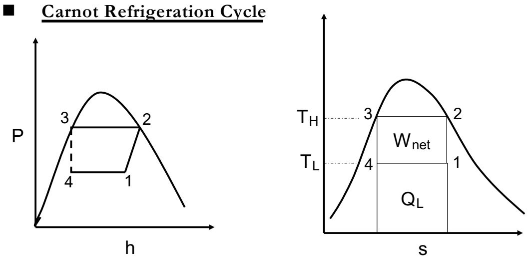


5

5

Vapour Compression Cycle

■ <u>Carnot Refrigeration Cycle</u>



$$COP_{Carnot} = \frac{T_L}{T_H - T_L}$$

6

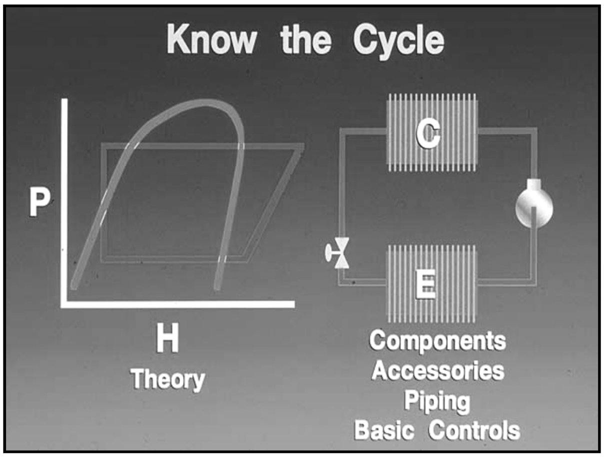
6

Vapour Compression Cycle

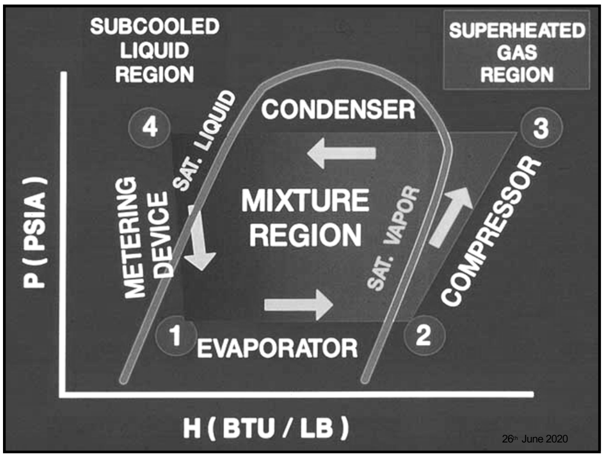
- Carnot Refrigeration Cycle- King of Cycles
  - Model of perfection for refrigeration cycle.
  - Most efficient cycle between temperature levels.
  - Consist of two isothermal processes and two isentropic processes.
  - Efficiency is independent of fluid properties.
  - All real cycles are compared with the Carnot cycle.
  - It is also called the Reverse Carnot Cycle.

7

7

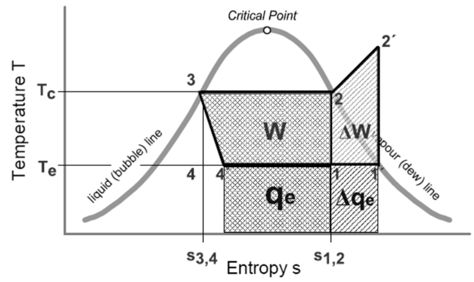


8



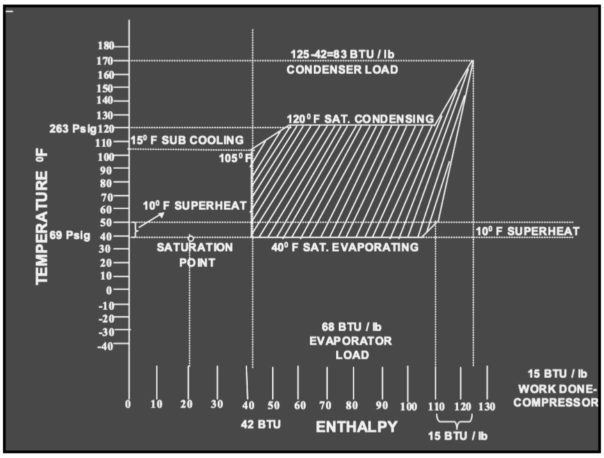
9

Standard vaour compression cycle



10

10

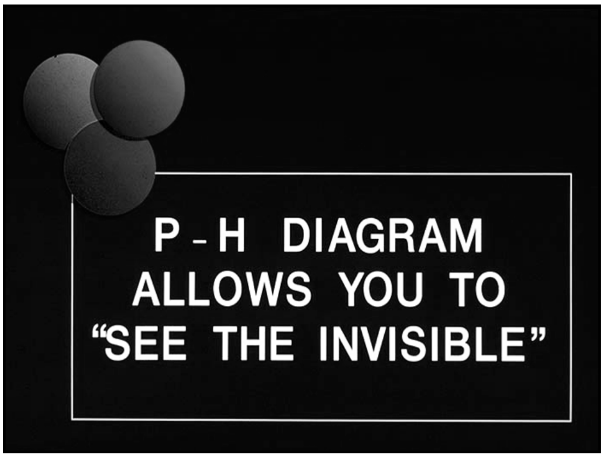


11

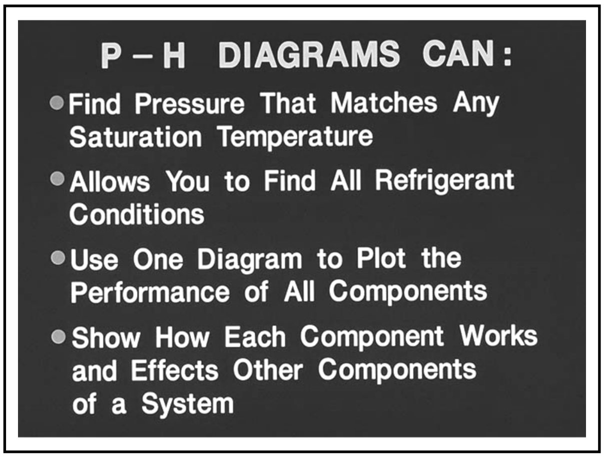
Basic Components of a Refrigeration System

1. Compressors
2. Condensers
3. Evaporators
4. Liquid metering Devices

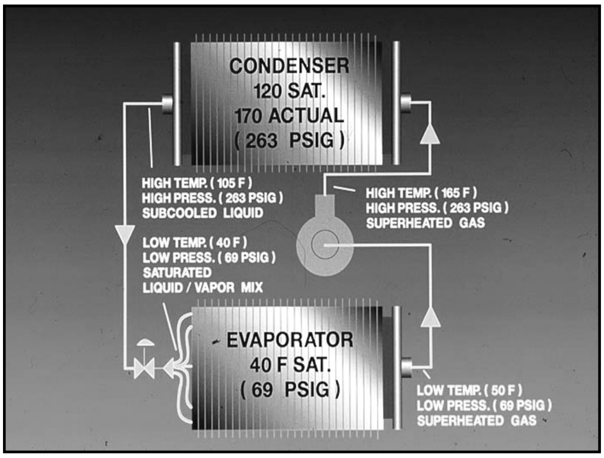
12



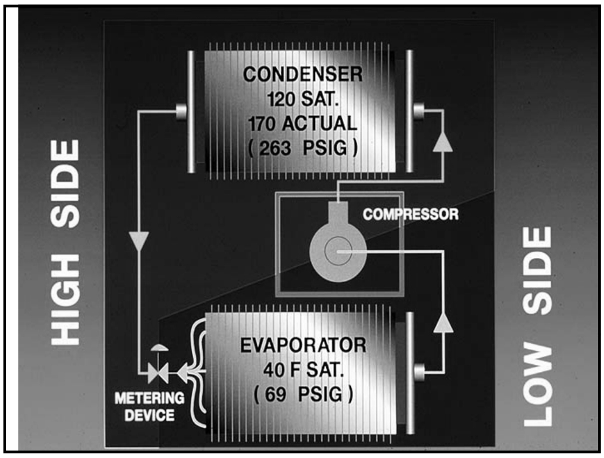
13



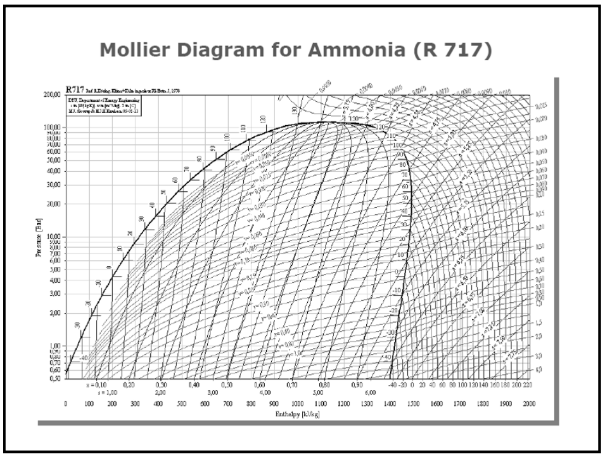
14



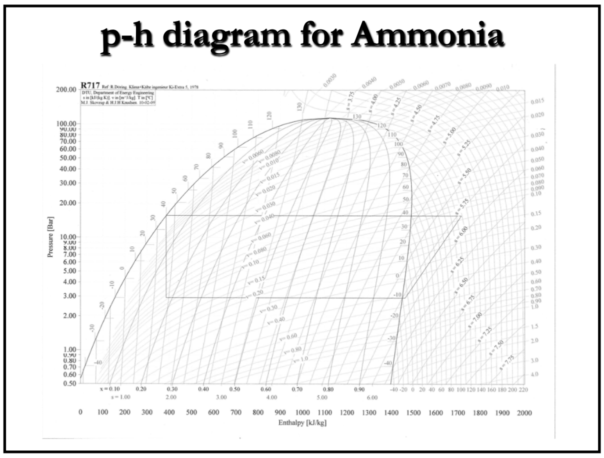
15



16



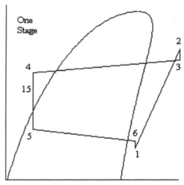
17



18

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

19

OBJECTIVES OF DESIGNING DIFFERENT REFRIGERATION SYSTEMS

1. To have highest Efficiency
2. Simplicity for operation
3. Minimum refrigerant quantity
4. Value for money-i.e. owning and operating cost
5. Life of system
6. Safety

20

Various Ammonia Refrigeration systems

1.Vapour Compression systems

a. Single stage systems for operation between +40^{0}C/-20^{0}C to -15^{0}C
b. Two stage systems for Temperatures up to -50^{0}C using same refrigerant-either single uni-built or two independent compressors
c. Cascade systems using two different refrigerants –Ammonia for high stage and another refrigerant or fluid for low stage for temperatures up to -60^{0}C

2.Different system Designs

a. Direct Expansion systems
b. Gravity Flooded systems
c. Force feed pump circulation systems
d. Low ammonia charge systems
e. LVS system-patented JBT

21

STANDARD COMPONENTS OF REGULAR SYSTEM

1. **Compressor-Reciprocating or screw –open type**
2. **Condensers- Atmospheric, shell and tube, evaporative or PHE- mostly water cooled in India**
3. **Expansion devices-Low side Float valve, Hand expansion valve, Flow regulating valve, or motorized control valve in high pressure liquid line before evaporator**
4. **Evaporator-Application oriented, such as cold room air coolers, Shell &Tube or. Plate Heat Exchanger chillers(PHE) for water or brine, ice makers, plate freezers, IQF or blast freezers etc.**

22

Direct Expansion or Flooded Evaporators

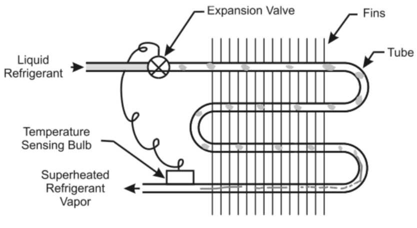
1. Direct expansion-Refrigerant is a mixture of dry & Wet at start- dry at outlet
2. Gravity Flooded –Wet from beginning to end

23

DIRECT EXPANSION SYSTEMS

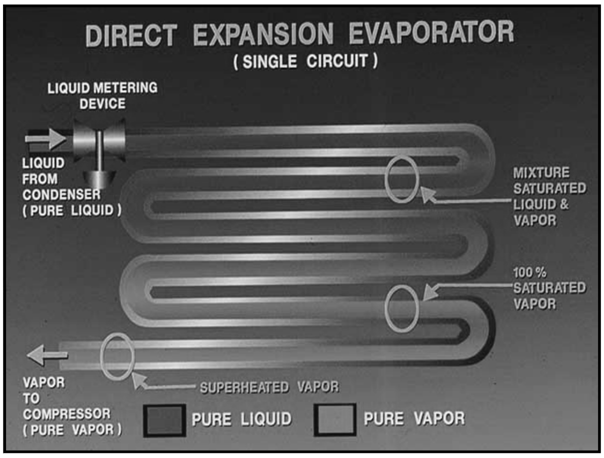
24

Direct Expansion Air Coil



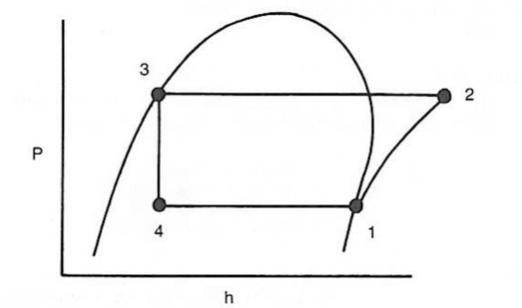
(a) Direct Expansion Air Coil

25



26

STANDARD D-X VAPOR-COMPRESSION CYCLE

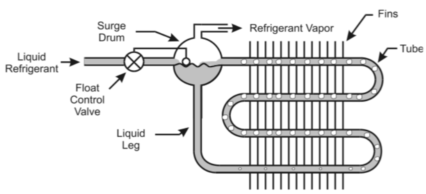


27

GRAVITY FLOODED SYSTEMS

28

Flooded Air Coil



(b) Flooded Air Coil

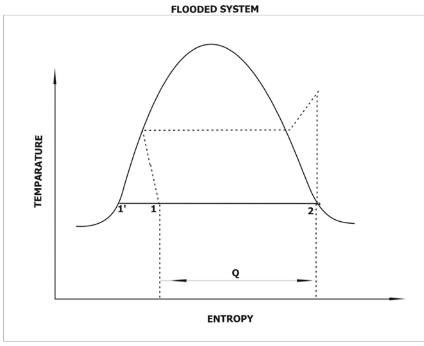
Flooded coolers are more efficient than DX coolers

29

REFRIGERAT IN LIQUID FORM - FROM INLET TO OUTLET

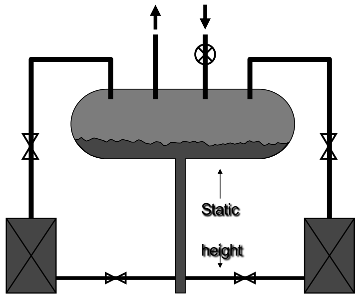
30

P-H DIAGRAM-FLOODED EXPANSION



31

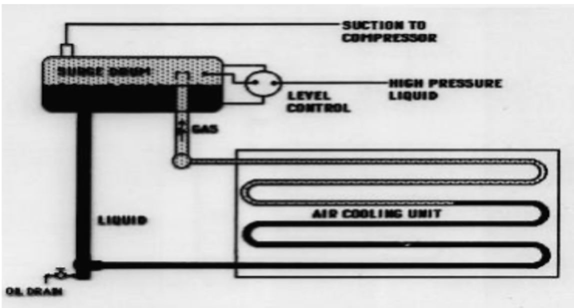
Gravity Flooded System



Circulation rate 1.5 to 2 Times depending on Evaporator design & it's pressure drop

32

GRAVITY FLOODED OVERFEED SYSTEM



33

WHY GRAVITY FLOODED SYSTEM IS BETTER

1. It is the latent heat which makes Refrigeration work
2. Higher the latent heat more efficient is the is the refrigerant
3. More the liquid in the evaporator more is latent heat, more efficient is the system
4. The DX evaporator, the refrigerant is mixture at the entry, depending on evaporating temperature , the liquid can be 70 to 80% and the gas could be 20 to 30%
5. It is the liquid Refrigerant when It gets converted into vapour absorbs maximum heat, the gas or vapour does very little work(sensible heat)
6. In Flooded system, it is liquid at the inlet as also liquid at the outlet and hence the flooded evaporators are more efficient

34

DIRECT EXPANSION OR FLOODED SYSYEM?

Advantages of Direct Expansion system
1. Quantity of refrigerant charge is low
2. Easier to operate and more compact
3. Can be used for low capacity system design
4. Air cooled condenser possible for small systems
5. Low initial cost

Drawbacks
1. Less efficient compared to flooded systems
2. Requires synthetic oils which are miscible with ammonia refrigerant
3. Control of moisture content in refrigerant essential to ensure proper operation of expansion valve

35

Flooded System Characteristics

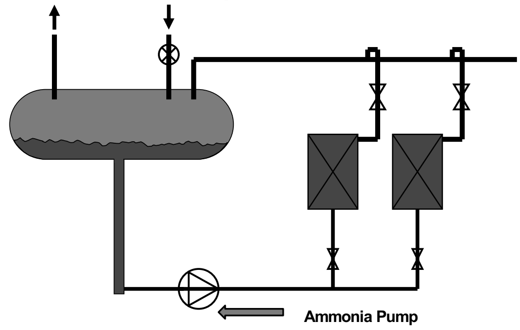
1. Similar characteristics as pumped systems
2. No extra pump & pump energy necessary
3. Static pressure (liquid column) necessary to compensate for pressure drop in coil
4. Used when less number of evaporators in the system for proper liquid distribution
5. Air coolers need to be near to compressor room so that suction line superheat is not excessive

36

FORCED CIRCULATION PUMPING SYSTEM

37

Forced Circulation with Ammonia Pump System



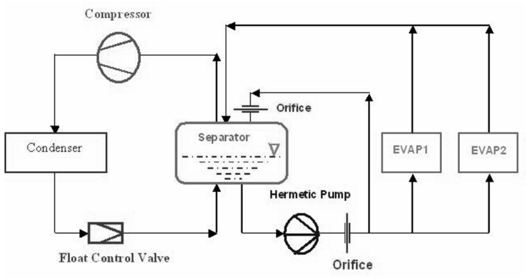
38

When To Use Overfeed System?

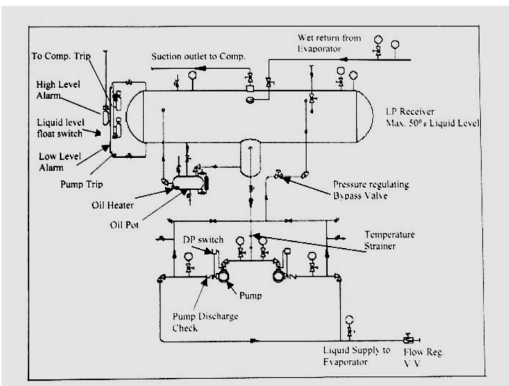
1. More than 3 to 4 air coolers or freezers
2. Processing area away from machine room
3. Low temperature applications

39

System layout



40



Piping and control arrangement

41

Circulation rate / Over feedrate

Circulation rate 4:1 =Total 4 Kg

Supply to freezer (4kg) Liquid/ Evaporation(1 kg) Liquid in to Gas, Liquid return(3kg)

OR

Overfeed rate 3:1 = Total 4 kg

Evaporation (1 kg) Liquid into Gas/ Liquid return (3 kg)

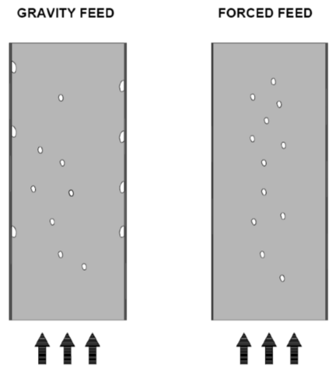
42

Recommended Circulation rates For Bottom Feed Evaporators

	CO_2	AMMONIA	R22
Blast freezers/Air Coolers	1.2-2	3-4	2-3
Plate Freezers	5-10	7-14	5-12
Liquid Chillers	1.2-1.5	1.2-1.5	1.2-1.5

43

GRAVITY FLOW V/S PUMPED FLOW



LIQUID CONTACT WITH WALLS - BETTER IN FORCED FEED PUMP CIRCULATION SYSTEM AS GAS BUBBLES ARE TRAPPED IN LIQUID DUE TO HIGHER LIQUID FLOW

44

Advantages with Overfeed

1. Higher circulation: Improved heat transfer by completely wetting internal tube surface
2. Compressors are protected from liquid slugs caused by fluctuating loads, Better Compressor operation less superheat
3. Efficient freezer operation: Freezer operation decoupled from main refrigeration system with introduction of L.P. vessel
4. Pumped refrigerant feed independent of fluctuating condensing conditions due to ambient temperature condition variations

45

Advantages with Overfeed

5. Minimum superheat since LP vessel is near the compressors, it means Less discharge temperature-better compressor operation

6. Oil recovery simple from L.P. vessel-oil drain pot

7.With simple controls, evaporators can be defrosted with hot gas with no disturbance to the main compressor- condenser, receiver system

8.Flash gas is removed in the L.P. vessel before the liquid enters the evaporators. This gas is then directly drawn by compressor.

46

Advantages with Overfeed

9. Trouble shooting is easier since L.P. vessel and evaporators are in independent circuits.

10. As long as L.P. vessel is having sufficient liquid at a required temperature, it means compressor circuit has no system fault

11. One can then concentrate on L.P. circuit and evaporators if there is malfunction

12.All major equipment is in plant room including controls and L.P. vessel ,Pump, is then under operator's surveillance

47

Advantages with Overfeed

13. Compressor life is extended

14. Less maintenance-fewer breakdowns

15.Liquid feed to evaporators more reliable since liquid is sub-cooled(pressurized) hence no flashing in the liquid feed line

16. Automatic operation convenient

48

Advantages with Overfeed

19. Oil does not accumulate in evaporators. Oil draining is convenient in the plant room from LP vessel

20.There is uniform liquid distribution in all evaporators.

21 Each evaporator does not require independent accumulator, and level controller & other accessories

22. More suitable for low temperature applications since flash gas is removed in LP vessel & only liquid goes to evaporators, (as the temperature is lowered, there is higher percentage of gas after expansion

49

Drawbacks

1. Total refrigerant charge in system is much higher
2. Due to higher flow rates of liquid to evaporator liquid line and wet return line sizes are of larger diameter
3. Insulation cost is more due to larger pipes
4. Longer liquid supply lines from machine room also need to be insulated
5. Installed cost is higher
6. Pump consumes extra power, but is usually compensated due to better efficiency

50

Drawbacks

8. Pumping units require maintenance

9. Mechanical pumps subjected to cavitations if proper precautions not taken in providing sufficient net positive suction pressure

10 Problems of liquid hammer during defrosting need to be taken care by proper piping design and defrosting sequences

11. Liquid traps to be avoided-safet**y valve may** be required in main liquid supply line

51

Low Charge Systems

52

What is Low Charge Ammonia Systems

1. Low charge systems are defined as systems having less than 1.3kg of ammonia quantity per kW of Refrigeration

2. Low charge factory made packaged refrigeration systems of less than 0.3kg/ton are available using shell and plate heat exchangers. Use of High side float eliminates use of H.P. receiver.

3. Systems with as low as 0.06kg/kW charge are also available for some applications

Ref: ISHRAE JOURNAL JAN-March 2017-Star Refrigeration UK-R. Lamb

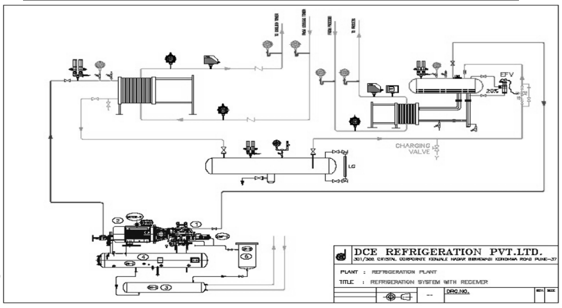
53

Various Design & Component options for Low charge systems

- 1. PHE condenser and chiller
- 2. High side float eliminating ammonia receiver
- 3. Micro channel heat exchangers –evaporators
- 4. DX evaporators and air cooled condensers
- 5. Aluminium air coolers and miscible oils
- 6. Cascade using high stage ammonia and low stage secondary fluids like brine, CO_2 etc.
- 7.One piece factory made unit for roof mounting
- 8. LVS systems-JBT patented

54

CONVENTIONAL AMMONIA REFRIGERATION SYSTEM USING PHE CONDENSER/CHILLER-



D

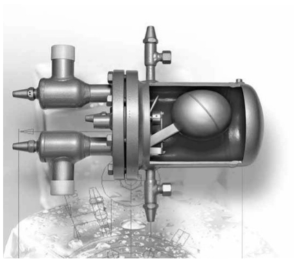
55

CONVENTIONAL AMMONIA REFRIGERATION SYSTEM
- AMMONIA CHARGE CALCULATIONS FOR 350 TR CAPACITY

Sr No.	Equipment	Volume	Volume	Vapour	Liquid	Vapour NH3	Liquid NH3	Total NH3
		Liters	m3	%	%	Kg	Kg	Kg
1	Compressor	500.00	0.50000	100.00%	0.00%	1.730	0.000	1.730
2	Suction line	94.26	0.09426	100.00%	0.00%	0.326	0.000	0.326
3	Discharge line	60.33	0.06033	100.00%	0.00%	0.723	0.000	0.723
4	Liquid Line	61.94	0.06194	0.00%	100.00%	0.000	35.891	35.891
5	Accumulator	1486.00	1.48600	70.00%	30.00%	3.599	284.692	288.292
6	Ammonia Receiver	967.00	0.96700	70.00%	30.00%	8.111	168.106	176.217
7	PHE Condenser 2.4 lit X 56 Cassetees	146.40	0.14640	80.00%	20.00%	1.403	16.967	18.371
8	PHE Chiller 1.4 lit X 69 Cassetees	96.60	0.09660	0.00%	100.00%	0.000	61.690	61.690
	TOTAL AMMONIA CHARGE					15.89	567.35	583.24

56

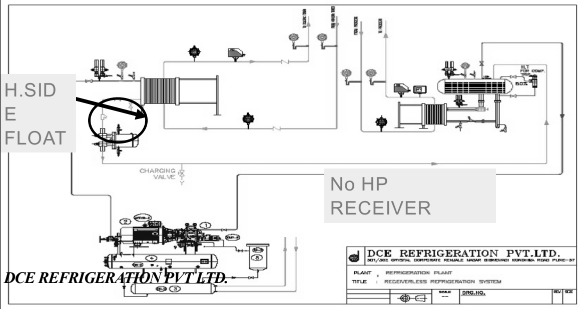
HIGH PRESSURE FLOAT – WITT OR DANFOSS



DCE REFRIGERATION PVT LTD.

57

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



DCE REFRIGERATION PVT LTD.

58

LOW CHARGE AMMONIA REFRIGERATION SYSTEM
- AMMONIA CHARGE CALCULATIONS FOR 350 TR CAPACITY

Sr No.	Equipment	Volume	Volume	Vapour	Liquid	Vapour NH3	Liquid NH3	Total NH3
		Liters	m3	%	%	Kg	Kg	Kg
1	Compressor	500.00	0.50000	100.00%	0.00%	1.730	0.000	1.730
2	Suction line	94.26	0.09426	100.00%	0.00%	0.326	0.000	0.326
3	Discharge line	60.33	0.06033	100.00%	0.00%	0.723	0.000	0.723
4	Liquid Line	29.87	0.02987	0.00%	100.00%	0.000	17.308	17.308
5	High Pressure Float	19.00	0.01900	40.00%	60.00%	0.026	7.280	7.306
6	Accumulator	1486.00	1.48600	90.00%	10.00%	4.628	94.897	99.525
7	PHE Condenser 2.4 lit X 56 Cassetees	134.40	0.13440	80.00%	20.00%	1.288	15.576	16.865
8	PHE Chiller 1.4 lit X 69 Cassetees	96.60	0.09660	30.00%	70.00%	0.000	43.183	43.183
	TOTAL AMMONIA CHARGE					8.72	178.25	186.97

DCE REFRIGERATION PVT LTD.

59

COMPARISION

PARTICULAR	LOW CHARGE AMMONIA REFRIGERATION SYSTEM (RECEIVERLESS)	CONVENTIONAL AMMONIA REFRIGERATION SYSTEM (WITH RECEIVER)
COMPONENTS	COMPRESSOR + CONDENSER + EVAPORATOR	COMPRESSOR + CONDENSER +EVAPORATOR +RECEIVER
EXPANSION DEVICE	HP FLOAT	HAND EXPANSION VALVE
LEVEL CONTROL DEVICE	NOT REQUIRED	ELECTRONIC FLOAT / LEVEL CONTROLER & SOLENOID VALVE
REGRIGERANT CHARGE	186 Kg	583 Kg
ADDITIONAL CONTROL	HIGH LEVEL TRIP	MAY BE PROVIDED
PLANT CAPACITY	350 TR	350 TR

60

REFRIGERATION SYSTEM WITH RECEIVER

DCE REFRIGERATION PVT LTD.

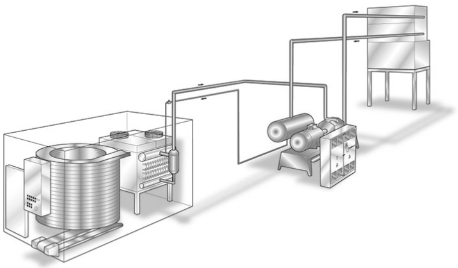
61

REFRIGERATION SYSTEM WITHOUT RECEIVER

DCE REFRIGERATION PVT LTD.

62

LVS (Low Volume System) SYSTEM BY JBT - FRIGOSCANDIA



63

Advantages as indicated by JBT

- Can be installed in a few days and is easy to retrofit on all your freezers and chillers; also easy to relocate
- Fully automatic controls integrate with the freezer control panel;
- Compact design, with smaller pipe dimensions and no need for a large pressure vessel, resulting in lower refrigerant costs
- Requires little floor space and provides great location flexibility
- Fast temperature pull-down. Low-temperature freezing (down to -50˚C/-60˚F) provides increased freezer capacity and lower food product dehydration
- No refrigerant pumps means easier maintenance with longer service intervals

64

TWO STAGE SYSTEMS

65

TWOSTAGE/BOOSTER/CASCADE --WHEN?

1. Allowable pressure difference exceeds Manufacturer's recommendations
2. Allowable discharge temperature exceeds-140^{0}C
3. Sat. Condensing temp minus sat. Evaporating temp for Ammonia more than 50K & for R-22 and other HCFC/HFC refrigerants more than 70K
4. For same pressure range ammonia may require two stage and R-22 single stage
5. Cascade system to be used using same refrigerant but different high stage low stage refrigeration loads
6. Cascade when different refrigerants for high stage and low stage or low stage using secondary fluid

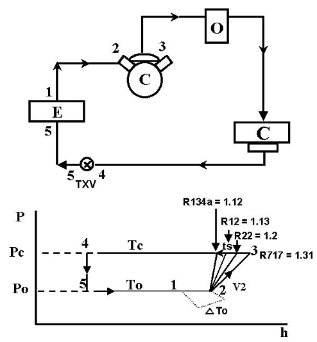
66

TWO STAGE SYSTEMS

- When the difference between Design condensing temperature and Design evaporating temperature exceeds 50K to 55K in case of ammonia refrigerant(40^0C condensing/-15^0Cevaporating Temperatures)-, it is recommended to use two stage systems, to limit compressor discharge temperatures and to improve efficiency

67

SINGLE STAGE



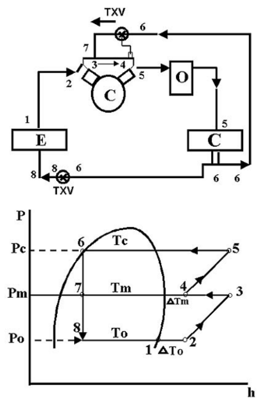
68

Two Stage Systems variations

1. Liquid injection in inter-stage
2. Closed inter-stage cooler vessel with coil for sub-cooling liquid
3. Open inter-stage cooler flash vessel

69

INJECTION INTERSTAGE GAS COOLING



70

INJECTION INTER-STAGE COOLING

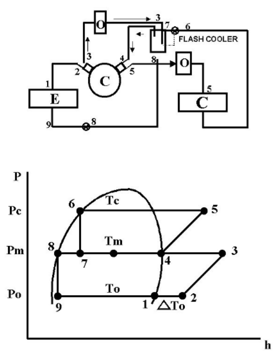
ADVANTAGES
1. Simple/inexpensive
2. No new additional –isolation valves/oil separator in L.P. discharge or strainer in hp suction
3. Saving in floor space
4. Easy to control
5. Suitable for all refrigerants
6. Low initial cost

DRAWBACKS
1. No subcooling-less refrigeration capacity
2. Higher specific power compared to other systems
3. Expensive compressor per unit capacity compared to other two systems
4. Operating cost higher compared to other systems
5. Hunting of expansion valve-at reduced capacity

6. APPLICATION-
SMALL/MEDIUM AMMONIA/R-22 INSTALLATIONS
WITH LOW INITIAL COST,SIMPLE IN OPERATION

71

OPEN FLASH INTERSTAGE COOLING



72

OPEN FLASH INTER-STAGE COOLER

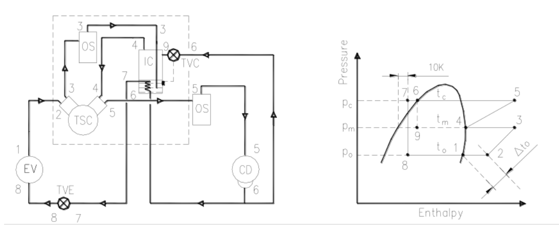
ADVANTAGES
1. Maximum capacity for given compressor
2. Minimum power consumption
3. Maximum cop
4. Minimum operating cost per year

DRAWBACKS
1. Inter-stage cooling section expensive
   Require- shut off valves/oil separator LP discharge, HP suction strainer
2. More floor space
3. Qualified operator necessary
4. Large refrigerant quantity
5. Oil trapping from L.P. discharge-less suitable for R-22
6. Low pressure difference across expansion Valve
7. Risk of flash gas in liquid line to evaporator.
8. Flash cooler in engine room above L.P. vessel With minimum height distance

Application
1. Optimized system
2. Medium/large plants where minimum running cost is important compared to initial cost

73

Closed Inter-stage Cooler



74

CLOSED FLASH INTER-STAGE COOLER

ADVANTAGES

1. Alternate to open flash cooler excluding disadvantages
2. Full pressure drop across expansion Valve
3. No risk of flash gas in liquid line to evaporator
4. Interstge cooler can be located in machine room on the floor

DRAWBACKS

1. Capacity some what lower than open flash cooler(3-5%)
2. Specific power consumption somewhat higher
3. Compressor price per unit capacity –higher
4. Inter-stage cooling more expensive than open flash cooler due to built in coil
5. All drawbacks of open flash cooler like extra LP oil separator

APPLICATION

MEDIUM/LARGE AMMONIA INSTALLATIONS

75

Inter-stage Cooling Systems

Method of Cooling	Capacity TR	Power kW	kW/TR
Liquid injection Inter-stage	51.22	95.1	1.856
Closed liquid sub-cooler	50.05	85.24	1.703
Open Flash Cooler	51.65	86.39	1.672

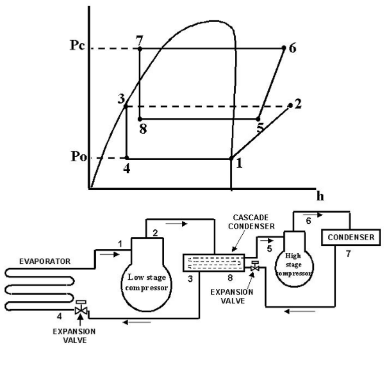
Savings - (1.856 - 1.672) x 100 TR x 16 hrs/day x 30 days x 8 months per annum = 70656 kWh@8Rs. Per kW=Rs.5.65.300

76

CASCADE SYSTEMS

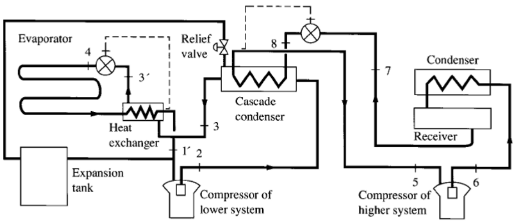
77

CASCADE REFRIGERATION SYSTEM



78

Cascade system – different refrigerants, equipment, oils



79

CASCADE REFRIGERATION SYSTEMS

APPLICATION

1. Very low temperature applications
2. Different load patterns for high and low stage
3. Very high temperature difference between condensing/evaporating temperatures

ADVANTAGES

1. Simplicity of operation
2. Regular skills enough to operate the plant
3. No oil circulation/recovery problems
4. Different refrigerants can be used for High and low stages
5. Three stage cascade possible

DRAWBACKS

1. Cascade condenser-penalty heat transfer differential
2. First cost higher-two compressors/motors/condenser
3. Liquid subcooling limited
4. Expansion valve pressure drop less-valves bigger

80

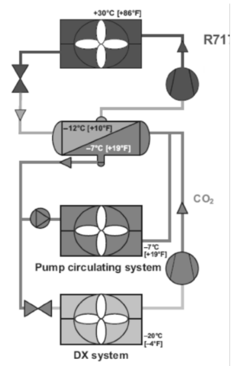


Figure 3. Cascade system diagram.
Source: Vestergaard (2007).

Ammonia –CO_2 Cascade

81

COMPARISON SINGLE STAGE/TWO STAGE/ CASCADE
R-22 REFRIGERANT, 105 DEG F CONDENSING/MINUS 40 F EVAPORATING
CAPACITY 50 TON

TYPE	SINGLE STAGE	TWO STAGE			CASCADE		
		LP	HP	TOTAL	LP	HP	TOTAL
POWER REQD.	120.6	41.73	60.27	102.0	39.754	74.89	114.644
C.O.P	1.955	5.646	4.602		5.927	3.673	
COMPRESSOR DISPLACEMENT CU.M./ HR	1574.37	873.45	365.362	1238.81	855.66	485.74	1341.4
DISCHARGE TEMP. DEG F	190	71	141		70	155	

82

THANK YOU
Questions?

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

83