Danfoss Ammonia Refrigeration

User Guide

Part 1 of 5

By Ramesh Paranjpey

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Preamble

This user guide has been prepared by Ramesh Paranjpey (Fellow life member ASHRAE & member IIAR) and the Danfoss team.

A good control system can make a marginal installation operate acceptably while a poor control system cannot make the best Equipment operate satisfactorily.

Ammonia Refrigeration installations are normally site assembled equipment piece by piece.

Although the individual equipment such as compressors, condensers, evaporators are selected from world's best available equipments having highest efficiencies and reliability and with least manual interference, if the assembled system is not provided with proper controls to work in harmony with each other to provide most reliable and efficient system, the efforts in investing in such equipment do not give desired results and client satisfaction.

Hence selection of appropriate controls becomes a major design exercise and this aspect is generally not given due importance as it should deserve.

The effort is therefore being made to make their task simpler by selecting proper solution covering all the controls involved as one package which would help in reducing the time involved in selection as well as reducing the chances of error in selection.

The user guide would not only provide this information but would also give information as to why particular control has been selected and what are the advantages in providing same. Value based solutions is the objective in preparing this booklet and for more information user is advised to refer to Danfoss Industrial product catalogue which is freely down loadable on Danfoss site as well as hard copy is available on request.

Ammonia Refrigerant

Ammonia is the most trusted refrigerant right from the 19th century. All those who are involved in food preservation and industrial process plants know Ammonia as refrigerant of choice due to its unmatched thermodynamic properties.

Environmental concerns are making scientists / technicians to take a serious look at natural refrigerants like air, water, ammonia and carbon dioxide and others as a long term alternative which would be looked at as **'NO REGRETS SOLUTION'.**

Ammonia refrigerant having withstood the test of time over more than a century as one of the best choices, is receiving attention in the areas of application where it was unthinkable earlier.

Background

Ammonia was used for refrigeration in 1876, for the first time in vapour compression machine by Carl Von Linde. Other refrigerants like CO_2, SO_2 also were commonly used till 1920s.

Development of CFCs (Chlorofluorocarbons) in USA, in 1920s swung the pendulum in favour of these refrigerants, as compared to all other refrigerants used in those days, CFCs were considered harmless and extremely stable chemicals.

The consequences to the outer environment of massive releases of refrigerant could not be foreseen in those days. CFC refrigerants were promoted as safety refrigerants, resulting in an accelerating demand and CFCs success. These refrigerants became known as God sent and man-made chemicals.

Due to success of CFCs, Ammonia came under heavy pressure, but held its position, especially in large industrial installations and food preservation.

In 1980s the harmful effects of CFC refrigerants became apparent and it was generally accepted that the CFC refrigerants are contributing to depletion of ozone layer and to global warming, finally resulting in Montreal protocol (1989) where almost all countries agreed to phase out CFCs in a time bound program.

In view of seriousness of damage to atmosphere and resulting dangers due to CFC/ HCFC emissions as also due to global warming effects, the revisions in Montreal protocol (1990), 1992 (Copenhagen) and 1998 Kyoto Japan demanded accelerated phase out schedule. Even HCFCs are also to be phased out and Europe has taken the lead.

Many countries in Europe have stopped use of HCFC refrigerants, and new refrigerants as well as well tried and trusted refrigerants like Ammonia/ Carbon Dioxide are being considered for various new applications as well.

Advantages of Ammonia Refrigerant

1. Performance

The COP (Coefficient of Performance or output per unit input) is highest for ammonia (4.76) (refer ASHRAE volume Fundamentals 2009 page 29.9) compared to other regularly used refrigerants such as 134a, 404A,410A, R-22 and many others.

Extract from Table:

Comparative Refrigerant performance per ton of refrigeration at standard cycle conditions of -15°C (258K) evaporation and 30°C (303K) condensing.

Refrigerant	Evaporating Pressure MPa	Condensing Pressure MPa	Compression ratio	Compressor Displacement l/s	Refrigeration effect kJ/kg	Power consumption kW	C.O.P.**
Ammonia R717	0.235	1.162	4.94	0.463	1103.1	0.21	4.76
R22	0.295	1.187	4.02	0.478	162.67	0.214	4.66
134a	0.163	0.767	4.71	0.814	148.03	0.216	4.6
R410A	0.478	1.872	3.92	0.318	167.89	0.222	4.41
R404A	0.365	1.42	3.89	0.47	114.15	0.237	4.21
Carbon Dioxide-R744*)	2.254	7.18	3.19	0.065	133.23	0.192	2.69

*) Carbon Dioxide-R744 in industrial refrigeration system is normally used in a cascade system with Ammonia. For low operating temperatures, Ammonia/Carbon Dioxide cascade system have higher COP values than Ammonia.

**) The COP values are based on properties of refrigerant alone at particular suction and discharge conditions. The overall system COP for ammonia would be better for typical operating parameters encountered in India.

2. Efficiency

Ammonia systems mostly operate on flooded designs. The head pressure control to artificially keep the discharge pressures high to ensure proper operation of expansion valve is therefore not necessary in ammonia plants. The condensing temperatures can be as low as possible, and this increases cycle efficiency and reduces energy consumption, in comparison with HCFC/HFC direct expansion or flooded systems.

3. Heat Transfer

Most of the thermal properties influencing heat transfer are favorable to ammonia compared to HCFC 22 refrigerant:

a. Specific heat of liquid is nearly 4 times	4 to 1
b. Latent heat of vaporization	6 to 1
c. Liquid thermal conductivity is	5.5 to 1
d. Viscosity is less	0.8 to1
e. Liquid density is less, as mentioned above	0.5 to 1

All these properties help in improving heat transfer correlation between ammonia relative to HCFC 22 for condensing and evaporating heat transfer processes.

The table below illustrates heat transfer rates of ammonia compared to the R22 refrigerant.

	Ammonia	HCFC-22
Condensation outside tubes (W/m^2K)	7500-11000	1700-2800
Condensation inside tubes (W/m^2K)	4200-8500	1400-2000
Boiling outside tubes (W/m^2K)	2300-4500	1400-2000
Boiling inside tubes (W/m^2K)	3100-5000	1500-2800

The higher heat transfer coefficients help in use of smaller evaporators and condensers or retain same heat transfer areas and operate at higher evaporating temperatures and lower condensing temperatures, thus improving the cycle efficiency.

4. Density

Density of ammonia is half of HCFC 22 (582 kg/m^3 density for Ammonia compared to 1128.4 kg/m^3 for HCFC 22). Thus refrigerant floats on oil (883 kg/m^3) layer even if it goes in the crankcase and possibility of oil getting diluted with refrigerant and thereby affecting lubrication is much less compared to HCFC 22.

5. Mass Flow Rate

Ammonia is more efficient. Its mass flow rate for a given refrigeration capacity is 1/7 times that of HCFC 22 (0.00091 kg/s for ammonia compared to 0.00616kg/s for R-22 at 250K evaporation and 303K condensation temperatures) which means only 1/7 liquid needs to be pumped for given refrigeration capacity. Thus mechanical pumping power will be much less in ammonia system.

6. Natural Refrigerant

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

The human liver has the capacity to convert 130 g of ammonia into urea each day.

The table below gives comparison of ODP and GWP values of currently used refrigerants. (ASHRAE Fundamentals 2009-page 29.4).

Refrigerant	ODP	GWP
Ammonia, R-717	0	<1
R22 (HCFC-22)	0.055	1810
R134a	0	1430
R404A	0	3900
R410A	0	2100
Carbon Dioxide	0	1

7. TEWI

The new terminology covering effect of direct and indirect leakage of refrigerant as well as energy consumption during life cycle of the equipment TEWI (Total Equivalent Warming Impact) is also very favorable for ammonia refrigerant due to its high thermal properties besides its nearly zero GWP and zero ODP characteristics.

8. Leak Detection

Ammonia has a pungent odour and even small leaks less than 5 PPM are detectable by smell so that maintenance staff can correct them. The odourless refrigerants like HCFC- 22 or HFC 134a and others, even if they leak from the system in large quantity, cannot be noticed till cooling performance drops.

9. Critical Temperature

Critical temperature for ammonia is 134.4°C and for HCFC22 is 96.0°C, hence ammonia is better suited for heat pump applications.

Critical temperatures for various refrigerants:

Ammonia-R717	134.4°C
HCFC-22	96.15°C
HFC134a	101.06°C
R404A	72.05°C
R410A	71.36°C
Carbon Dioxide	30.978°C

From the above it can be observed that critical temperature is highest for ammonia refrigerant and is thus better suited for heat pump applications. It has been also the experience of many that in air cooled applications with R-22, where very high ambient temperatures are encountered it becomes difficult to condense liquid as one is working too close to critical temperatures.

10. Lighter Than Air

Since ammonia in vapor form is 1.7 times lighter than air, it quickly rises up in the air in case of leaks and does not stagnate in the plant room. Critical density* of ammonia is 225 kg/m^3, for air is 335.94 kg/m^3 and for HCFC 22 is 523.84 kg/m^3, R134a is 511.9 kg/m^3. In case of leaks, since these refrigerants are heavier than air and due to their odourless character, they settle down in plant room when leaks develop without anyone noticing it and deaths have been reported due to suffocation since required quantity of oxygen has been displaced by refrigerant.

**Critical density: Density at thermodynamic critical temperature*

11. Leakage Losses

The molecular weight of ammonia is 17.03, whereas HCFC 22 is 86.48, R134a is 102.03, R404A is 97.604 and R410A is 72.585. This means if plant develops leak of equal size on both plants, loss of higher density refrigerants would be greater than ammonia. Similarly during purging the loss of refrigerant is less in ammonia plants compared to other refrigerants for the same reason.

12. Water contamination

Ammonia systems are more tolerant to water contamination than HCFC/HFC systems. A little leak of moisture in the system which does not exceed concentration beyond 100 PPM stays in the solution and does not freeze out. Hence modest contamination with water does not usually interfere with ammonia system operation; however, it is important to avoid water to penetrate into the system. At low operating temperatures, the evaporating pressure will be below atmosphere, and it is important to make sure that air and moisture is not penetrating into the system. Larger amount of water in ammonia system will reduce the efficiency, and can create various problems in the system. Water can be removed from the system by installing water "cleaning" systems.

13. Solubility in Water

Ammonia is eagerly absorbed by water; 1cum of water is able to absorb 120 kg of ammonia. The maximum concentration of ammonia in water (a saturated solution) has density of 0.88 kg/cm^3 and is often known as 880 ammonia.

14. Air Purgers

Since ammonia boiling point is -33°C, in many applications the systems work below atmospheric pressures. Ammonia systems till date mostly use open compressor designs with independent motor. The shaft seal is therefore present in all ammonia compressor and chances of air and moisture leaking in when plant is operating at negative pressures are more. An automatic air purger ensures that non condensables entered into system are purged out periodically to keep system efficiencies high.

15. Behaviour with Oil

HCFC 22 and other HFC refrigerant liquids and commonly used lubricating oils are mutually soluble in varying degrees depending upon type of oil, operating temperature and pressure, while ammonia and oil are virtually insoluble. Hence recovering oil from various parts of system is easier and requires different approach to oil management. Oil recovery problems are nonexistent with ammonia at partial loads unlike HCFC 22 systems.

16. Pipe Sizes

Ammonia pipe line sizes are smaller or in other words same size would carry 2 to 3 times more refrigeration capacity than HCFC 22. The cost of piping is therefore less. For example a 10 cm diameter pipe has 280 kW suction line capacity with HCFC 22 at pressure drop equivalent to 10k per 30 m length, whereas for ammonia the same line would be suitable for 728 kW capacity.

The table given below would illustrate required line size requirements for various refrigerants under identical conditions and based on steel piping; refer ASHRAE volume – Refrigeration 2011.

Capacity -200kW, evaporating temperature +50°C:

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

17. Latent Heat

Ammonia refrigerant has highest latent heat compared to other refrigerants except water and therefore per kg of refrigerant can absorb or reject lot of heat when phase transformation takes place in evaporator and condenser. Thus very low flow rates are required to provide a given refrigerant effect. In pump circulation systems the pumping power required is low compared to other refrigerants.

18. Net Refrigerating Effect

Net refrigerating effect is the vapour enthalpy minus liquid enthalpy.

The approximate net refrigerating effect at 4-5°C for various refrigerants is listed below:

Refrigerant	Net refrigerating effect (KJ/kg)
Water R-718	2489.04
Ammonia – R717	1247.85
R410A	214.48
HCFC 22/R22	201.79
HFC 134a/R134a	195.52
R404A	162.03
Carbon Dioxide	124.98

As observed from the above table Ammonia has higher refrigeration effect per kg compared to other refrigerants.

19. Safety Group

Earlier gases were grouped only in two categories, group I and group II.

ANSI standard and ASHRAE regrouped these to differentiate them as Group A1, A2, A3 and B1, B2, and B3. Ammonia is in B2 category. ANSI/ASHRAE standard 34 now classifies ammonia refrigerant as B2L, which means it is less flammable than B2 since its burning velocity is less than 10cm/s.

20. Costs

Ammonia costs are 20 times lower than HCFC 22 or HFC 134a in India. Not only ammonia is cheaper but is available in any part of the country and is produced indigenously. The HFC refrigerants which have been introduced recently as CFC substitutes need to be imported still.

Limitations/Drawbacks

Having covered most of the advantages and positive points of ammonia as refrigerant, we need to also look at its drawbacks/limitations for its use in some of the major applications like air conditioning. General public perception is ammonia is flammable and toxic and therefore it is not permitted in direct cooling air conditioning plants for public areas.

1. Flammability

Ammonia is extremely hard (above 650°C) to ignite and breaks down above 450°C. The leaks are detectable above 5PPM by most. It is therefore extremely rare to encounter such high temperatures in normal air conditioning and refrigeration applications. There is no reason for any concern that exposure to ammonia is a health hazard. Flammable limit by volume in air at atmospheric pressure is as high as 16% to 28% concentration.

Due to the very low flammability of ammonia, no explosion proof controls are required.

2. Toxicity

Laboratory trials have proved that continuous exposure levels for 10 to 15 years up to and exceeding 24 PPM has no adverse effect on human beings. Exposure to 100 PPM causes irritation but no health hazard. Exposure for ½ an hour above 5000 PPM may be fatal. Since the pungent smell of ammonia above 5 PPM is detectable, and serves as early warning, no one in its right senses would remain in the vicinity of ammonia leaks and would run away if the leaks are not controllable.

3. High Discharge Temperatures

Since index of compression for ammonia being 1.31 compared to 1.18 for HCFC 22 refrigerant, for the same pressure ratio, discharge temperatures in ammonia plants are substantially higher. For example at 60°C condensing and -15°C evaporating temperatures, for ammonia it is around 180°C, whereas for R-22 it is 115°C. If the design discharge temperature is exceeding 140°C, a 2 stage system design is recommended.

Above 120°C, mineral lubricating oil properties start deteriorating and for ammonia refrigerant applications, one has to therefore go in for two staging system design beyond 50K temperature difference between saturated condensing and evaporating temperatures. These applications can normally be met with single stage system design, if R-22 refrigerant is used. The recommended limit for single stage operation for R-22 is 70K. (Beyond which two stage designs are preferred). In heat pump application this can be looked at as an advantage. The available heat at discharge is much higher for ammonia compared to R-22 systems.

4. Incompatibility with Certain Materials

Ammonia is not compatible with copper and copper alloys. It is fully compatible with iron, steel and aluminum.

Since chlorofluorocarbons are compatible with all metal materials, any material can be chosen and thus provides greater flexibility. Technicians are more comfortable with simple soldering or brazing copper than welding steel. This is however not an issue with those who are used to work on ammonia plants and therefore cannot be considered as an area of concern.

It is important to notice that almost all refrigerants including Ammonia, Carbon Dioxide, Chlorofluorocarbons, and the oil use in these systems, can affect several types of sealing material. It is therefore important only to use the sealing materials supplied by the component supplier, which has documented the suitability of the sealing material and the refrigerants / oils.

From the foregoing advantages and disadvantages of ammonia refrigerant, one can easily see that the advantages overwhelmingly outweigh disadvantages.

Use of natural refrigerants like ammonia and carbon dioxide are finding increasing use even in air conditioning applications. Recently Ammonia refrigerant has been used for air conditioning of Oslo airport, in the expansion of Heathrow airport and in the London Olympics games village.

Various Applications Using Ammonia Refrigerant

1. Cold storages for potatoes, fruits, vegetables
2. Ice plants-conventional block ice, flake ice , tube ice plants
3. Fish freezing plants –spiral freezers, plate freezers, IQF, blast and trolley freezers
4. Slaughter houses and meat processingplants
5. Dairies and ice bank systems
6. Process refrigeration plants for chemical/dyestuff industries
7. Breweries and wineries
8. Bottling plants for Coca-Cola/Pepsi and other soft drink bottlers
9. Ice cream plants
10. Concrete cooling applications for river dams, air port runways and concrete expressways
11. Fertilizer plants
12. Recently some super markets have also tried using R717/R744 systems
13. Liquefaction of gases
14. Pharmaceutical plants for process cooling
15. Air conditioning of large complexes like airports
16. Compact ammonia packages for air conditioning telegraph and other office premises
17. Air conditioning of processing halls for cold chain facilities

Ammonia Refrigerant Properties

The term Ammonia, refers to compound formed by combination of nitrogen and hydrogen, having a chemical formula as NH_3. It is not commercial grade ammonia and means refrigerant grade anhydrous ammonia. The ASHRAE number is R717 where all refrigerants beginning with number 7 are natural refrigerants and 17 refers to molecular weight of ammonia.

Purity requirements of anhydrous ammonia as defined in ANSI/IIAR74-2 are:

Ammonia content	99.95%
Water	33 PPM max.
Oil	2 PPM max.
Salts	None
Pyridine, Hydrogen sulfide, Naphthalene	None
Molecular weight	17.031g/mol
Boiling point at one atmosphere (101.33 kPa)	-33.33°C (239.82K)
Freezing point at one atmosphere	-77.66°C(195.5K)
Critical temperature	134.4°C(407K)
Critical pressure	(11.34 MPa)g
Latent heat at -33°C and at one atmosphere	1.369 MJ/kg
Relative density of vapour compared to air at 0°C	0.5967
Vapour density at -33°C	0.8896 kg/m^3
Specific gravity of liquid at -33°C compared to water at 4°C	0.6816
Liquid density at -33°C and at one atmosphere	681.6 kg/m^3
Specific volume of vapour at 0°C at one atmosphere	1.299 m^3/kg
Flammable limit by volume in air at atmospheric pressure	15.5% to 27%
Ignition temperature	651.10°C(924.13K)
Specific heat at constant pressure-Cp	2.1706 kJ/kg k
Specific heat at constant volume-Cv	1.6444 kJ/kg k
Ratio of specific heats at 15°C and one atmosphere (γ = Cp/Cv)	1.320

Part 2 of this series will appear in the November-December 2013 issue of Cold Chain.

Danfoss Ammonia Refrigeration

User Guide

Part 2 of 5

By Ramesh Paranjpey

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General Description of Ammonia Refrigeration Systems

The essential components in vapour compression refrigeration system are:

1. Compressor
2. Condenser
3. Evaporator
4. Expansion valve / liquid metering controls

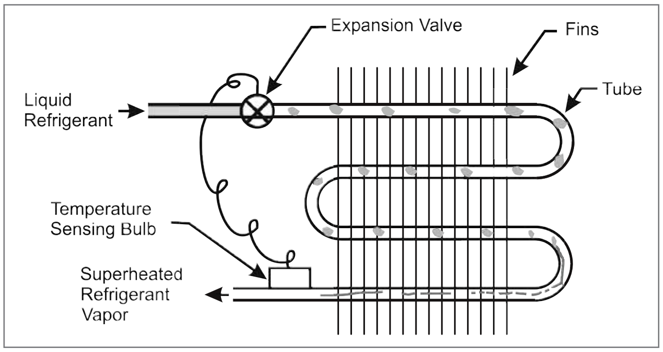
The ammonia refrigeration systems mostly use water cooled condensers, or evaporative type condensers. Air cooled condensers in India or other tropical countries are generally not used due to high ambient temperatures encountered in most parts of these regions.

Further there are two types of systems used in evaporator design with most of the refrigerants:

1. Using direct expansion evaporators
2. Using flooded operation evaporators

The evaporators are classified depending on the method used to control refrigerant flow through them.

Direct expansion evaporator, also called DX evaporator, is most popular in all applications of comfort air conditioning systems below 150 tons. These systems mostly work with HCFC/HFC refrigerants and are generally not used in ammonia applications.

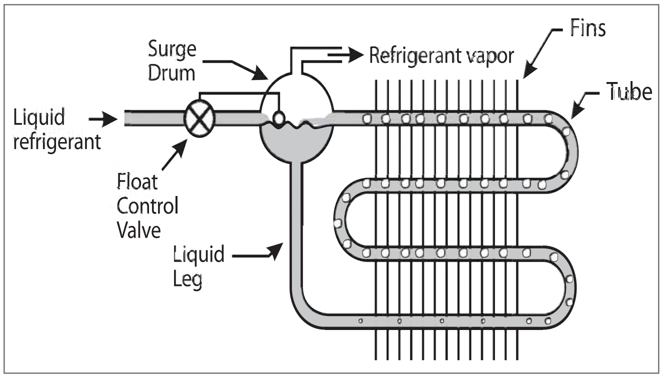


Direct expansion evaporator coils

In DX evaporators, the flow of refrigerant is controlled so that the refrigerant mixture of liquid and gas enters the evaporator. DX evaporator is a continuous tube through which refrigerant flows. At the outlet there is saturated or superheated gas since the liquid refrigerant has been converted into gas due to system load. No recirculation of liquid or gas occurs in the evaporator; rather it is a once through process – refrigerant passes through the entire system before it enters the evaporator once again.

DX evaporator has no clear point of separation between liquid and gas forms of refrigerant. As liquid/ gas mixture travels gradually the proportion of gas increases until the refrigerant becomes all gas near the evaporator outlet.

The refrigerant in the evaporator is mostly liquid (flooded) from the beginning to the end of the process. The flooded evaporator provides for recirculation of refrigerant within the evaporator by the addition of a surge drum. The liquid refrigerant enters the surge drum through the metering device, and gravity causes it to flow down to the bottom tube.



Gravity flooded evaporator coil

The entire coil surface is in contact with wet refrigerant under any load condition. This design produces excellent heat transfer. The vapour produced in the evaporator is separated from liquid in surge drum. The liquid is re-circulated through the evaporator, while the vapour is sucked by the suction action of compressor.

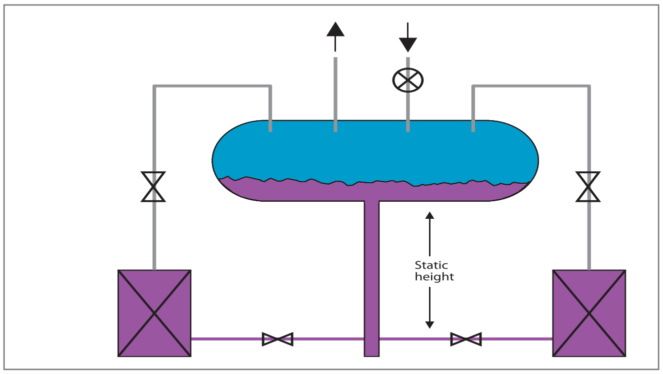
The flooded evaporator regulates refrigerant flow by a float device, which is designed to maintain a predetermined liquid level in surge drum. The vapour leaving the surge drum is saturated and not superheated as in case of DX evaporator. Flooded evaporators are therefore more efficient as entire coil surface is exposed to wet refrigerant and therefore the heat transfer is better. In dry evaporators part of coil area is wasted in superheating gas and the coil surface is always in contact with part liquid and part gas.

Although these are more efficient compared to DX evaporators, careful design has to be made to ensure proper liquid/ vapour separation in surge drum to ensure that liquid is not carried over to the compressor. The design of surge drum, its various connections and velocity of refrigerant has to be taken care of.

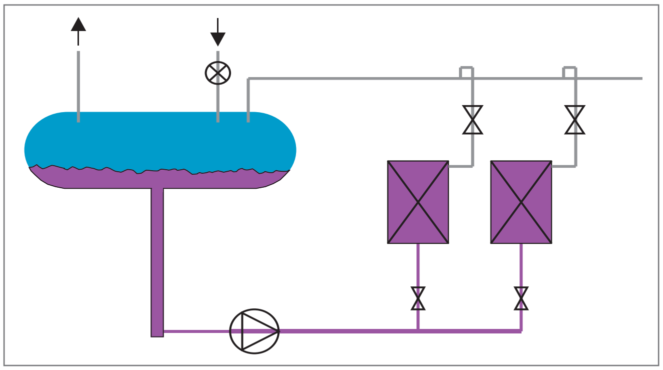
Ammonia refrigeration systems normally work on flooded operation principle.

In flooded evaporators again there are two system designs:

1. Gravity flooded evaporator systems
2. Force feed pump circulation systems



Gravity flooded evaporator system



Forced feed pump circulation system

In liquid overfeed systems the refrigerant liquid coming out of receiver is expanded to the required pressure/temperature and this liquid is stored in low pressure receiver. It is then pumped in the various operating evaporators, like product coolers, blast freezers or plate freezers. It thus forms an independent low side circuit. The compressor sucks the vapour from this low pressure receiver and the cycle repeats.

The overfeed means much more liquid is fed to evaporator than the liquid actually vaporizing. Excess liquid is called overfeed, which returns to low pressure side accumulator known as L.P. receiver. Thus the mass flow rate handled by the compressor is less than the mass flow rate circulated in the evaporator.

As the number of evaporators increase and as the temperature requirement gets lower and lower, liquid recirculation/ overfeed systems are preferred. Normally for more than 3 to 5 evaporators, located considerably away from machine room, liquid recirculation is the best option.

Properly designed flooded evaporators and evaporators operating with liquid recirculation operate with equal effectiveness. Crankcase heater is used in ammonia systems when ambient conditions are low and liquid carry over is experienced after prolonged shut down.

The dominant refrigeration system for intermediate to large storage facilities is the liquid overfeed ammonia refrigeration system. This system is suitable for low and medium temperature cold storage.

Having covered the various systems used for ammonia refrigeration systems, it is also necessary to highlight which other components are specific to ammonia plants and which are the components normally not used in the systems.

Components Normally used in Ammonia Gravity Flooded Systems

1. Oil Separator

Since oil and ammonia are immiscible in all proportions and at all temperatures, it is essential to ensure that minimum oil in the form of mist is carried to the system along with discharge gas.

As we all know, oil has no refrigeration cooling properties, and is required only for lubrication of compressors; lesser the oil goes in the system, better is the system performance. Oil separator is therefore an essential component in all ammonia systems.

2. Receiver

Since ammonia systems are of flooded design as discussed earlier, there is higher quantity of refrigerant in the system compared to direct expansion evaporator designs. Hence liquid ammonia needs to be stored at one place and that function is served by the high pressure receiver.

The ammonia receiver also serves the purpose of accommodating the entire charge of system in case some system component needs servicing. The system ammonia charge is then pumped down in the receiver; the outlet valve from the receiver, popularly called king valve, is closed and the defective component is attended.

3. Accumulator/Liquid Separator

Since ammonia systems are either gravity flooded or pump circulation systems, it is essential to separate gas component from the mixture of low temperature/low pressure liquid and gas coming out of expansion device. The liquid separator serves this function and allows only the liquid to be admitted to evaporator whereas the gas part is sucked by the compressor along with evaporated gas coming out of evaporator. Accumulator is therefore an essential component for all gravity flooded air coolers.

Surge Drum

This vessel is used as a protection device from accidental liquid refrigerant being carried to compressor. This vessel is similar to accumulator except that it has no liquid in it. Normally it is mounted on top of flooded shell and tube evaporators to ensure that any liquid droplets due to vigorous boiling action in the evaporator do not enter compressor suction line due to high suction velocities. In surge drum the velocities are reduced and liquid droplets fall back to evaporator instead of going to compressor, thus saving compressor from damage.

4. De-superheater

Since compression index for ammonia is high for same compression ratio as with CFC/HCFC refrigerants, the discharge temperatures at the end of compression are high. Advantage to recover this heat before it is rejected in condenser can be taken by providing heat exchanger, and hot water can be generated.

5. Air Purgers

Since ammonia boiling point is -33°C, in many applications the systems work below atmospheric pressures. Ammonia systems till date mostly use open compressor designs with independent motor. The shaft seal is therefore present in all ammonia compressor and chances of air leaking in when plant is operating at negative pressures are more. An automatic air purger ensures that non condensables that may have entered the system are purged out periodically to keep system efficiencies high.

6. Separate Electric Motor

All ammonia compressors are driven by independent electric motor. The compressors are driven through flywheel, motor pulley and 'v' belts or directly driven through couplings. Since ammonia and copper are not compatible, semi hermetic or hermetic compressors cannot be used.

Currently some manufacturers have developed semi hermetic compressors using aluminum windings instead of copper, but use of these designs is yet to be commercialized barring few installations.

Components Normally not Required in Ammonia Systems

1. Crank Case Heater

Since oil is heavier than ammonia liquid, in case liquid ammonia migrates to compressor during standstill period it floats on top of oil layer and hence during start up the lubrication does not suffer. In HCFC/HFC plants oil heater is a must since these refrigerants are heavier than oil and during start up if these condensed refrigerants are not boiled off, the oil pump operation and lubrication suffer. Where ambient temperatures are very low, sometimes crankcase heater is also used in ammonia compressors, but in India it is very rare.

2. Suction/Liquid Line Heat Exchanger

Since ammonia gas coming out of evaporator is in saturated condition, it is essential to keep superheat as low as possible before gas enters the compressor. If suction/liquid line heat exchanger is used, suction gas superheat increases leading to high discharge temperatures due to higher index of compression of ammonia, the lubricating oil gets burnt, carbon formation takes place, oil becomes black and viscosity reduces, leading to higher wear and tear of compressor parts.

It is therefore essential to keep superheat minimum and hence use of suction/liquid line heat exchanger is avoided in ammonia systems.

3. Liquid Line Dryer

Since ammonia and water are miscible in all proportions, ammonia systems are more tolerant to presence of moisture, unlike other systems using HCFC/HFC refrigerants. Hence only liquid line strainer or filter is provided to capture suspended solids, and dryer is not required. However the moisture from the system should be removed by a suitably designed water cleaning system.

4. Liquid Line Sight Glass

Since ammonia plants operate on flooded evaporators, there is no thermostatic expansion valve in the liquid line. Chances of gas bubbles entering the liquid line are not there since liquid is taken from stored quantity in the high pressure receiver. Moreover there is liquid level indicating sight glass in the evaporator side; hence liquid line sight glass is normally not provided in ammonia plants.

Having understood the various requirements of ammonia system components, we shall now concentrate on our main objective of selection of right controls to enhance system performance, reliability and design systems to operate with minimum human interference and skills.

Controls

The controls can be direct reading type field instruments, or PID (Proportional, Integral, Derivative) type or DDC (Direct Digital Control) type, depending upon customer requirements and/or complexities of plants.

The controls for any refrigeration system are generally classified in two categories:

A. Operating controls

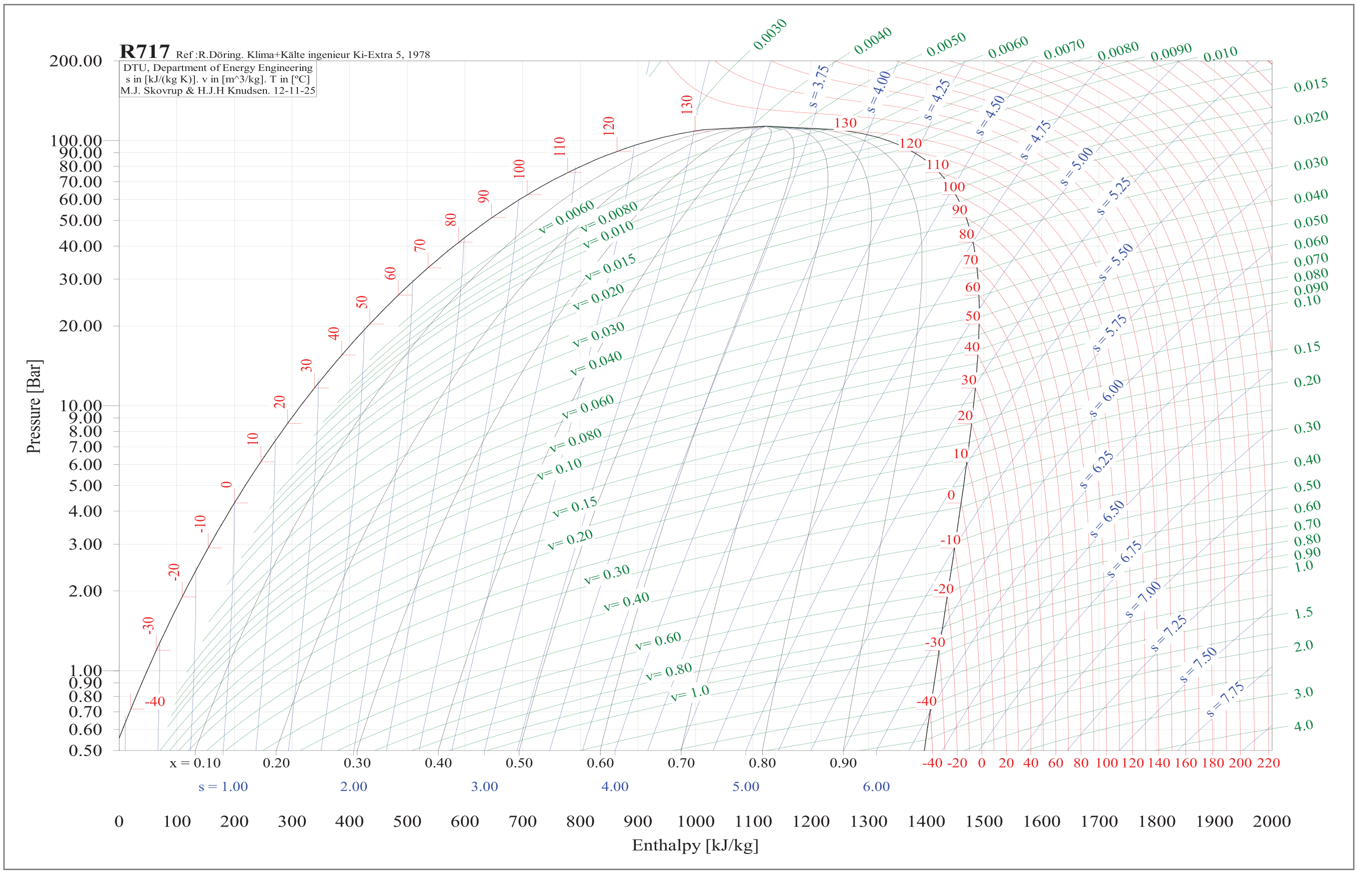
B. Safety controls

A. Operating Controls:

1. Liquid regulation devices
2. Defrost controls
3. Capacity controller for compressor
4. Temperature/humidity controllers
5. Pressure controllers
6. Variable frequency drives
7. Other specific to application

B. Safety Controls:

1. High pressure cutout
2. Low pressure cutout
3. Oil pressure cutout
4. Discharge temperature cutout
5. Flow failure switch for compressors, ammonia pumps and water pumps
6. Motor protection devices
7. Safety relief valves on pressure vessels.



The refrigerant properties and PH diagram can easily be accessed on a free software downloadable link:

http://www.danfoss.com/BusinessAreas/RefrigerationAndAirConditioning/Product+Selection+Tools+Details/Coolselector.htm

The pipe sizing and the controls selection can be easily done using the DIRcalc available - also free downloadable:

http://www.danfoss.com/BusinessAreas/RefrigerationAndAirConditioning/Product+Selection+Tools+Details/DIRcalc.htm

Table of saturated values for R717 (Ammonia)

T °C	P Bar	v_l dm^3/kg	v_g m^3/kg	h_l kJ/kg	h_g kJ/kg	R kJ/kg	s_l kJ/(kg K)	s_g kJ/(kg K)
-46,00	0,515	1,4340	2,11333	-6,20	1397,63	1403,83	0,1760	6,3562
-45,00	0,545	1,4364	2,00458	-1,80	1399,25	1401,06	0,1953	6,3363
-44,00	0,576	1,4389	1,90242	2,60	1400,87	1398,27	0,2146	6,3166
-43,00	0,609	1,4414	1,80641	7,01	1402,48	1395,47	0,2338	6,2971
-42,00	0,644	1,4440	1,71612	11,42	1404,08	1392,66	0,2529	6,2778
-41,00	0,680	1,4465	1,63116	15,84	1405,67	1389,83	0,2719	6,2587
-40,00	0,717	1,4491	1,55117	20,25	1407,25	1387,00	0,2909	6,2398
-39,00	0,756	1,4516	1,47582	24,68	1408,82	1384,14	0,3098	6,2211
-38,00	0,797	1,4542	1,40480	29,10	1410,38	1381,27	0,3286	6,2026
-37,00	0,840	1,4568	1,33783	33,53	1411,93	1378,39	0,3474	6,1843
-36,00	0,885	1,4594	1,27465	37,97	1413,46	1375,50	0,3661	6,1662
-35,00	0,931	1,4621	1,21501	42,40	1414,99	1372,59	0,3847	6,1483
-34,00	0,980	1,4647	1,15868	46,84	1416,51	1369,66	0,4033	6,1305
-33,00	1,030	1,4674	1,10545	51,29	1418,01	1366,72	0,4218	6,1130
-32,00	1,083	1,4701	1,05513	55,74	1419,50	1363,77	0,4403	6,0956
-31,00	1,138	1,4728	1,00753	60,19	1420,99	1360,80	0,4587	6,0783
-30,00	1,195	1,4755	0,96249	64,64	1422,46	1357,81	0,4770	6,0613
-29,00	1,254	1,4782	0,91984	69,10	1423,92	1354,81	0,4953	6,0444
-28,00	1,315	1,4810	0,87945	73,57	1425,36	1351,80	0,5135	6,0277
-27,00	1,379	1,4837	0,84117	78,03	1426,80	1348,77	0,5316	6,0111
-26,00	1,446	1,4865	0,80488	82,50	1428,22	1345,72	0,5497	5,9947
-25,00	1,515	1,4893	0,77046	86,98	1429,64	1342,66	0,5677	5,9784
-24,00	1,587	1,4921	0,73779	91,45	1431,04	1339,58	0,5857	5,9623
-23,00	1,661	1,4950	0,70678	95,93	1432,42	1336,49	0,6036	5,9464
-22,00	1,738	1,4978	0,67733	100,42	1433,80	1333,38	0,6214	5,9305
-21,00	1,818	1,5007	0,64934	104,91	1435,16	1330,25	0,6392	5,9149
-20,00	1,901	1,5036	0,62274	109,40	1436,51	1327,11	0,6570	5,8994
-19,00	1,987	1,5065	0,59744	113,89	1437,85	1323,95	0,6746	5,8840
-18,00	2,076	1,5094	0,57338	118,39	1439,17	1320,78	0,6923	5,8687
-17,00	2,168	1,5124	0,55047	122,90	1440,48	1317,59	0,7098	5,8536
-16,00	2,263	1,5154	0,52866	127,40	1441,78	1314,38	0,7273	5,8386
-15,00	2,362	1,5184	0,50789	131,91	1443,07	1311,15	0,7448	5,8238
-14,00	2,464	1,5214	0,48810	136,43	1444,34	1307,91	0,7622	5,8091
-13,00	2,570	1,5244	0,46923	140,94	1445,59	1304,65	0,7795	5,7945
-12,00	2,679	1,5275	0,45123	145,46	1446,84	1301,38	0,7968	5,7800
-11,00	2,791	1,5305	0,43407	149,99	1448,07	1298,08	0,8140	5,7657
-10,00	2,908	1,5336	0,41769	154,52	1449,29	1294,77	0,8312	5,7514
-9,00	3,028	1,5368	0,40205	159,05	1450,49	1291,44	0,8483	5,7373
-8,00	3,152	1,5399	0,38712	163,58	1451,68	1288,09	0,8653	5,7233
-7,00	3,280	1,5431	0,37285	168,12	1452,85	1284,73	0,8824	5,7094
-6,00	3,412	1,5463	0,35921	172,66	1454,01	1281,35	0,8993	5,6957
-5,00	3,548	1,5495	0,34618	177,21	1455,16	1277,95	0,9162	5,6820
-4,00	3,688	1,5527	0,33371	181,76	1456,29	1274,53	0,9331	5,6685
-3,00	3,833	1,5560	0,32178	186,32	1457,40	1271,09	0,9499	5,6550
-2,00	3,982	1,5593	0,31037	190,87	1458,51	1267,63	0,9666	5,6417
-1,00	4,136	1,5626	0,29944	195,43	1459,59	1264,16	0,9833	5,6284
0,00	4,294	1,5659	0,28898	200,00	1460,66	1260,66	1,0000	5,6153
1,00	4,457	1,5693	0,27895	204,57	1461,72	1257,15	1,0166	5,6022
2,00	4,625	1,5727	0,26935	209,14	1462,76	1253,62	1,0332	5,5893
3,00	4,797	1,5761	0,26014	213,72	1463,79	1250,07	1,0497	5,5764
4,00	4,975	1,5795	0,25131	218,30	1464,80	1246,50	1,0661	5,5637
5,00	5,158	1,5830	0,24284	222,89	1465,79	1242,91	1,0825	5,5510
6,00	5,345	1,5865	0,23471	227,47	1466,77	1239,30	1,0989	5,5384
7,00	5,539	1,5900	0,22692	232,07	1467,73	1235,66	1,1152	5,5259
8,00	5,737	1,5936	0,21943	236,67	1468,68	1232,01	1,1315	5,5135
9,00	5,941	1,5972	0,21224	241,27	1469,61	1228,34	1,1477	5,5012
14,00	7,046	1,6155	0,18029	264,34	1474,02	1209,67	1,2281	5,4408
15,00	7,285	1,6193	0,17462	268,97	1474,85	1205,88	1,2441	5,4290
16,00	7,530	1,6231	0,16916	273,60	1475,66	1202,06	1,2600	5,4172
17,00	7,781	1,6269	0,16391	278,24	1476,46	1198,21	1,2759	5,4055
18,00	8,039	1,6308	0,15885	282,89	1477,24	1194,35	1,2917	5,3939
19,00	8,303	1,6347	0,15398	287,53	1478,00	1190,46	1,3075	5,3823
20,00	8,574	1,6386	0,14929	292,19	1478,74	1186,55	1,3232	5,3708
21,00	8,851	1,6426	0,14477	296,85	1479,47	1182,62	1,3390	5,3594
22,00	9,136	1,6466	0,14041	301,51	1480,17	1178,66	1,3546	5,3481
23,00	9,427	1,6506	0,13621	306,18	1480,86	1174,68	1,3703	5,3368
24,00	9,725	1,6547	0,13216	310,86	1481,53	1170,68	1,3859	5,3255
25,00	10,031	1,6588	0,12826	315,54	1482,19	1166,65	1,4014	5,3144
26,00	10,343	1,6630	0,12449	320,23	1482,82	1162,59	1,4169	5,3033
27,00	10,664	1,6672	0,12085	324,92	1483,43	1158,51	1,4324	5,2922
28,00	10,991	1,6714	0,11734	329,62	1484,03	1154,41	1,4479	5,2812
29,00	11,326	1,6757	0,11396	334,32	1484,60	1150,28	1,4633	5,2703
30,00	11,669	1,6800	0,11069	339,04	1485,16	1146,12	1,4787	5,2594
31,00	12,020	1,6844	0,10753	343,76	1485,70	1141,94	1,4940	5,2485
32,00	12,379	1,6888	0,10447	348,48	1486,21	1137,73	1,5093	5,2377

Table of saturated values for R717 (Ammonia) - *Continued*

T °C	P Bar	v_l dm³/kg	v_g m³/kg	h_l kJ/kg	h_g kJ/kg	R kJ/kg	s_l kJ/(kg K)	s_g kJ/(kg K)
33,00	12,746	1,6933	0,10153	353,22	1486,71	1133,49	1,5246	5,2270
34,00	13,121	1,6978	0,09867	357,96	1487,19	1129,23	1,5398	5,2163
35,00	13,504	1,7023	0,09593	362,58	1487,65	1125,07	1,5547	5,2058
36,00	13,896	1,7069	0,09327	367,33	1488,09	1120,75	1,5699	5,1952
37,00	14,296	1,7115	0,09069	372,09	1488,50	1116,41	1,5850	5,1846
38,00	14,705	1,7162	0,08820	376,86	1488,89	1112,03	1,6002	5,1741
39,00	15,122	1,7210	0,08578	381,64	1489,26	1107,62	1,6153	5,1636
40,00	15,549	1,7257	0,08345	386,43	1489,61	1103,19	1,6303	5,1532
41,00	15,985	1,7306	0,08119	391,22	1489,94	1098,72	1,6454	5,1428
42,00	16,429	1,7355	0,07900	396,02	1490,25	1094,22	1,6604	5,1325
43,00	16,883	1,7404	0,07688	400,84	1490,53	1089,69	1,6754	5,1222
44,00	17,347	1,7454	0,07483	405,66	1490,79	1085,13	1,6904	5,1119
45,00	17,820	1,7505	0,07284	410,49	1491,02	1080,53	1,7053	5,1016
46,00	18,302	1,7556	0,07092	415,34	1491,23	1075,90	1,7203	5,0914
47,00	18,795	1,7608	0,06905	420,19	1491,42	1071,23	1,7352	5,0812
48,00	19,297	1,7660	0,06724	425,06	1491,59	1066,53	1,7501	5,0711
49,00	19,809	1,7713	0,06548	429,93	1491,73	1061,79	1,7650	5,0609
50,00	20,331	1,7767	0,06378	434,82	1491,84	1057,02	1,7798	5,0508
51,00	20,864	1,7821	0,06213	439,72	1491,93	1052,21	1,7947	5,0407
52,00	21,407	1,7876	0,06053	444,63	1491,99	1047,36	1,8095	5,0307
53,00	21,961	1,7932	0,05898	449,56	1492,03	1042,47	1,8243	5,0206
54,00	22,525	1,7988	0,05747	454,50	1492,04	1037,54	1,8391	5,0106
55,00	23,100	1,8046	0,05600	459,45	1492,02	1032,57	1,8539	5,0006
56,00	23,686	1,8103	0,05458	464,42	1491,98	1027,56	1,8687	4,9906
57,00	24,284	1,8162	0,05320	469,40	1491,91	1022,51	1,8835	4,9806
58,00	24,892	1,8221	0,05186	474,39	1491,81	1017,42	1,8983	4,9707
59,00	25,512	1,8282	0,05056	479,40	1491,68	1012,28	1,9131	4,9607
60,00	26,143	1,8343	0,04929	484,43	1491,52	1007,09	1,9278	4,9508
61,00	26,786	1,8404	0,04806	489,48	1491,33	1001,86	1,9426	4,9408
62,00	27,440	1,8467	0,04687	494,54	1491,12	996,58	1,9573	4,9309
63,00	28,107	1,8531	0,04571	499,61	1490,87	991,25	1,9721	4,9209
64,00	28,785	1,8595	0,04458	504,71	1490,58	985,87	1,9869	4,9110
65,00	29,476	1,8661	0,04348	509,83	1490,27	980,44	2,0016	4,9011
66,00	30,179	1,8727	0,04241	514,96	1489,93	974,96	2,0164	4,8911
67,00	30,894	1,8795	0,04137	520,12	1489,55	969,43	2,0312	4,8812
68,00	31,622	1,8863	0,04036	525,29	1489,13	963,84	2,0460	4,8713
69,00	32,363	1,8933	0,03937	530,49	1488,68	958,19	2,0608	4,8613
74,00	36,264	1,9297	0,03482	556,83	1485,89	929,06	2,1351	4,8113
75,00	37,084	1,9374	0,03398	562,17	1485,21	923,04	2,1500	4,8012
76,00	37,919	1,9452	0,03316	567,54	1484,49	916,95	2,1649	4,7912
77,00	38,767	1,9531	0,03236	572,94	1483,74	910,79	2,1799	4,7810
78,00	39,629	1,9612	0,03158	578,37	1482,93	904,56	2,1949	4,7709
79,00	40,506	1,9694	0,03083	583,83	1482,09	898,26	2,2099	4,7607
80,00	41,397	1,9778	0,03009	589,32	1481,19	891,87	2,2250	4,7505
81,00	42,303	1,9863	0,02936	594,84	1480,26	885,41	2,2401	4,7402
82,00	43,224	1,9950	0,02866	600,40	1479,27	878,87	2,2553	4,7299
83,00	44,159	2,0039	0,02797	606,00	1478,23	872,24	2,2705	4,7195
84,00	45,110	2,0129	0,02730	611,63	1477,14	865,52	2,2857	4,7091
85,00	46,076	2,0222	0,02665	617,29	1476,00	858,71	2,3010	4,6986
86,00	47,057	2,0316	0,02601	623,00	1474,81	851,81	2,3164	4,6881
87,00	48,055	2,0412	0,02538	628,75	1473,56	844,81	2,3318	4,6775
88,00	49,067	2,0510	0,02477	634,54	1472,25	837,70	2,3473	4,6668
89,00	50,096	2,0611	0,02418	640,38	1470,88	830,50	2,3628	4,6561
90,00	51,141	2,0713	0,02359	646,26	1469,45	823,18	2,3785	4,6453
91,00	52,203	2,0819	0,02302	652,20	1467,95	815,76	2,3942	4,6343
92,00	53,281	2,0926	0,02247	658,18	1466,39	808,21	2,4100	4,6233
93,00	54,375	2,1036	0,02192	664,22	1464,76	800,55	2,4258	4,6122
94,00	55,487	2,1149	0,02139	670,31	1463,06	792,75	2,4418	4,6010
95,00	56,616	2,1265	0,02087	676,46	1461,28	784,82	2,4579	4,5897
96,00	57,762	2,1384	0,02036	682,67	1459,43	776,76	2,4741	4,5783
97,00	58,926	2,1506	0,01986	688,94	1457,49	768,55	2,4904	4,5667
98,00	60,107	2,1631	0,01937	695,29	1455,47	760,19	2,5068	4,5550
99,00	61,306	2,1760	0,01889	701,70	1453,37	751,67	2,5234	4,5432
100,00	62,524	2,1892	0,01842	708,18	1451,16	742,98	2,5401	4,5312
101,00	63,760	2,2029	0,01796	714,75	1448,87	734,12	2,5569	4,5190
102,00	65,014	2,2169	0,01751	721,39	1446,47	725,08	2,5739	4,5066
103,00	66,287	2,2314	0,01707	728,12	1443,96	715,84	2,5910	4,4941
104,00	67,580	2,2464	0,01663	734,94	1441,34	706,40	2,6084	4,4814
105,00	68,891	2,2619	0,01621	741,86	1438,60	696,74	2,6259	4,4684
106,00	70,223	2,2780	0,01579	748,88	1435,73	686,85	2,6437	4,4552
107,00	71,574	2,2946	0,01537	756,02	1432,74	676,72	2,6616	4,4418
108,00	72,945	2,3118	0,01497	763,35	1429,55	666,21	2,6801	4,4279
109,00	74,336	2,3297	0,01457	770,68	1426,28	655,59	2,6984	4,4140
110,00	75,748	2,3484	0,01418	778,14	1422,84	644,70	2,7171	4,3997
111,00	77,181	2,3678	0,01379	785,74	1419,24	633,49	2,7360	4,3851

Table of saturated values for R717 (Ammonia) - *Continued*

T °C	P Bar	v_l dm³/kg	v_g m³/kg	h_l kJ/kg	h_g kJ/kg	R kJ/kg	s_l kJ/(kg K)	s_g kJ/(kg K)
112,00	78,635	2,3881	0,01341	793,58	1415,40	621,81	2,7555	4,3700
113,00	80,111	2,4093	0,01303	801,55	1411,38	609,83	2,7752	4,3545
114,00	81,608	2,4316	0,01266	809,69	1407,14	597,44	2,7954	4,3386
115,00	83,128	2,4549	0,01229	818,04	1402,66	584,63	2,8159	4,3221
116,00	84,670	2,4796	0,01193	826,59	1397,92	571,33	2,8370	4,3051
117,00	86,235	2,5057	0,01157	835,38	1392,90	557,51	2,8585	4,2875
118,00	87,823	2,5333	0,01121	844,43	1387,55	543,12	2,8807	4,2692
119,00	89,435	2,5627	0,01086	853,77	1381,84	528,07	2,9035	4,2501
120,00	91,071	2,5942	0,01050	863,44	1375,74	512,30	2,9270	4,2301
121,00	92,731	2,6279	0,01015	873,47	1369,18	495,71	2,9514	4,2091
122,00	94,417	2,6645	0,00979	883,92	1362,09	478,17	2,9767	4,1868
123,00	96,128	2,7042	0,00943	894,86	1354,40	459,54	3,0032	4,1632
124,00	97,865	2,7479	0,00907	906,36	1345,98	439,62	3,0310	4,1380
125,00	99,629	2,7962	0,00870	918,54	1336,69	418,15	3,0604	4,1107
126,00	101,421	2,8506	0,00833	931,55	1326,34	394,78	3,0918	4,0809
127,00	103,241	2,9127	0,00794	945,71	1314,47	368,76	3,1259	4,0475
128,00	105,091	2,9854	0,00752	961,21	1300,81	339,60	3,1632	4,0098
129,00	106,972	3,0734	0,00708	978,64	1284,46	305,82	3,2052	3,9657
130,00	108,885	3,1860	0,00659	999,04	1263,91	264,87	3,2544	3,9114
131,00	110,833	3,3457	0,00599	1024,83	1235,28	210,45	3,3167	3,8374
132,00	112,822	3,6555	0,00510	1065,59	1183,18	117,58	3,4157	3,7059
132,35	113,530	4,2735	0,00427	1122,77	1122,77	0,00	3,5561	3,5561

Part 3 of this series will appear in the March-April 2014 issue of Cold Chain

Danfoss Ammonia Refrigeration

User Guide

Part 3 of 5

By Ramesh Paranjpey

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Liquid Regulation Devices

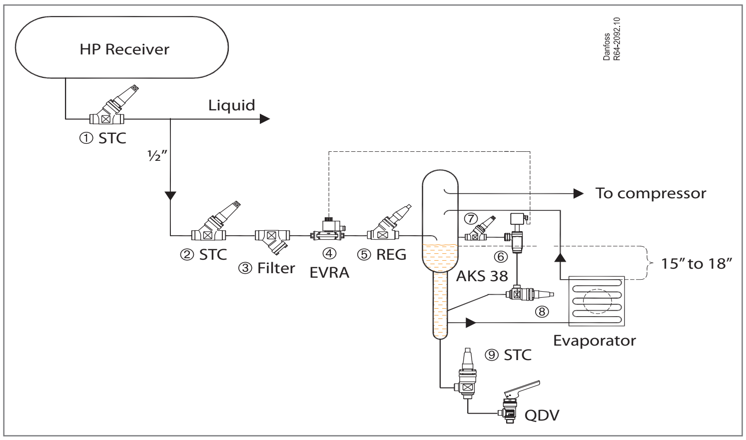
We shall start with liquid regulation devices whose primary function is:

A. To feed required amount of liquid as per the load demand to evaporators and liquid separator.

B. To create pressure drop across the expansion valve to maintain desired temperature in the evaporator.

Liquid Regulation Devices for Gravity Feed Systems

1. At the outlet of ammonia receiver there is a stop valve which is popularly also known as king valve, as this is the main valve used for pumping down of ammonia in the receiver in case of long shut down or in case of emergency.
2. After the stop valve in the liquid line towards the air cooler/chiller, the liquid line strainer is installed. The strainer protects the expansion device from choking by capturing contaminants, as expansion device has a small orifice.



Liquid feed regulation and level controls

3. A solenoid valve follows whose coil is activated by liquid level control. When the desired liquid level reaches, the solenoid valve coil is de-energized, which shuts off the liquid flow; when the liquid level in the accumulator reduces below the set point of float switch, the coil is energized and the valve opens. Frequent on/off operation of the solenoid valve or hunting is prevented by adjusting the opening/closing of hand expansion valve.
4. The solenoid valve is followed by the hand expansion valve. This valve has a taper stem to regulate and adjust flow accurately to match the amount of refrigerant evaporating in the air cooler.
5. Properly designed accumulator follows. It can be vertical or horizontal type. The sizing of accumulator is critical to ensure liquid is not carried back to compressor.
6. The accumulator is positioned near the air cooler in such a manner that enough liquid height in the liquid leg is maintained to overcome the pressure drop in the coil and to maintain proper liquid circulation in the coil.
7. The amount of liquid circulating is in excess of circulation rate in the system so that the surface of the tubes is kept constantly wetted. The heat for boiling the refrigerant is provided by the warm air and a mixture of un-evaporated liquid and vapour bubbles enters the accumulator.

   The liquid and vapour components are separated due to density difference and the excess liquid again enters the coil whereas gas formed due to evaporation is sucked by the compressor. Equal amount of liquid is fed by the expansion valve and thus the steady state condition and liquid level is maintained in the accumulator.
8. The liquid level in the accumulator should also not be very high since higher liquid column means sub cooled liquid at the entry to evaporator and part of the heat transfer area then is wasted in overcoming this extra sub cooling before the actual evaporation starts.
9. The liquid level in the accumulator is maintained at the desired level by a float switch or level sensor. The float switch has a float and electrical coil. As the liquid level increases beyond set point, the coil energizes and signal is given to liquid line solenoid valve to close and prevent further liquid entering the accumulator. Similarly when level falls below set point, the solenoid valve in the liquid line opens admitting more liquid in the accumulator. Thus the liquid level is maintained constant in the accumulator.
10. Each cooler is required to be provided with independent accumulator. The float switch is connected to accumulator with the help of gas and liquid equalizing lines and thus the liquid level in the float chamber is maintained at the same level as in the accumulator.
11. A mechanical float is also used by some manufacturers, which does not require liquid line solenoid valve on/off control.
12. A more advanced control by way of motorized valve is also available which regulates liquid level more uniformly compared to on/off control. This eliminates requirement of solenoid valve as well as float switch. One may provide solenoid valve as an added precaution or connect main motorized valve to UPS so that in case of power failure the motorized valve will close the liquid supply going to the cooler.
13. The liquid line solenoid valve is also required in case pump down cycle is to be activated. When the air coolers need to be attended or when defrost cycle is to be activated, the solenoid valve closes and liquid supply to cooler stops. The compressor continues to pump out refrigerant from the coolers and the low side of the system is freed from ammonia charge.
14. The liquid line solenoid valve is also activated by overriding from thermostat kept in the return air path of air cooler, and closes when the desired room temperature is reached.
15. In pump circulation system the individual cooler does not need accumulator and excess liquid is returned to common low pressure vessel kept in the plant room.

Gravity Flooded evaporators

Applications

A. Cold storages
B. Ice plants: block ice, tube ice, flake ice machines
C. Small capacity water and brine chillers

Danfoss offers various controls for liquid level control in evaporators and the subsequent pages would cover various alternatives one can use depending on type of requirement, criticality, and initial cost.

The following pages would suggest 3 alternatives which Danfoss can offer. The designer and end user can select the alternative which best suits his application requirements.

Alternatives

1. Use of mechanical float valve-SV1 and SV3
2. Use of combination of float switch and solenoid valve- EVRA solenoid and AKS38
3. Use of continuous modulation devices –AKS4100 with ICM valve

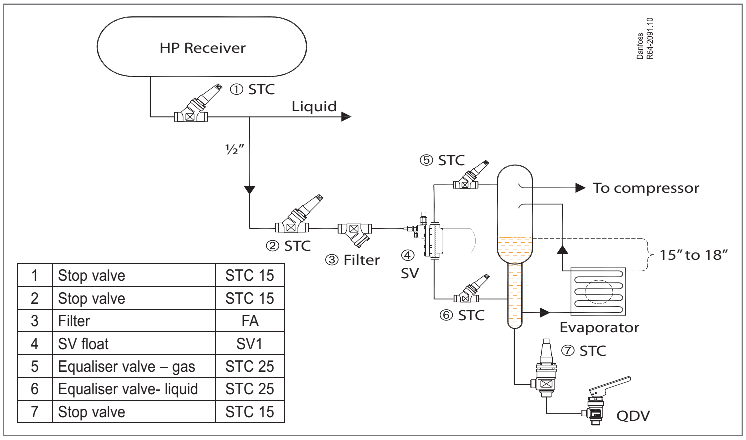
Alternative 1: Use of Mechanical Float Valve SV1 and SV3

Mechanical modulating liquid level regulating float valves SV1 and SV3: This is the simplest form of mechanical liquid ammonia control which does not require an electrical signal, separate expansion valve or inlet solenoid valve.

When the liquid level falls in the accumulator, the float (2) position moves downwards. This opens the orifice more, increasing the amount of liquid that is admitted. When the liquid level rises above the set point, the float closes the orifice (9) and no further liquid is admitted.

The liquid inlet line comes from the main HP receiver and is connected to the inlet of the float valve (C). A liquid line of size ½" is recommended for both SV1 and SV3 since this line can handle a capacity of up to 118.4KW (ASHRAE Table 2, pp 3-9).

Care should be taken with the liquid inlet pipe sizing and valve positioning to ensure that no gas bubbles are generated at the entry of the expansion orifice, since the valve capacity is reduced considerably if flash is present at the inlet of the orifice.



1	Stop valve	STC 15
2	Stop valve	STC 15
3	Filter	FA
4	SV float	SV1
5	Equaliser valve – gas	STC 25
6	Equaliser valve- liquid	STC 25
7	Stop valve	STC 15

Liquid level regulation using float value

The flash gas generated after the expansion in the orifice of the float valve is removed through the equalising pipe (D).

The sizing of the equalising connections and the positioning of valves in these lines are equally important to ensure an identical liquid level in the accumulator and float valve.

Generally in systems equipped with an accumulator/ surge drum, the liquid leg is extended downward below the point from where the liquid is fed to the evaporator and a drain valve is provided to allow periodic manual draining of the oil.

Float valve SV1

+40°C / -5°C, capacity 32 kW, ΔP = 12 bar

Float valve SV3

+40°C / -25°C, capacity 79 kW, ΔP = 14 bar

Alternative 2: Use of Combination of Float Valve and Solenoid Valve – EVRA and AKS 38

For those who prefer to use electrical controls as a more advanced solution, the suggested alternative is to use a combination of liquid line solenoid valve EVRA and float switch AKS 38.

1. The advantage of this combination is better liquid level control compared to Alternative 1.
2. This combination also allows pump down by de-energizing the solenoid valve either manually or through a timer.

Design/ Function

AKS 38 is an electro-mechanical float switch designed to provide a reliable electromechanical response to liquid level changes. AKS 38 can control liquid levels in vessels and accumulators or can be used as a low/high level safety alarm/ trip. The simple design provides reliable long life performance for many liquid level regulation applications in industrial refrigeration.

The design is based on a mechanical float, which will operate according to level of liquid refrigerant in the float chamber. When the set level is reached, an electrical micro switch will be activated. The micro switch is located in the switch box which has a clear front cover and allows viewing of the switch position. The micro switch is fully isolated from the refrigeration system and operates by means of a magnet.

The micro switch provides contacts to open/ close a solenoid valve that is placed in the liquid feed line and thus regulates the flow of refrigerant in order to maintain the set level in the vessel. A regulating valve REG is also placed in the liquid line to further create the desired pressure drop.

AKS 38 is also used to energize/de-energize contactors for the starting/stopping of refrigerant pumps/compressors.

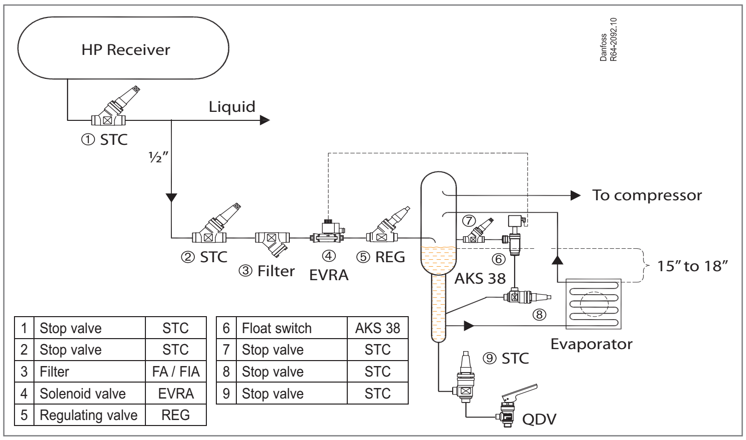
AKS 38 is mounted externally on a stand pipe at the same level as that required to be maintained in the main vessel. The float switch is connected to the stand pipe with properly sized gas and liquid equalizing connections.

The sizing of connections and position of valves in these line is important to ensure no oil accumulation in the liquid line equalizing pipe or high pressure drop in gas equalizing; both these may lead to incorrect liquid level in the vessel and in the float chamber.

The liquid level float switch AKS 38 can also be used with an indicator to indicate liquid level at remote location on control panel.

The switch assembly, in case required to be replaced, can be easily replaced by loosening the screws and lifting the float switch assembly of the tank.

This scheme uses hand expansion valve REG which is selected for the required capacity. In order to select correct size of the expansion valve REG the designer has to specify the cooler capacity in kW, evaporating temperature and condensing temperature. Normal practice is to select the valve in such a manner that the opening degree will be around 50%-60% of the total valve capacity with minimum possible pressure drop, say up to 0.5 bar. The REG sizes available are from 6mm to 65mm with different sizes of cones to match the required capacity.



1	Stop valve	STC	6	Float switch	AKS 38
2	Stop valve	STC	7	Stop valve	STC
3	Filter	FA / FIA	8	Stop valve	STC
4	Solenoid valve	EVRA	9	Stop valve	STC
5	Regulating valve	REG			

Liquid level regulation using EVRA and AKS 38

Generally on systems equipped with accumulator/ surge drum, the liquid leg is extended downward below the point from where the liquid is fed to the evaporator and a drain valve is provided to allow periodic manual draining of the oil.

Alternative 3: Use of Continuous Modulation Device AKS 4100 and ICM Valve

Modulating liquid level control: This is the most advanced continuously modulating liquid level control system with high accuracy monitoring and controlling of liquid level.

This alternate uses liquid transmitter AKS 4100/AKS 4100U in combination with controller EKC 347 and ICM motorized continuous modulating valve.

The AKS 4100/4100U liquid level sensor is designed specifically to measure liquid levels of most of the refrigerants in vessels, accumulators, receivers, stand pipes, etc. It is based on a proven technology called Time Domain Reflectometry (TDR) or Guided Radar Micro Wave.

The level transmitter AKS 4100 monitors the liquid level in the separator and sends a level signal to the Liquid Level Controller EKC 347 which sends a modulating signal to the actuator of the motor valve ICM.

The ICM motor valve acts as an expansion valve.

The EKC 347 also provides relay outputs for upper and lower limits and for alarm level. However an additional AKS 38 is recommended as a high level cutout to serve as a back-up protection.

AKS 4100 is suitable for different lengths as required and length can easily be adjusted at site. It is available in different lengths from 800 mm to 5000 mm.

AKS 4100/4100U sensors are available in two options either with cable directly immersed in the liquid refrigerant or with co-axial (sleeve) tube. However a stand pipe for installation is generally recommended. The stand pipe diameter can be between 50 mm and 100 mm and the stand pipe length should be vessel diameter plus 120mm each way from top and bottom.

The signal output is 4-20 mA, two wire loop powered proportional to liquid level and does not need separate transformer.

The HMI Display Unit mounted on the top is used during commissioning for quick on-site level adjustments. The digital display can be both in SI and FPS units.

In case of power failure, either a liquid line solenoid valve is recommended to be installed to stop liquid supply or a backup DC power to close the ICM modulating valve is suggested, since the ICM modulating valve would remain open in the same position at the time when power supply fails. Supply voltage to the ICM motorized valve is 24 V dc.

Special features of AKS 4100/4100U

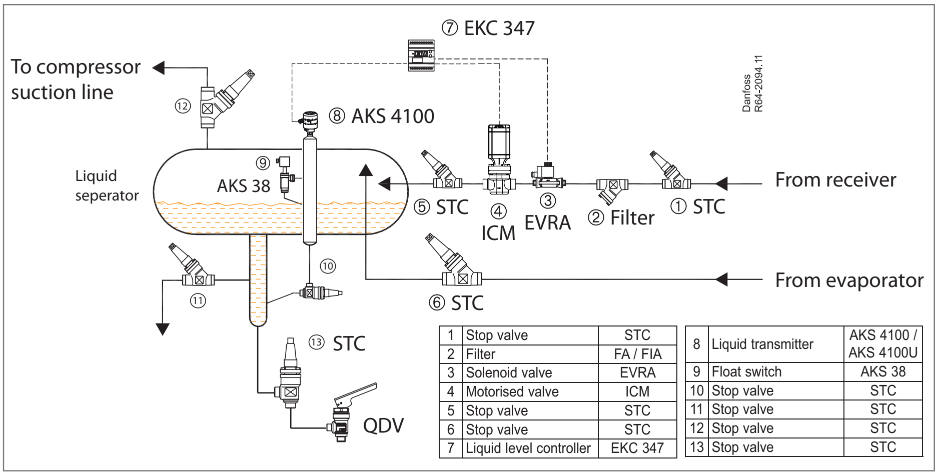
- No need to clean cable version when fully covered in oil.
- Changes of liquid di-electric constant do not affect operation.
- Dust, foam , vapour, agitated surfaces, boiling surfaces, changes in the density for the liquid have no influence on the AKS 4100/4100U.
- Oil accumulated at the bottom of standpipe will not disturb the liquid level signal and it is not necessary to remove AKS 4100/4100U for cleaning after oil has been drained out of the standpipe.
- No stop valves are required between the standpipe and the vessel.
- The HMI Display Unit mounted on the top is used during commissioning for quick on site level adjustments. The digital display can be both in SI and FPS units.
- To carry out check on radar control the head can be easily removed without removing entire steel wire from the standpipe.

Liquid Regulation Devices for Pump Circulation Systems

We shall first look at the advantages/ disadvantages of use of pump circulation system over conventional gravity feed system

The advantages of liquid overfeed or pump circulation systems are

1. The evaporator surface is used efficiently because of good refrigerant distribution and completely wetting of internal tube surfaces.
2. At low temperatures, achieving good heat transfer in the evaporator is crucial since the plant operates with high compression ratios, where quantities of flash gas are appreciable affecting proper wetting of the surface. The fundamentally liquid pump circulation or overfeeding causes more wetting of tubes associated with high velocity of refrigerant results in higher heat transfer rate.
3. There is uniform liquid distribution in all coolers and all perform equally. In gravity flooded systems if the number of coolers is more, the evaporator closer to compressor receives more



1	Stop valve	STC
2	Filter	FA / FIA
3	Solenoid valve	EVRA
4	Motorised valve	ICM
5	Stop valve	STC
6	Stop valve	STC
7	Liquid level controller	EKC 347
8	Liquid transmitter	AKS 4100 / AKS 4100U
9	Float switch	AKS 38
10	Stop valve	STC
11	Stop valve	STC
12	Stop valve	STC
13	Stop valve	STC

Liquid level regulation using continuous modulation device - AKS 4100 and ICM valve liquid whereas the evaporator far away may starve. Also the pressures/temperatures are not equal in all evaporators.

4. Refrigerant feed is unaffected by fluctuating ambient conditions and condensing temperatures. The flow controls need not be adjusted after initial setting since overfeed rates are not very critical.
5. Since all the major equipments containing refrigerant are housed in plant room, the distance between compressors and low pressure ammonia storage vessel is less, thus reducing suction line pressure drops and superheat thereby elevating compressor saturated suction temperature which can lead to power saving.
6. Overfeeding ensures that the vapours coming out of the low pressure evaporator are at close to saturated condition without any superheat, thus lowering compressor inlet gas temperature, which also means corresponding lower discharge gas temperatures, which are critical factors for ammonia systems working at low temperature applications. Higher discharge temperatures pose many problems for compressor lubrication.
7. The compressors are protected from liquid slugs resulting from load fluctuations and due to malfunctioning of controls since suction gas first returns to low pressure vessel and not directly into compressor.
8. Flash gas resulting from refrigerant throttling losses is removed at low pressure receiver before entering the evaporator. This gas is then directly drawn to compressor and eliminated in low side system. It does not contribute to increased pressure drop in evaporators or wet suction return line to low pressure receiver.
9. Because of ideal entering suction gas conditions, compressor lasts longer, there is less wear and fewer breakdowns compared to conventional system.
10. In pump circulation system design, the advantage is one effectively decouples refrigeration system with load allowing more efficient operation and a lot of flexibility for design and operation.
11. Fault finding and trouble shooting is also easier as one can be sure that refrigeration system design is OK so long as enough liquid is available in low pressure receiver at the required temperature to meet the demands of all the evaporators. It is then easier to concentrate on performance analysis of low/evaporator side independently in case proper results are not being achieved. This is not so easy where system is directly responding to load.
12. Refrigerant containing parts like HP/LP receivers, controls, level indicators, alarms, refrigerant pumps and oil drains are located in the plant room under supervision of operator and not far away and therefore can be supervised effectively.
13. Automatic operation is convenient. With simple controls, evaporators can be hot gas defrosted with little disturbance to the system.
14. Oil does not accumulate in evaporators and need not be drained from each evaporator. Oil draining is convenient as low pressure receiver is located in plant room.
15. In case of sudden stoppage of plant the production does not suffer as some liquid at low temperature is available in L.P. receiver acting as a reservoir for some duration.
16. Cost of accumulators and level controllers for each evaporator is eliminated as these are not required for pump circulation systems.

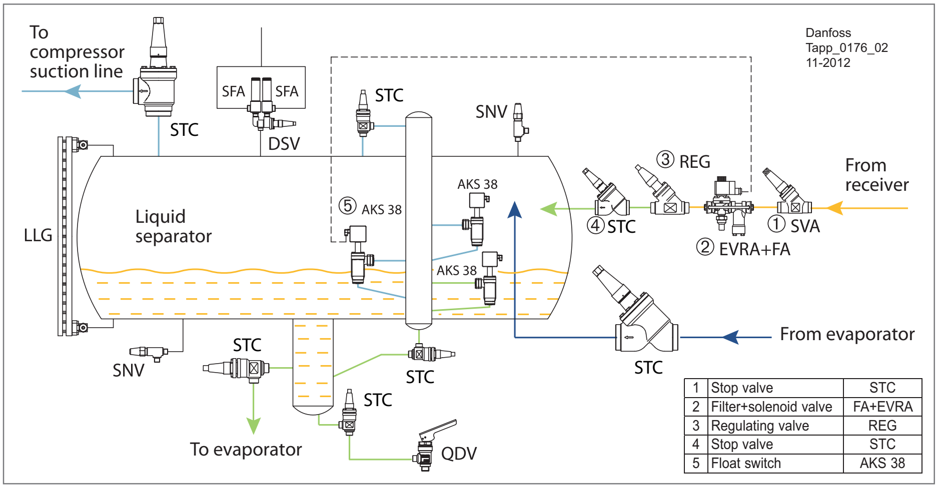
Disadvantages

1. Higher initial cost due to the additional components in overfeed system design over and above the normal gravity flooded systems such as low pressure receiver, circulation pumps and associated controls.
2. Refrigerant quantity in the system is more thus the size of high pressure receiver also increases.
3. Larger diameter of liquid and wet return suction line sizes are needed due to higher circulation rate.
4. Piping insulation is much more since liquid supply lines are also cold needing additional insulation, and suction lines are much bigger.
5. Additional power is required for the refrigerant pumps as also its associated additional maintenance, since it is an additional moving part.
6. In gravity flooded system or pump circulation system, compressor power can be saved by unloading them in response to load and maintenance of room temperatures during holding periods, but pumps would continue to consume power since they have to work round the clock.
7. Expert designer is needed to ensure proper sizing, construction of L.P. vessel, selection of controls, pipe sizing and location and elevations of various equipments to make a package.
8. It is important to design the system in a proper way with sufficiently high liquid column to avoid pump cavitation problems caused by low available net positive suction pressure. Many installations are seen where the NPSH required by pump is more than NPSH available leading to cavitation.
9. Requires proper adjusting of low temperature liquid flow rate and its pressure at the inlet of coolers. Many installers have experienced poor evaporator performance if these are not adjusted properly as most of the surface of evaporator is then used to overcome sub cooling instead of evaporation.
10. If hot gas defrost system is not properly engineered, with both liquid and gas being present in the suction line hydraulic shocks are experienced in many plants using pump circulation systems.

Conclusion

The use of liquid overfeeds system is advantageous:

- When there are more than 4 to 6 evaporators of larger capacity in medium or large cold size cold storages or process plants.
- Plant room is located far away from the processing area where evaporators are located involving lengthy refrigerant distribution pipe work.
- Special evaporators like spiral freezers/IQF or plate freezers are involved.
- The requirement is for medium or low temperature commodity storage.



1	Stop valve	STC
2	Filter+solenoid valve	FA+EVRA
3	Regulating valve	REG
4	Stop valve	STC
5	Float switch	AKS 38

Electronic solution with 38 float switches and liquid regulation valve

The following pages would suggest 4 alternatives which Danfoss can offer for the controls.

The designer and end user can select the alternative which best suits his application requirements.

Alternatives

1. Electronic solution using AKS 38 float switches and REG liquid regulation valve.
2. Using AKS 4100 and AKVA liquid regulation valve
3. Using AKS 4100 float switches and ICM liquid regulation valve, and
4. Using AKS 4100 float switches and ICF liquid regulation module

Alternative 1

Electronic solution using AKS 38 float switches and REG liquid regulation valve.

This is the most practiced and popular solution currently being used. The system uses 3 float switches AKS 38. The main float switch controls liquid level in the LP vessel at around 50% level. The upper float switch serves as a compressor trip in case liquid level rises beyond 65%. This switch can also be used to serve as an alarm. The lower float switch is used to trip the liquid ammonia pump in case the level falls below preset level, around 20%. This switch also serves as an alarm for low level.

All these three switches are mounted on a stand pipe of minimum 100mm diameter and extending 150mm above and below the diameter of the LP vessel. A separate oil drain at the bottom of the stand pipe is provided.

The equalizing connections between float switches and the stand pipe have to be carefully designed so that all three float switches have liquid equalizing on the liquid side and gas equalizing on the gas side. The liquid equalizing lines should be sloping downwards to ensure oil does not accumulate in these lines, which may lead to wrong signal. If the stop valves are installed in the equalizing lines they should be installed with horizontal stems.

The main float switch controlling liquid level activates energizing /de-energizing of the solenoid valve provided in the main liquid line before hand expansion valve REG. The setting of REG is done at the time of commissioning to ensure infrequent hunting of solenoid valve, not more than 3 times per hour.

A stop valve and a cleanable filter prior to the solenoid valve should be installed.

Alternative 2

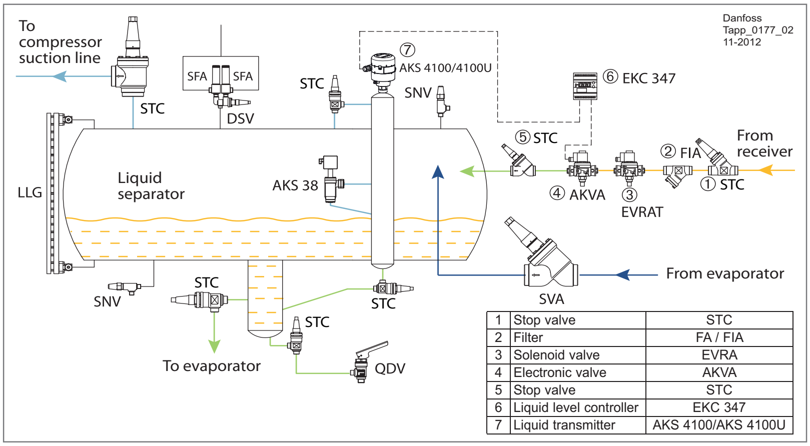
Using AKS 4100 and AKVA liquid regulation valve.

Now in this alternative the hand operated expansion valve REG has been replaced with AKVA pulse with electronically operated expansion valve. The servo valve EVRAT is being used as an additional solenoid valve to ensure 100% closure during OFF Cycle.

Although liquid level controller EKC 347 also provides relay outputs for upper and lower limits of liquid and for alarm levels it is recommended to install an additional high level switch AKS 38 to protect compressor from liquid entry, as an additional safety.

Advantages of AKVA:

1. It does not require adjustment unlike REG valve.
2. It can be used for very wide regulation range.
3. It has a replaceable orifice assembly.
4. Wide range of coils for DC/AC supply.
5. Quick reaction in the whole range of rated capacity.
6. Can be used both as expansion valve and solenoid valve in some applications.



1	Stop valve	STC
2	Filter	FA / FIA
3	Solenoid valve	EVRA
4	Electronic valve	AKVA
5	Stop valve	STC
6	Liquid level controller	EKC 347
7	Liquid transmitter	AKS 4100/AKS 4100U

Using liquid regulation valves

Alternative 3

Using AKS4100 float switches and ICM liquid regulation valve.

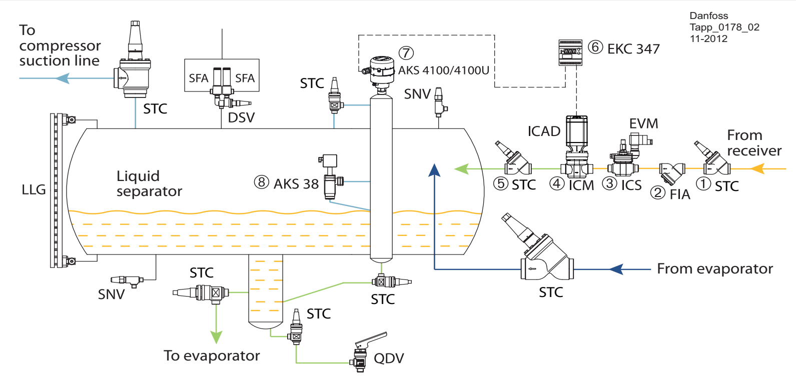
This alternative is similar to alternative 2, except that the AKVA has been replaced by ICM motorised valve.

ICM valves are designed to regulate an expansion process in the liquid lines with or without phase change and therefore can be used to control pressure or temperature in the dry or wet suction lines as wll as in the hot gas lines.

ICM valves are designed so that the opening and closing forces are balanced and therefore only three sizes of actuators are needed to cover entire range from 20 mm to 150 mm. The ICAD actuator gives 4-20 mA output signal by default. In case of power failure a fail safe supply (battery or UPS) is required or a solenoid valve in the liquid line to close the liquid supply may be provided.

These valves provide continuous liquid flow regulation as the load demands and therefore the evaporator receives correct amount of liquid at all times and thus underfeeding or overfeeding is avoided.

For more details on ICM motorized valves and actuators please refer to the Danfoss product documentation.

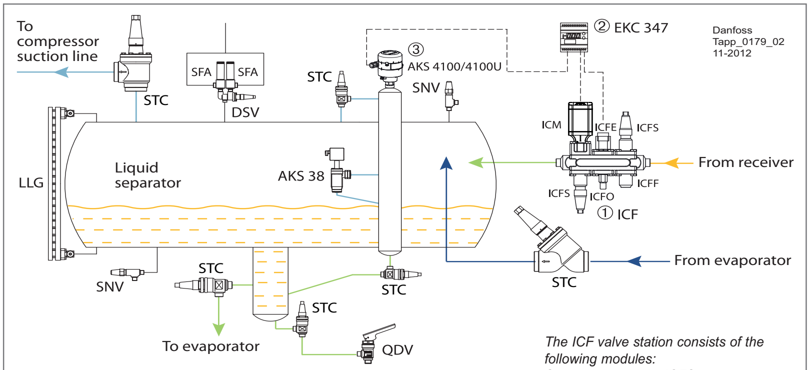


1	Stop valve	STC
2	Filter	FA / FIA
3	Solenoid valve	ICS+EVM
4	Motorised valve	ICM
5	Stop valve	STC
6	Liquid level controller	EKC 347
7	Liquid transmitter	AKS 4100 / AKS 4100U
8	Float switch	AKS 38

Using float switches and liquid regulation valves

Alternative 4

Using AKS4100 float switches and ICF liquid regulation module.



1	ICF valve station	ICF
2	Liquid level controller	EKC 347
3	Liquid transmitter	AKS 4100 / AKS 4100U

The ICF valve station consists of the following modules:
Stop valve module, ICFS
Filter (strainer) module, ICFF
Solenoid valve module, ICFM
Motorised valve, ICM

Using float switches and liquid regulation module

Alternative 4 is the most advanced alternative using all the components as per alternative 3. However these components are mounted on an ICF module. The advantages of this design are;

1. The number of welding joints is reduced from 12 to 2 thus reducing the chances of leakages and site labour.
2. It is supplied as a complete assembly incorporating several functions in a single housing and thus can replace series of conventional mechanical, electro-mechanical and electronically operated valves.
3. It is supplied as a complete assembly and it is leak tested in the factory at high pressure under controlled conditions.
4. The valve is supplied with direct weld connections and thus avoids flange joints.
5. The ICF module uses low temperature steel housing with low weight and compact design thereby avoiding extra piping supports.
6. Side ports for connection of pressure gauges, transmitters, sight glasses or service valves are available.
7. The valve can be used for applications ranging from -60°C to +120°C.
8. This type of design allows maximum capacity with minimum pressure drop using advanced technology and double seats offering higher capacity than conventional systems using individual valves and components.
9. The valves come in 4 and 6 module ports on which following accessories can be fitted depending upon the requirement:
   a. Inlet/outlet stop valves
   b. Manual REG valves
   c. Filter module
   d. Solenoid valve module
   e. Electronic expansion valve module
   f. Check valve/ stop check valve module
   g. Motorized valve module.
10. The external surface is zinc chromated to provide corrosion protection.

For more details on ICF valve station please refer to the Danfoss product documentation.

Part 4 of this series will appear in the July-August 2014 issue of Cold Chain ❖

Danfoss Ammonia Refrigeration

User Guide

Part 4 of 5

By Ramesh Paranjpey

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Defrosing of Air Coolers - Various Methods

The evaporator being the coldest surface in the cold room attracts moisture from the air. This moisture condenses on the evaporator surface, and when the surface temperature is below 0°C frost is formed.

If this frost is not removed, the performance of the evaporator deteriorates since the frost acts as resistance to heat flow as also increases the air side resistance reducing the flow. If the frost is not removed in time and plant is allowed to operate, the evaporator may become totally ineffective, as there will be no air flow or heat transfer and un-evaporated liquid ammonia coming back is likely to damage compressor.

It is therefore essential to defrost the coolers in time to maintain efficiency levels and avoid damage to components. Improper and incomplete defrosting can damage compressor and evaporator coil to the extent that irreparable refrigerant leaks develop when ice is allowed to build up and crush one or more coil tubes. The fan blades are also likely to be damaged if ice builds up on the fan ring. The drain pan gets totally blocked by ice slab and water spills over to floor and ice is formed on the floor as well.

Defrosting is therefore necessary but not in excess also. Defrosting is doubly expensive procedure because energy is used to pump heat into cooler and its surroundings, after which further energy is used to extract the heat from the cooler and its surroundings before the system gets back to its operating temperature. The energy is thus consumed twice, once for forming ice and second time for melting ice.

Defrosting as the name suggests should be activated when frost is formed and not wait till ice is formed on the coil surface. The total energy required to form the ice and defrost it is estimated to be nearly 1.5 kW/Kg of ice (IIAR Condenser Magazine May 2010 issue).

There are various methods of defrosting the coolers and these are described on the following pages with their advantages and disadvantages as well as which method is more suitable for the application under consideration.

Off Cycle Defrost

1. Warm outside air: Outside warm air can be ducted inside to defrost the coil. This method can be adapted to any temperature

in the cold room. It requires ducting and personnel to carry out this defrosting. In colder climates this method is either ineffective or less efficient. The outside air brings moisture and additional heat load on the system.

2. For cold stores operating above 2°C, the evaporator coils can be defrosted by simply turning off the refrigerant flow to the evaporator while maintaining fans running and allowing room air to pass over the evaporator, thus melting off frost. The disadvantage of this process is that it is very slow; however it has the lowest cost and requires no additional controls or energy. This method also does not help in removing accumulated oil in the cooler.

Electric Defrost

This is one of the popular methods for small size air coolers particularly for HFC/HCFC refrigerants. The method can be applied to any cold room application operating at any temperature.

While manufacturing and assembling coils, the dummy tubes are inserted in the coil blocks in a particular pattern and these tubes contain electrical heating elements.

In some designs the heating elements are strapped to the outside of the fin/tube assembly. The advantage of this method is the manufacturer does not have to provide extra dummy tubes.

The advantage of electric defrost is it does not interfere with the refrigerant circuit, and chances of liquid or hydraulic hammer are eliminated.

The system is low in initial cost but high in running cost since it consumes a lot of electrical energy; also it does not help in oil removal from evaporator. In general for a cooler of 30 to 40 kW capacity one requires heaters of nearly 18 kW including drain pan heating and if defrost is done 4 times a day for 30 minutes each cycle, the cost of defrosting alone is 36kWh x ₹5/kWh = ₹180/day or ₹5400/per cooler per month. High maintenance due to frequent failure of resistance heating elements and replacement of burnt heaters is also a tedious job.

Water Defrost

The second most popular method of defrosting air coolers is spraying water on the coil.

The mixture of water and melted frost collects in the drain pan and taken outside the refrigerated space. The advantages of water defrost over other methods are

1. Inexpensive source of defrost medium
2. Short defrost time say 30 to 45 minutes
3. Provides automatic cleaning action of coil
4. Water defrost is most advantageous when there is only one or two coolers and out of which one needs to be defrosted. In such cases enough hot gas is not available to defrost and the hot gas defrost becomes ineffective
5. Normally spiral freezers or blast freezers prefer this method since these are many times single compressor and single cooler units.
6. Water defrosting provides rapid defrosting of coils for virtually all room temperatures. Water is sprayed over the coil and the mixture of water and melted frost flows in the drain pan. The normal water temperature should be around 16 to 18°C or more depending upon wet bulb temperature in the area and flow to be 1 to 3 liters per second per square meter of coil face.
7. This method is less desirable when temperatures decrease below freezing; however it has been successfully used in many applications as low as -40°C.
8. The water used for defrosting needs to be with neutral PH value so that it does not damage fins and filtered so as to prevent choking of spray nozzles.
9. The quantity of water sprayed and the velocity needs to be controlled to ensure that water droplets are not carried in the air stream and into cold room.
10. Warm water from heat reclaim unit can also be used for defrost purpose.

Brine Defrost

The second most popular method of defrosting air coolers is spraying water on the coil.

In case of coils using brines instead of refrigerant, the coils can defrosted by remotely heating brine for the defrost cycle. This system is effective since it provides heat from inside and is therefore as rapid as hot gas-defrost. The heat source for brine could be steam, electricity or condenser water.

Reverse Cycle Defrost

This defrosting method is used in air cooled applications where condenser and evaporator both work on air as cooling medium.

The ideal defrosting should terminate the defrost cycle when the whole cooler is sufficiently warmed above the melting point of ice to ensure the cooler is dry and frost free. This is done most easily in reverse cycle defrosting system where the pressure within cooler gradually rises till the frost disappears.

The defrost cycle may be then terminated. The reverse cycle defrost is very efficient but seldom used since a very reliable four way reversing valve is required. Also this system is used where single cooler and single compressor are working in a system. Rotation of the four way valve through 90° routes the hot gas to cooler instead to the condenser.

When multiple coolers are working on single compressor in the system this system cannot be used for the obvious reason that all coolers cannot be defrosted at a time by reversing the refrigeration cycle. This system is popular in truck refrigeration units

Hot Gas Defrost

It is necessary to thoroughly understand details of working of this system before using the same.

1. Hot gas defrost is the best and most efficient alternative as heat source acts from within whereas water/electrical defrost heat source is from outside.
2. During hot gas defrost cycle, evaporator acts as condenser giving up the heat and converting gas to liquid.
3. Although hot gas defrost is the most effective way of defrosting, it is equally complicated, troublesome and may be inefficient if not properly designed.
4. The basic procedure in hot gas defrost method is to interrupt the supply of liquid refrigerant to evaporator, pump out the liquid to empty the evaporator, restrict the liquid outlet by closing the valve, supply hot gas at high pressure either from compressor discharge or from high pressure receiver to warm the evaporator coil and melt surface frost/ice formation.

5. During the operation the heat from hot gas is absorbed by the metal in the coil/plate and its temperature rises. Once the temperature is high enough, ice/frost on the surface melts and is drained off.
6. Out of the total heat supplied by the hot gas, nearly 50% is used for heating the metal and balance 50% or even more is lost to space surrounding tubes/plates since the temperature of surrounding air is much lower than temperature of the unit.
7. Typical freezer coils have internal volume between 4-6 litres/kW. A coil of 35 kW will have approximately 27 to 50 kg of ammonia liquid and with the initial boil off rate of approximately 1.2kg/min it will take about 20 to 40 minutes to boil out all the liquid from the freezer.
8. Lower the temperature/pressure of hot gas supply, lower would be the loss to space.
9. If the temperature of hot gas is too high, the tendency of plates is to steam. Also as the air temperature goes up, its relative humidity drops. This leads to increased evaporation of surface water. It also adds to refrigeration load if it is a cold storage or if the freezers are in the open area, it leads to fog/mist formation.
10. Warmer temperatures will not necessarily improve defrost efficiency. This is because most of the defrost heat comes from latent heat of hot gas, rather than sensible heat.

The following table for ammonia refrigerant will make the matter more clearer:

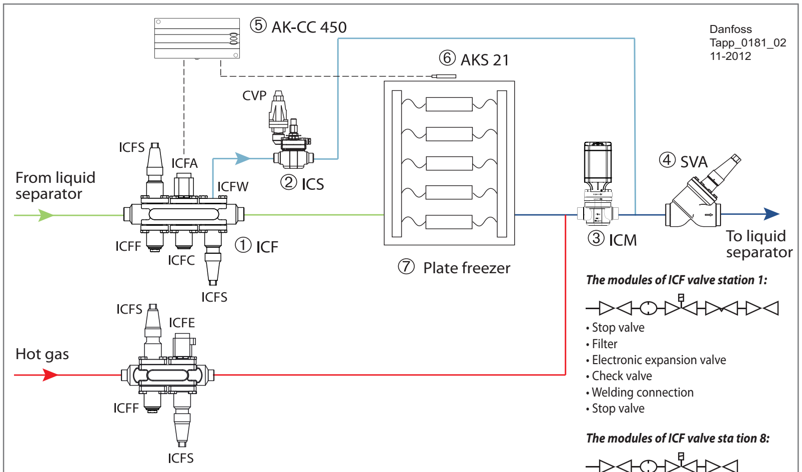
Temperature (°C)	Pressure (Bar)	Latent heat (KJ/Kg)
4°C	4	1240
10°C	5	1220
16°C	6	1200
21°C	8	1180

From the above it can be seen that 21°C defrost temperature would actually require 5% (1240-1180)/1180, more hot gas than 4°C to provide the same latent heat content.

11. At lower defrost pressures the defrosting takes slightly longer time say around 20 to 30 minutes. However with slightly extended defrost times at lower temperature, the overall defrost efficiency is much better than at higher temperature/pressures due to reduction of refrigeration requirements.
12. A pressure regulator in the plant room is therefore required to be installed on the hot gas defrost pipe, set at 7 bar(g) maximum outlet pressure. Another advantage of this lower pressure is less liquid would condense in hot gas line as the condensing temperature is reduced between 11 to 16°C. It is also recommended to have this valve with electric shutoff feature. When no coils are calling for hot gas flow, this regulator will be closed, minimizing the ammonia condensate formed in hot gas supply header.
13. Also having higher pressure in the evaporator means slowing down the flow of hot gas as the pressure difference between hot gas supply pressure and evaporator pressure reduces, since pressure difference is the driving force which allows the hot gas to flow.
14. It is also necessary to keep the defrost gas mains free of liquid. A condensate drainer needs to be installed to drain trapped condensed liquid in the hot gas defrost line. The hot gas tends to continuously condense during cold climate conditions if the pipe is running outside the building or in the cold space in processing areas. The liquid formed must be drained to low pressure liquid line or vessel. The defrost relief regulator setting or OFV setting should be around 5.0 bar(g).
15. It is most important to recognize that at the most only 1/3 of all evaporators/freezers can be defrosted at a time to ensure availability of adequate hot gas for defrost generated due to load on other 2/3 working coolers/freezers. If only one or two coolers are operating and if one of it needs defrost then hot gas defrost system will not work as not enough hot gas is available for defrost.
16. This means if the system has 6 freezers each of 70 kW, total load when all freezers are operating is 420 kW. In such condition only two coolers at the most can be defrosted at a time.
17. Hot gas pipe line sizing should be done to 3 times the working capacity. It means for an installation having 3 nos. 70 kW coolers each, the hot gas defrost line should be sized for 70 x 3=210 kW (50 mm) and the main header from machine room to the production area should be sized for 2 x 70 x 3= 420 kW (80 mm).
18. Defrost condensate return line from freezer should be sized one size higher than liquid supply line as this condensate line may have to sometimes return hot gas in addition to condensed liquid.
19. The critical periods during defrost are at its initiation and at its termination. In both the situations high pressure vapours moving at considerable speed come in contact with cold liquid causing pressure shock waves. One stream is nearly at 7 bar(g), whereas other is nearly at atmospheric pressure or below it.
20. To prevent this, soft hot gas system is adopted for coolers/freezers of larger than 50 kW capacity, which has two solenoid valves; the smaller one opens first reducing pressure gradually in the coil before returning to refrigeration operation. This is a pressure sensing operation either through microprocessor or with set pressure device. Similarly at the initiation of defrost cycle, two valves are used; the smaller one opens first thus gradually increasing pressure in the coil before the second bigger valve is opened. Refer *ASHRAE Refrigeration Handbook,* volume 2010, page 2.26.
21. The soft hot gas defrost system is designed to gradually increase the coil pressure as the defrost cycle is initiated. Sometimes this is done by using small hot gas feed with 25 to 30% of the duty with solenoid valve and hand expansion valve adjusted to bring pressure up to 2 to 2.5 bar(g) within 3 to 5 minutes, before the main defrost valve opens. These days this is done with help of two step valves which perform the above function. The use of these valves avoids extra solenoid valves, expansion valves and extra piping and timers.
22. Similarly once the defrost period is completed a small suction line solenoid valve is opened so that coil/plates can be gradually brought down to operating pressures before full liquid is admitted.
23. A manual initiation of defrost for larger coils/freezers is

recommended based on physical condition of freezer with respect to amount of ice/frost formed on the surface.

24. It is recommended that evaporator defrost should be returned to intermediate pressure vessel and not to low pressure vessel in case of two stage system. This has two advantages. Firstly it does not disturb the LP vessel pressure/temperature conditions during defrost operation and thus other operating coolers work without any disturbance. Secondly defrost liquid pressure and intermediate vessel pressure difference is much lower than defrost pressure and LP vessel pressure and thus saves considerable energy.
25. The non-return valve in main supply line after solenoid valve is essential to ensure that high pressure developed during defrost in the coil does not exert back pressure at the outlet of solenoid valve , since the inlet pressure is normally either equal to evaporator pressure or pump discharge pressure.
26. Advantage of regulating pressure to 7 bar(g) in the equipment room is there is less chance of coils getting damaged or bent or ruptured as low side of the system is normally designed for 10 bar(g) and hot gas at 8 bar(g); higher pressure is dangerous to the low side parts of the system. To be safe it is recommended that low side should be also designed for 20 bar(g) and pressure tested to 1.25 times pneumatic pressure.
    Example: A 70 kW coil defrosting for 12 minutes will condense up to 11kg/min of ammonia of total 132 kg. The enthalpy difference between returning low stage –40°C and intermediate vessel at –7°C is 148kJ/kg. i.e. 27kW removed from the –40°C booster compressor for 12 minutes during each defrost.
27. An excessive noise and shock or vibrations observed during defrost is not normal and if observed cause must be corrected.
28. Many times hot gas is taken from top of receiver instead of compressor discharge, to ensure adequate amount of hot gas availability.



1	Valve station	ICF
2	Pressure regulator	ICS
3	Pressure regulator	ICM
4	Suction line stop valve	STC
5	Digital thermostat	AK-CC
6	Temperature sensor	AKS 21
7	Plate freezer	
8	Valve station	ICF

Standard hot gas defrost circuit for cold rooms and freezer rooms used for holding the product

Defrost Control

Defrost initiation can be done once the frequency and duration of defrost cycle is established. Control schemes are generally implemented by means of an electric or electronic timer, or a computer based control logic.

1. Mechanical timer clock: This allows coolers to be defrosted at fixed but adjustable set intervals. The advantage is the operator does not have to remember when to defrost. The disadvantage is even when coil does not need defrosting the timer would automatically activate defrost cycle. Many times when the products are freshly loaded the required defrosting frequency is higher and once the products reach the desired temperatures, defrosting frequency is less. This requires re-adjusting timer settings.
2. Microprocessor controllers: They have mostly replaced mechanical timer clocks. The use of microprocessors reduces energy consumption and helps in maintaining product quality.
3. Thermostat: A return air thermostat is also used to activate defrost cycle or timer by closing the liquid line solenoid valve.
4. Ice thickness sensor: An ice thickness sensor is attached to the coil and when thickness builds to a particular size it touches the sensor and activates defrost cycle. This method is used many times in ice bank/ice reserve units for dairies.
5. Air temperature difference: Sensors are provided at coil inlet air path and outlet path and defrost controller is set at particular ΔT. If the coil gets frosted this temperature difference reduces and the defrost sequence is activated.
6. Air pressure differential controls: Instead of temperature difference, one can use a differential pressure monitor/controller. As the frost accumulates the ΔP across the coil increases , activating defrost cycle.
7. Reverse cycle defrost: this system uses four way valve and at preset intervals the refrigerant flow is reversed so that condenser acts as evaporator and evaporator acts as condenser. These systems are popular in truck refrigeration units using HFC refrigerants.

Many times a combination of hot gas defrost for coil and electric defrost for drain pan is used. It is also essential to provide ring heaters for fans to avoid fan blades getting damaged.

To terminate hot gas if the room temperature tends to rise is also provided which overrides the pressure/temperature differential sensors and activates cooling cycle even when coils are not defrosted fully so that product and room temperatures are maintained within the allowable limits.

Sequence of Operation of Hot gas Defrost Cycle

Initiation of Defrost

1. Based on the condition of ice formation on the freezer, defrost toggle switch provided on the control panel is activated manually. In certain cases the defrost sensors, which either sense ice buildup thickness, or preset pressure drop across the coil or fixed timer setting frequency is used to defrost based on demand.
2. For batch load applications like Blast Freezer/Plate Freezer or Individual Quick Freezer (IQF), the demand defrost method should not be used. The defrost sequence should be initiated manually. A separate Electric switch to manually activate defrost cycle shall be provided. Once the cooling cycle is over and the doors are opened the control can be put on defrost mode. The defrost timing or room temperature sensor(s) are over ridden. Before the product is reloaded and doors are closed and the control can be put on cooling mode. The cooling cycle time is variable based on the product to be frozen and hence a manual operation of initiation and termination through control switch has to be carried out.
3. ***Closure of Liquid Line Solenoid Valve: Liquid Pump Down***
   On defrost cycle activation; first the liquid line solenoid valve shall be closed which starts evaporator liquid pump out cycle.
4. ***Fan Time Delay Phase to Switch Off***
   All the fans at this stage must be running to provide high liquid refrigerant boiling off rate. Fan motor heat also additionally provides quicker boiling off liquid. If the fans are on VFD, during starting of defrost cycle the fans must be run at full speed. This is to ensure the coil gets empty as quickly as possible. After a time delay of 3-5 minutes the fans are stopped through a preset timer thereby stopping the air circulation. The period required is around 3 to 5 minutes depending on size of evaporator and the internal volume to ensure that entire liquid has been pumped out. During this period the suction line or wet return line valves remain open and pump out the liquid from evaporator.
5. ***Closure of Wet Suction Valve***
   After the time delay of 3 to 5 minutes based on adjustable set point timer, the wet suction line solenoid valve is closed and the fans are switched off thus isolating the cooler from the system.
6. ***Supply of Hot Gas***
   a. Soft Gas Phase (for coolers having capacity higher than 50 kW): On low temperature pump recirculation systems, a small solenoid valve should be installed in parallel with the larger hot gas solenoid valve. This smaller valve opens and gradually introduces hot gas in the coil. Opening of this valve first further reduces the likelihood pressure shocks. At the conclusion as per electronic adjustable timer settings this solenoid closes, simultaneously opening main hot gas solenoid valve, admitting hot gas in the evaporator and warming up the evaporator surface.
   b. Main solenoid valve in hot gas line then opens by using two solenoid valves thus achieving soft gas defrost for coils above 0.14m^3 of internal volume.
   c. During this period the condensate liquid line valve also remains closed so that evaporator has no outlets open and thus allows the coil pressure to build up around 5 bar as the OFV valve is preset for this pressure.
7. ***End of Hot Gas Defrost Cycle***
   a. Once hot gas defrost cycle is completed (normally 5 to 15 minutes based on the size of the coil), the suction line opens gradually by using a two step solenoid valve and pressure from freezer is released to wet return line.
   b. The condensate accumulated due to condensation of hot gas is also drained to wet return line as the OFV valve opens at this time. Some systems use condensate float trap also.
   c. There is also an overriding thermostat which terminates the defrost cycle if the room temperature tends to increase beyond acceptable limits.
   d. Liquid line solenoid valve and suction stop valves will now open and would allow liquid refrigerant to evaporator. The amount of liquid admitted is controlled by pre adjusted flow regulating valve cum non return valve or hand expansion valve or motorized valve as the case may be. This initiates cooling operation.
   e. If the dual opening valve has not been installed in wet return line and normal solenoid valve has been provided in line, then similar to liquid line an additional solenoid valve in parallel is required to be installed. This valve opens first and allows the pressure in the coil to reduce slowly. This eliminates system disruptions, which would occur if warm refrigerant were released quickly into suction piping. This also reduces vapour propelled liquid, and prevents sudden loading of compressor if suction pressure rises quickly.
8. ***Fan Delay Time***
   The fan is not yet energized. Instead, the coil temperature is allowed to drop, freezing any water droplets that might remain on the coil surface after the hot gas defrost phase, thereby preventing the possibility of blowing water droplets off the coil into refrigerated space.
9. ***Start of Cooling Cycle***
   After the fan delay has elapsed, the fan gets energized automatically based on time setting. The refrigeration phase continues until the next defrost cycle is initiated.
10. The entire process can take maximum 15 to 30 minutes depending on size of evaporator and available quantity of hot gas.

Steps 1 to 10 are all built into the control circuit of the controller. The timings can be adjusted to suit particular evaporator model and size since adjustable electronic timers are provided in the controller.

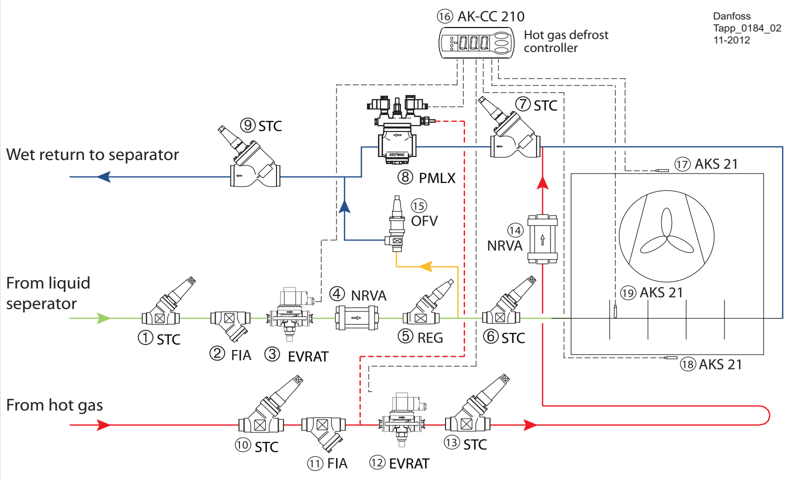
If the application is a blast freezer/plate freezer or spiral freezer/IQF which is a batch production the demand defrost method should not be used. The defrost sequence should be initiated manually. A separate electrical switch to manually activate defrost cycle can be provided. Once the batch cooling is over and the doors are opened, the switch can be put on defrost mode. The timing of defrost or room temperature sensor are over ridden because of the switch. Once the product is reloaded and doors are closed the switch can be put on cooling mode. The timing of cooling cycle is variable based on the product and hence a manual operation of initiation and termination through switch has to be carried out.

The diagrams shown are for freezers having bottom feed arrangement. Similar arrangement is possible for top feed coils also. The suggested diagrams are shown in *ASHRAE Refrigeration Handbook* 2010, page 2.24-2.26.

The simplest approach, from a defrost standpoint is top fed, medium temperature unit with vertical circuits. The liquid in such coils drains by gravity through open suction stop valve when liquid solenoid is closed. Any cold liquid that remains in the coil when suction valve is closed will be distributed evenly among the circuits. Hot gas injected into top of the coil will condense and force the colder liquid out.

As long as hot gas is condensing, only liquid will flow through the defrost regulator. This permits the use of regulator much smaller than either the hot gas solenoid or the suction stop valve.

Attention should be given to this arrangement at the end of the defrost cycle. If hot gas continues to be injected after all the frost is melted, condensation will cease and vapour will flow through the regulator. This will cause the coil pressure to increase, which serves as an indication to the operator that hot gas injection period need to be adjusted or decreased.



Hot gas Defrost for bottom Feed Evaporator Coils

1	Stop valve	STC
2	Filter	FA / FIA
3	Solenoid valve	EVRAT
4	Check valve	NRVA
5	Regulating valve	REG
6	Stop valve	STC
7	Stop valve	STC

8	Solenoid valve	PMLX
9	Stop valve	STC
10	Stop valve	STC
11	Filter	FA / FIA
12	Solenoid valve	EVRAT
13	Stop valve	STC
14	Overflow valve	OFV

As an alternative to STC stop valves SVA stop valves can also be used.

For further information please contact your local Danfoss sales office.

Hot gas defrost for pumped liquid circulation

The defrost cycle has two major areas which need to be considered while designing the system.

1. ***Hydraulic Shock/ Pressure Shock:*** This occurs in two phase systems experiencing pressure changes. This occurs most frequently in low temperature ammonia systems and is often associated either at the beginning or at the termination of hot gas defrosting.

   Pressure shocks can be grouped in 3 categories:

   a. Sudden liquid deceleration is caused by fast acting solenoid valve which suddenly closes. Sudden stoppage of liquid flow generates a pressure pulse similar to water hammer.

   b. Vapour propelled liquid is normally observed in liquid overfeed systems. Vapour propelled liquid results from the sudden release of high pressure vapour into a line that is partially filled with liquid, i.e. wet return line. The impact can severely damage system components/piping.

   c. Condensation shock occurs when high pressure vapour is quickly introduced in the liquid slugs remaining in the coil. This causes the imploding pockets to generate large pressure waves in the system.

The components that normally fail are evaporators, wet return lines or headers from evaporators. Generally noise is associated when hydraulic shock is experienced.

To decrease the possibility of hydraulic shocks, the following engineering guidelines are suggested:

   a. Hot gas piping should include no liquid traps. A liquid drainer is suggested in the defrost line if it is running too long. Minimize condensate in the hot gas header line.

   b. The evaporator must be fully drained before opening the hot gas valve. No liquid slugs/pockets should remain in the coil.

   c. Size hot gas pipe lines and valves as small as possible to reduce peak mass flow rate of the hot gas.

   d. The liquid level in L.P. vessel is maintained not higher than 80% or lower than 20%. Draining the vessel or overfilling puts gas in the liquid lines or liquid in gas lines and can cause hydraulic shock.

2. The second area of concern is draining the condensed water from the drain pans in the headers or to outside drains and requires special engineering and piping design skills to ensure that drained water is easily drained out from the cold rooms and does not freeze in the trays, overflow in the cold room getting converted into ice or choke the drain lines with ice.

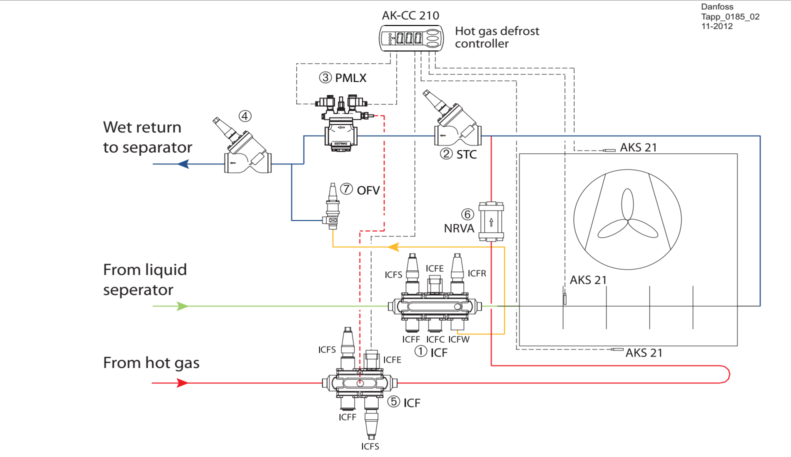
The drain points coming out of rooms should be provided with sufficient height to have liquid leg and provided with 'S' trap to ensure outside air does not leak in the room.

- IIAR-T163 – *Hot Gas Defrost Systems for Large Evaporators in Ammonia Liquid Overfeed Systems*
- ASHRAE, volume 2010, Refrigeration, Chapter 2.24-2.26
- Danish Technological: *Guidelines for hot gas defrost*
- Danfoss Denmark: *Refrigeration Controls for industrial Refrigeration*

Refrigeration liquid and hot gas flow, depending on whether refrigeration or defrost cycle is ON, takes place in the following manner:

Refrigeration: 1→2→3→4→5→6→Evaporator→7→8→9→Liquid separator

Hot gas defrost: 10→11→12→13→Evaporator→6→14→Liquid separator



Hot gas Defrost for bottom Feed Evaporator Coils

1	Valve station	ICF
2	Stop valve	STC
3	Solenoid valve	PMLX
4	Stop valve	STC
5	Valve station	ICF
6	Check valve	NRVA
7	Overflow valve	OFV

The modules of ICF valve station 1:

- Stop valve
- Filter
- Electronic expansion valve
- Check valve
- Welding connection
- Stop valve

The modules of ICF valve sta tion 5:

- Stop valve
- Filter
- Electronic expansion valve
- Stop valve

As an alternative to STC stop valves SVA stop valves can also be used.
For further information please contact your local Danfoss sales office.

Hot Gas Defrost for Pumped Liquid – ICF Valve station

Valve number	Type	Refrigeration cycle	Hot gas cycle
3	EVRAT	OPEN	Closed
8	PMLX	OPEN	Closed
12	EVRAT	CLOSED	Open
14	OFV	CLOSED	Open

Refrigeration Cycle

The solenoid valve EVRAT (3) in the liquid line is kept open. The liquid injection is controlled by the hand regulating valve REG (5).

The solenoid valve PMLX (8) in the suction line is kept open and the defrost line solenoid valve EVRAT (12) is kept closed.

Defrost Cycle

After the initiation of the defrost cycle, the liquid supply solenoid valve EVRAT (3) is closed. The fan is kept running for 120 to 600 seconds depending upon the evaporator size to pump down the evaporator of liquid.

The fans are stopped and the PMLX valve (8) is closed. It takes about 45 to 70 seconds for the PMLX valve to close depending upon the size of the valve. A further delay of 10-20 seconds is required for the liquid in the evaporator to settle down in the bottom without bubbles of vapor. The solenoid valve EVRAT (12) is then closed and hot gas is supplied to the evaporator.

During the defrost cycle the overflow valve OFV (14) is initially closed; however it opens automatically subject to the set differential pressure. The overflow valve allows the condensed hot gas in the liquid form, from the evaporator to be released into the wet suction line. It is advisable to install a pressure gauge to accurately set the OFV between 5-6 bar differential.

When the temperature in the evaporator reaches the set value (measured by the AKS 21 on the coil surface) the defrost cycle is terminated, the solenoid valve EVRAT (12) is closed and the PMLX valve (8) is opened. After the PMLX fully opens, the liquid supply solenoid valve EVRAT (3) is opened to start the refrigeration cycle. The fan is started after a delay in order to freeze remaining liquid droplets on the surface of the evaporator.

Refrigerant liquid and hot gas flow depending on whether refrigeration or defrost cycle is ON, takes place in the following manner:

Refrigeration: 1→Evaporator→2→3→4→Liquid separator

Hot Gas Defrost: 5→6→7→8→Evporator→9→Liquid separator

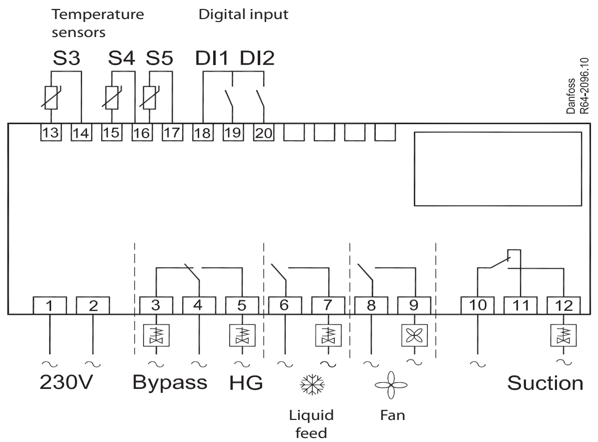
Hot Gas Defrost Controller – AK-CC 250

This controller is used for controlling the hot gas defrost cycle start and end. It contains a temperature control where the signal can be received from one or two temperature sensors.

These temperature sensors are placed in the cold air flow after the evaporator and the warm air flow before the evaporator. These are denoted by S4 and S3. The measurement of the defrost temperature is directly obtained through the use of another sensor designated as S5. This is placed on the evaporator.

The controller will constantly follow the temperature at S5. Between two defrosts the evaporator ices up (the compressor operates for a longer time and pulls the S5 temperature further down). When the temperature passes a set allowed variation the defrost will be started. Depending on this logic signal from this controller is used to solenoid valves to either start the hot gas defrost or continue with the refrigeration.

The wiring logic of the AK-CC 250 to be followed for the defrost control is shown below:



Wiring logic of AK-CC 250 hot gas defrost controller

In general, the defrost system with demand defrost actuator can be employed for coils up to 350 kW that are installed in holding freezers. If the coils are used in a spiral freezer, and Individually Quick Frozen (IQF) freezer or Blast/Plate/Trolley Freezer, the demand defrost feature is not suitable. The defrost sequence in such cases should be initiated only manually. ❖

Danfoss Ammonia Refrigeration

User Guide

Part 5 of 5

By Ramesh Paranjpey

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Capacity Control for Refrigeration Systems

Why and how to use Capacity Control

The simplest form of capacity control is on-off cycling for the reciprocating compressors. Under light load conditions, this could lead to short cycling and could reduce the life of the compressor.

On systems where ice formation is not a problem, users will sometimes lower the low pressure cut out setting beyond the design limits in order to prevent short cycling. As a result, the compressor may operate for long periods at extremely low evaporator temperatures. Compressor capacity decreases as suction pressure decreases. Refrigerant velocity is inadequate to return oil to the compressor resulting in high compressor superheat, which causes the compressor to overheat. All of these conditions can cause pre-mature compressor failure.

Capacity control allows more continuous operation of the compressor, minimizing electrical problems and improving lubrication.

There are many ways to achieve capacity control. Variable speed compressors, hot gas bypass with or without liquid injection, unloading, digital control for scrolls, and simple on/off compressor operation on multiple compressor setups.

Some applications will use two or more methods for smoother switching and better control such as unloading in conjunction with hot gas bypass.

It is an accepted fact that refrigeration systems seldom operate at the peak load for which they are designed. In any refrigeration application, the load on the system varies over a wide range.

The refrigeration system designer has to, however, provide enough capacity to meet peak demand as well as some methods to make the system operate efficiently at reduced loads.

For example, the loads in cold storage vary widely due to the fact that when product is loaded at ambient temperautre in cold rooms, the amount of heat to be removed to bring the product to the desired temperature in a given time is very high, whereas once the product cools down to design storage temperature, the refrigeration load requirement reduces considersbly. Freezing plants may have varied equipments like IQF, blast/trolley freezers, plate freezers to process a variety of products but all equipment may not run simultaneously. In process plants the load may vary due to the fact that all processes may not be working at a time or peak output may not be required and products are produced in quantities to match market demands. The variation in ambient temperature conditions also affects the refrigeration load on systems.

When the system operates under partial load conditions, suction pressure and temperature are lower than they are under full-load conditions. This is due to the fact that less vapour is generated in evaporator due to reduced load, whereas the compressor running at constant RPM displaces a constant volume per unit of time. It does not recognize reduction in system load.

If the system capacity is in excess of load requirement, freezing of moisture on the evaporator coil may result. The 'frost' on the coil decreases the amount of air that can pass through the coil, which in turn lowers the suction pressure and temperature further. The excess un-evaporated liquid may enter the compressor suction line and cause damage to compressor parts.

It is also important to understand that the stabilized system capacity is determined by all the components working together in equilibrium and not by the compressor alone. The weakest/smallest component generally governs the overall capacity. Although the capacity is measured in terms of Btu/hr or Kcal/hr or watts, the number of pounds/kg of refrigerant circulating, meaning mass flow rate, determines the capacity.

The system that operates most efficiently, safely and with the most stability will be the one that does the best job of matching system capacity with load for the entire load range, and each and every component of the system, therefore, has to have some means of capacity modulation to match the load.

For high, medium, and low temperature applications, compressor capacity modulation can reduce power and energy consumption, provide better and continuous dehumidification, reduce compressor cycling and decrease the starting electrical load and provide good oil return if properly piped.

Working of Compressor

The refrigeration compressors used in ammonia refrigeration systems are of two types:

- Reciprocating compressors - open drive with external motor
- Screw compressors - open drive with external motor

Both type of compressors are classified as positive displacement machines which means increase in pressure takes place due to reduction in volume.

The reciprocating compressor for a given speed is a constant displacement volume, variable mass flow and variable compression ratio machine, whereas a screw compressor has fixed internal compression ratio due to the geometry of discharge port profile.

Riding with the Load

To a certain extent, the compressor automatically adjusts its capacity downward as system load decreases. A compressor running at constant speed displaces a constant volume per unit of time. For example a reciprocating compressor pumping 10 cubic meter/hr is displacing a constant volume of 10 m^3/hr. As long as the compressor runs without any speed reduction or cylinder unloading, it will continue to displace gas at this rate.

Its capacity to transfer heat, however, is determined by its mass flow rate. That is, its capacity to move heat depends upon how many kgs of refrigerant (the mass) it pumps per unit time (kg/hr) and not on how many cubic meter of refrigerant it moves per unit time (m^3/hr). The mass flow rate changes depending upon suction or inlet pressure conditions. This means that while the volume flow rate is constant, capacity will change with changing operating conditions.

For example, Ammonia compressor having saturated suction temperature as 5°C has specific volume of vapour as 0.243m^3/kg. It means the mass flow rate would be 41.15 kg/hr.

When the load reduces the suction pressure drops. Let us consider that it drops to 2°C. The specific volume then is 0.27m^3/hr, and the mass flow rate therefore is 10/0.27= 37 m^3/hr. It can be thus observed that compressor has automatically adjusted to reduced load by pumping lower mass (kg/hr).

Now let us consider that the load increases and the suction pressure increases to SCT 10°C. The specific volume now is 0.206 m^3/kg and the mass flow rate would be 10/0.206 = 48.54 kg/hr, indicating that the same 10 cubic meter/hr displacement compressor is now pumping more mass of 48.54 kg/hr instead 41.15 kg/hr at 5°C saturated suction conditions.

If floating with the load as indicated above satisfied all necessary capacity adjustments at part load, controlling the capacity of compressor would not be necessary. However, there are limitations as to how far the load can vary while maintaining safe stable part load operation while maintaining efficiency. Maintaining constant suction pressure as designed would lead to better efficiency at all part load conditions and hence some methods of capacity control are necessary.

To discuss compressor capacity control systems so that the load and output from refrigeration system are matched, it is necessary to briefly look at how the compressor works.

The refrigeration compressor circulates refrigerant in the system. The compressor takes in low pressure, low temperature and superheated refrigerant gas after it has done its work of picking up heat in the evaporator where liquid refrigerant gives up its latent heat and gets converted to gas. This gas is compressed by the compressor to a high pressure and high temperature, superheated gas and high enough temperature to reject heat to the condenser, where refrigerant is condensed back in to a liquid.

The compressor manufacturer cannot determine the system capacity. All that a refrigeration compressor can do is to pump a volume of gas. Once the suction and discharge conditions at the compressor are specified, the mass flow of refrigerant can be calculated. But the refrigeration capacity is not related directly to the conditions at the compressor. The system designer should ask for the mass flow rates at specified conditions in order to get correct selection of the compressor from the manufacturer.

The designer must accept that when they buy a refrigeration compressor it pumps only a volume of gas, and not refrigeration capacity.

Capacity Control Methods for Various Types of Compressors

We shall now discuss capacity control arrangements for compressors for optimum system performance.

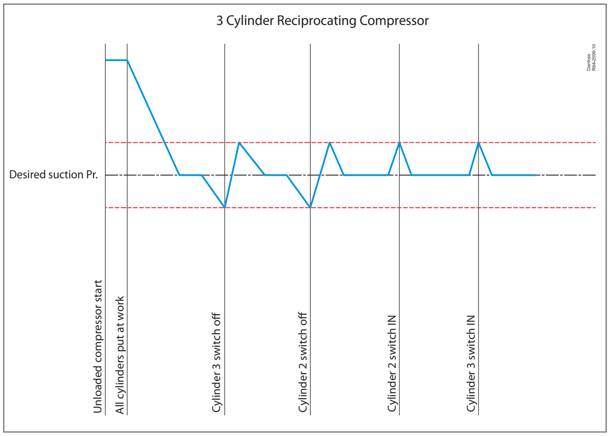
Reciprocating Compressors

Following strategies are generally adopted depending upon the size of plant, accuracies required, degree of automation and other considerations:

1. Use of multiple compressors - Rack systems: Depending upon the load, compressors are cycled on/off and this leads to a large amount of power reduction. Each compressor is of maximum 20 ton capacity ared racks can be build with 4 or 5 compressors.
2. Hot gas bypass arrangement with or without liquid injection: This arrangement ensures that compressor does not trip on suction pressure when system load is extremely low, below the compressor minimum capcity control step. Artificial load is imposed by high preesure hot gas in the suction line or before the evaporator entry. The disadvantage of this system is that if the compressor is overdesigned, the period of compressor operation on hot gas bypass circuit is too long and compressor wear out is faster. Also, running on hot gas by-pass does not lead to power saving.
3. Two speed compressors: Normally used in semi-hermetic compressors. The speed is changed in response to a thermostat or pressure signal. When initial load is high, one can run the compressors at higher speed with 2 pole motor and when the load comes down and the requirement is holding load, one can switch to 4 pole windings so that speed is reduced to half from 3000 RPM to 1500 RPM.
4. Use of VFD drives/speed control: This solution is applicable fro all types of compressors, and is an efficient method. VFD costs have come down substantially and it is now arttractive to use variable drive for compressors.

   The advantage is that during initial cool down, when load is high one can run the compressor with 60/70 Hz frequency for a short duratiion to get higher capacity and then match the capacity to load requirement by sensing either suction pressure or, if it is fluid, sensing the temperature. The frequency converter thus can vary the rotational speed continuously to satisfy the actual laod demand.

   The other advantage of frequency converter is that it allows low start-up current. The limitation being one cannot exceed allowable lower and higher speed limits of compresors, especially reciprocating due to the likelihood of suffering from inadequate lubrication. In screw compressors, where independant oil pump has been provided and lubrication circuit is not dependent on compressor RPM, VFDs are preferred options.
5. Step control - Cylinder unloading in multicylinder compressors:



Sequence of cylinder loading and unloading in case of a typical 3 cylinder reciprocating compressor

The capacity of these compressors is regulated by means of a valve lifting mechanism.

As soon as the compressor starts running on fully unloaded condition, the high pressure oil pump begins to develop oil pressure and after set time delay the high pressure oil is delivered through three way solenoid valve to valve lifting mechanism and the cylinders get loaded. The arrangement of loading or unloading the cylinders differs from manufacturer to manufacturer.

Some manufacturers use compressed gases instead of oil pressure to load the cylinders.

The cylinders can be switched on or off by using pressostats or thermostats.

In refrigeration plants, using several compressors on common suction line or using single compressor with multiple capacity control steps through 3 way solenoid valves, a suction pressure transmitter is preferred, whereas for applications using chilled water or brine, signal from thermostat can be used.

The pressostat fitted in the suction line carries a contact on both sides of its neutral middle position.

When pressure gets too high due to increase in load requirement, the contact

Screw Compressors - Capacity Control

Screw compressors, unlike reciprocating compressors, do not have suction and discharge valves. They have what is called a built-in volume ratio. Vi is the ratio of volume at the rotor groove pair at the beginning of compression and volume of the same rotor pair grooves at the end of compression at the outlet.

Volume ratio (Vi) is the same ratio of discharge pressure to suction pressure since volume ratio is also related to pressure ratio. In most of the screw compressor designs, Vi by design and selection of particular model is fixed unlike reciprocating compressors, where Vi is constantly changing automatically, the reason being for a given Vi, the discharge port pressure is fixed irrespective of the condensing pressure imposed by the system.

For screw compressors, two forms of variable volume control are available:

1. Adjustable volume ratio (Vi)
2. Automatic variable volume ratio (AVi)

Care is taken during compressor selection to ensure that the correct volume ratio is selected by comparison to the chosen operating conditions. However, in many instances the compressor is selected for peak conditions which apply only for few days in a year.

While it is essential to select a compressor that is capable of operating in extreme conditions, it does not follow that the compressor will necessarily always perform at the highest possible efficiency.

The variable Vi concept, coupled to slide valve, which moves parallel to the axis of rotors, offers alternative method of controlling capacity and volume ratio to suit site conditions.

Where the pressure ratio across the compressor is consistently high or changes in pressure ratio are infrequent (e. g. change from winter to summer), MVi manually adjustable system, which is economical, will work satisfactorily.

Where the pressure ratio is lower and where condensing conditions vary frequently, the automatic AVi system is ideal.

The system works as under:

The compressor is fitted with a built in sliding valve which controls the capacity of the machine by altering the point on rotor length at which compression begins. The slide valve moves along the axis of the rotors.

The slide valve can be operated either manually, or automatically by hydraulic actuator.

The position of slide valve ensures that the discharge pressure of the compressor is equal to the system pressure, thus over or under compression, which leads to system inefficiency and excessive power consumption, is eliminated.

When partial load operation is taking place, a signal is provided by the microprocessor and the slide valve is adjusted to allow partial gas bypass to the suction side, delaying the compression and reducing the suction volume. As the suction volume is reduced, in part load, in order to maintain the discharge port pressure, the discharge port area is also reduced by moving the slide valve.

The oil pressure for the hydraulic actuator is provided from the compressor oil system and the solenoid valves responding to suction pressure or air/fluid temperature through microprocessor energize/de-energize leading to movement of slide valve.

This movement of slide valve, in response to evaporator load, is by different mechanisms in different screw compressor designs such as an electric impulse motor or a linear variable displacement transducer - operating through hydraulic piston. Control down to 10% with approximately proportional saving in power is obtained.

It can be thus seen that in screw compressor control through unit's microprocessor, the system provides very accurate control at maximum efficiency at all operating conditions; providing capacity control from 100 to 10% is possible but the efficiency drops at part load. The power consumption below 50% capacity however is not reduced linearly and therefore running screw compressors below 50% capacity is not economical.

Some manufacturers have developed multistage control systems which function similar to slide valve control.

The control unit comprises of hydraulically operated pistons, which at full load operation form fit with the end flange. The pistons open when the pressure in the crankcase is above the normal operating pressure, which is usually the oil/condensing pressure. Thus automatic start unloading is guaranteed and also protects against abnormal high discharge pressure or over compression.

In part load operation, it is two step capacity control. The piston moves due to energizing of solenoid valve in two steps controlled by either time delay or on demand control and is adjustable to suit exact load. When the solenoid is de-energized, the piston moves to the right and thus causes space to be opened up between profile chamber and suction side, thus reducing active volume.

The system is designed for two control steps, so that through the intermittent switching of the solenoids valves it is possible to achieve exact match of compressor capacity with load. The step is 70% of the capacity (0-75%-100%).

Danfoss Capacity Controller AK-PC 530

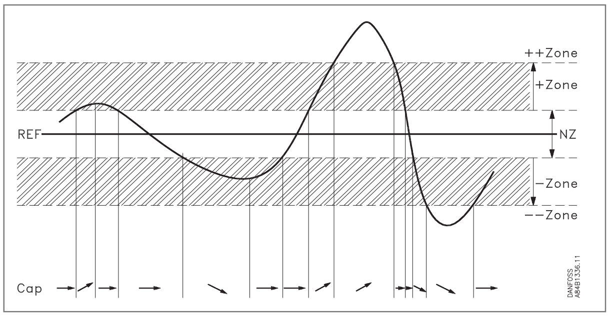
Danfoss uses AK-PC 530 capacity controller for the purpose of capacity control of reciprocating compressors. A number of compressors and condensers can be connected as required. There are up to eight outputs and more can be added via external relay modules. For the operation of this controller, display type EKA 164 or EKA 165 has to be connected with this controller.

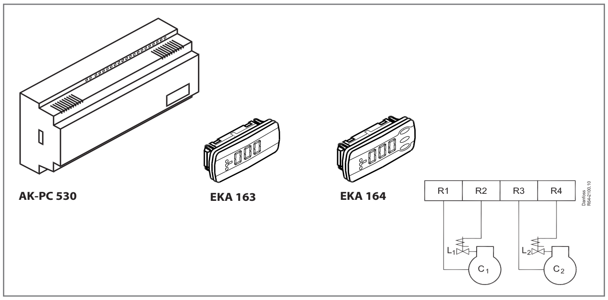
Function

Capacity Regulation:

The cut-in capacity is controlled by signals from the connected pressure transmitter/temperature sensor and the set reference. Outside the reference a neutral zone is set where the capacity will neither be cut in nor out. Outside the neutral zone (in the hatched areas named +zone and -zone) the capacity will be cut in or out if the regulation registers a change of pressure 'away' from the neutral zone.

Cut-in and cutout will take place with set time delays. If the pressure however 'approaches' the neutral zone, the controller will make no changes of the cut-in capacity. If regulation takes place outside the hatched area (named ++zone and --zone), changes of the cut-in capacity will occur somewhat faster than if it were in the hatched area.





Cut-in of steps can be defined for either sequential, cyclic, binary or 'mix and match' operation.

Sequential (first in - last out): The relays are here cut in sequence – first relay number 1, then 2, etc.

Cut-out takes place in the opposite sequence, i.e. the last cut-in relay will be cut out first.

Cyclic (first in - first out): The relays are coupled here so that the operating time of the individual relays will become equalized. At each cut in the regulation scans the individual relays' timer, cutting in the relay with least time on it. At each cut-out a similar thing happens. Here the relay is cut-out that has most hours on the timer.

If capacity regulation is carried out on two compressors with one unloader each, the following function can be used: Relays 1 and 3 are connected to the compressor motor. Relays 2 and 4 are connected to the unloaders. Relays 1 and 3 will operate in such a way that the operating time for the two relays will become equalized. Similar logic is applied for more than 2 compressors having each more than one un-loader. Please refer to the above figure for details. ❖