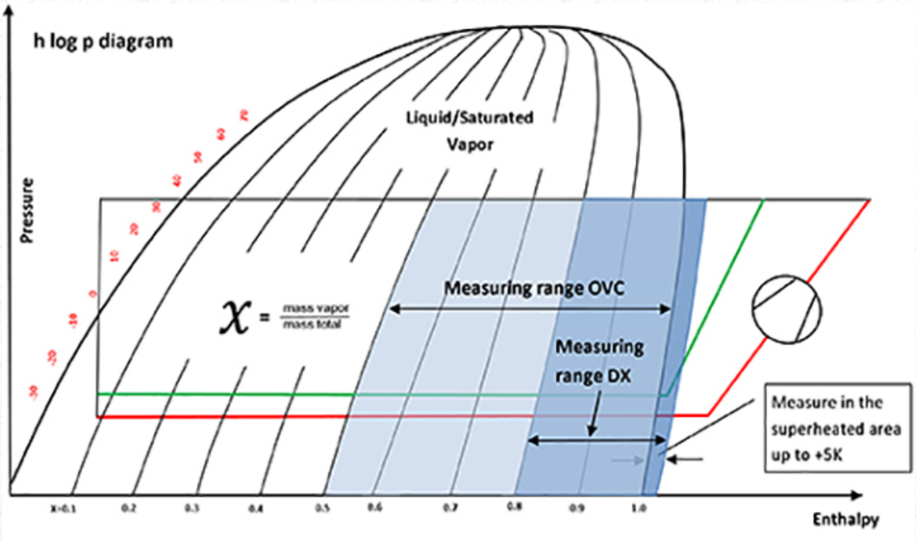

Low Charge Ammonia DX System Controlled by HBX Vapor Quality Sensors

It`s now possible to design Low Charge dry expansion systems, more energy efficient than conventional flooded and pump circulation systems.

The potential for the application of this new technology is very large and used with the latest energy efficient evaporators and compressors it can achieve energy savings of up to 30%. Description of new possibilities using gas quality measurement and facts from a new Cold Store in Melbourne using HB Products HBDX gas quality sensor.

EUDP
Energiteknologisk udvikling og demonstration

13-11-2017

<u>The Myth Regarding the Use of Ammonia in a DX Designed refrigeration system:</u>

The desire to use the world's most energy-efficient refrigerant, ammonia, in DX-designed refrigeration systems has led to many challenges and has rightfully earned the reputation of being a poor solution that does not always work well. There have been many problems, and over time, many attempts have been made without any significant breakthroughs. It was necessary to compromise the normal DX design and install liquid separators before the compressors and set superheating very high in order to avoid liquid flood-back and potential compressor damage. High superheating, and inefficient/non-dynamic evaporators combined with ammonia's high latent heat of vaporization have caused most of the challenges. Altogether, this has led to very poor energy efficiency. It is also a fact that water content in ammonia changes the boiling point and thus the regulation of superheating, which is calculated based on pressure and temperature; 1% water increases the bubble point by around 5K towards the end of the evaporation process. In DX evaporators, the water concentration in the ammonia will increase as evaporation progresses. Gradually this leads to an increase in bubble point, which conventional superheat control will identify as a "false" superheat signal and react accordingly. In addition, the water content in an ammonia refrigeration will reduce the refrigeration capacity and hence reduce coefficient of performance (COP).

Thanks to new sensor technology, new evaporator designs with new liquid distributors, as well as new practical experiences it`s now possible to design an ammonia DX system with all the advantages of a DX system design. The advantages consist of low charge refrigerant, no wet suction lines/pipes, and thus a high level of energy efficiency, smaller suction and liquid pipes, and in particular, much lower refrigerant inventory and reduced system capital costs particularly for large expansive plants.

<u>Facts concerning gas quality control versus superheat and pump circulation systems:</u>

It is now possible to control and regulate an evaporator in a refrigeration system using a sensor mounted on the evaporator outlet, as an alternative to traditional superheat measurement/control based on pressure and temperature where two sensors employ calculations to indicate superheat.

For low-temperature ammonia systems in particular, superheat control has not functioned optimally. There are many reasons for this:

- Inappropriate selection of evaporator materials with poor thermal conductivity of the evaporator tupe/pipe
- A lack of exposure of the internal pipe surfaces in the air cooler to the boiling refrigerant
- The presence of oil, which leads to oil fouling and hence reduced heat transmission
- The presence of water, which results in an increase in the refrigerant's boiling point towards the end of the evaporation process

- Inappropriate evaporator design, which does not adequately consider the fundamental thermodynamic principles that should be incorporated in all heat exchangers during the design process
- Time delay and critical placement of the temperature sensor for measurement of the boiling point are often associated with a faulty indication

For example, water content of about 1% in the ammonia will lead to an increase in the boiling point towards the end of the evaporation process of 5-6°C in low-temperature evaporators. The use of superheat-based injection regulation would not be able to differentiate between superheat and a boiling point increase caused by water. This situation may result in liquid flood-back from the evaporator to the compressor. Using a new kind of regulation such as the HBDX gas quality sensor, which can differentiate between the presence of liquid/vapour and gas, would naturally improve this situation.

The refrigeration industry has thus far attempted to solve this problem using pump circulation or liquid overfeed. A pump circulation system circulates a quantity of refrigerant that is several times larger than that evaporated in the evaporator. This eliminates a large part of the effect of the boiling point increase. The disadvantages are an increase in the refrigerant inventory, increased pressure loss in the suction pipes and riser pipe, and the resulting increased energy usage.

Using an HBX Vapor/gas quality sensor, which measures refrigerant/liquid content as degree of wetness at the outlet of the evaporator, results in a measurement signal that can be used directly for controlling liquid injection into the evaporator, without all the disadvantages of a superheat calculation/measurement. Furthermore, a substantially better efficiency is achieved than with pump circulation systems and flooded systems. Among other things, this is due to the elimination of liquid content in the suction pipes and riser pipes, where the presence of liquid can increase the pressure drop by a factor of 7-10 compared with dry suction lines.

In general, dry-expansion evaporator design requires that users are perfectly aware of the capacity range within which the evaporator will be used. These considerations are also important for evaporators that are installed for pump circulation, but the consequences of an incorrect number of channels is easier to compensate for in a pump circulation system than in a dry expansion system with limited refrigerant charge.

In a dry-expansion system (especially using ammonia as the refrigerant) the choice of evaporator tube diameter is often of great importance. For evaporators with small capacities, the distribution of refrigerant can also result in difficulties simply because the distributor pipe diameters become so small that commercially available pipe material is not available. In these situations, other distributor types must often be used rather than the conventional choices or design evaporators with one circuit. Our recommendation for low temperature evaporators is to use liquid distribution works by gravity, designed as small tanks/pots without pressure drop as Küba and Colmac Coil tank distributor.

It is not possible to generalise regarding the optimal average vapour velocity in the evaporator. Small pipes will have acceptable results with lower vapour velocities than larger pipes. Pipes with internal surface enhancements would also yield acceptable results with lower vapour velocity than smooth pipes. In general, dry expansion evaporators are designed for a substantially higher refrigerant pressure drop than pump circulation evaporators. To avoid this pressure drop resulting in a reduction of the logarithmic temperature difference, it is often necessary to use innovative evaporator circuiting methods/designs such as physical parallel flow (thermodynamic counterflow), consideration of the possible effect of gravity on the evaporator function, oil accumulation, sensor placement, etc.

Other important parameters for attaining good thermodynamic performance include that the evaporator pipes are made of a material with high thermal conductivity, such as aluminium. Today, there are many evaporator manufacturers offering industrial evaporators manufactured from aluminium. To ensure high efficiency as well as optimal boiling/flash gas formation, we recommend aluminium pipes for ammonia.

The system must be designed with a small liquid separator designed with a subcooler, which can collect the small refrigerant excess and use the evaporation energy for subcooling. The liquid separator can be located locally by the evaporator or as a common liquid separator/intercooler located centrally at the compressors.

Experience gathered from four ammonia systems set up in Australia shows that the systems with vapor quality measurement/control are more energy efficient and do not result in pressure variations of the same magnitude as DX systems based on superheat controlled refrigerant injection. Sensor set-up in preparation for start-up is very simple and consists of a zero calibration, with the span value being set beforehand so the measurement range covers “X” 0.7 to 1.0, i.e. the 0.7 value (wet) corresponds to 20mA and 1.0 (dry) corresponds to 4mA. Using an internal or external controller, “X” is set to 0.98; to increase gas wetness a lower “X” value is chosen. With regard to the adjustments/optimisation, we recommend that this is done in line with a maximum increase/reduction of “X” of 0.02 (experience shows that X values between 0.95 and 0.98 yield slight superheat of 1 to 5 °K).

A new cold store in Melbourne uses:
Freezing: 3 Colmac Coil DX evaporators -31°C evaporating temperature, unit refrigeration capacity approx. 60kW, refrigerant operating charge of 1.42 kg per evaporator.
Medium temperature: 1 Colmac Coil DX evaporators -3°C evaporating temperature, refrigeration capacity approx. 37W, refrigerant operating charge 2.5 kg.

Ante room: 2 Colmac Coil DX evaporators, evaporating temperature - 3°C, unit refrigeration capacity approx. 58kW, refrigerant operating charge 4.4 kg per evaporator.

The main points regarding the implementation of the system in Melbourne are:

- Use of aluminium evaporators with patented tank distributors and internal surface enhancement in low-temperature evaporators
- Use of piston compressors with very low oil carry-over (<3 ppm at the design point – less at reduced rotational speed)
- Use of piston compressors arranged for air cooling
- Frequency converters on all compressors and fan motors
- The possibility of switching between superheat based refrigerant injection control and gas quality based injection control
- Oversized evaporative condenser
- Use of internally smooth stainless steel pipes for all interconnecting refrigerant pipe lines
- High-pressure float control between the condenser and the intercooler
- Return of the condensate formed during hot gas defrost directly to the intercooler, using a high-pressure float and dedicated condensate return lines
- Two hot gas solenoid valves per cold store evaporator enabling warming of the drain pan prior to defrosting the evaporator coil
- Desiccant dryer in the freezer, which distributes the dry air to the doors using air distribution ducts
- Automatic evaporator fan speed control, optimised on the basis of the entering temperature difference between the air and ammonia for the individual evaporator
- Possibility of regulating the cold store temperature directly using compressor capacity modulation
- Evaporative condenser made entirely in stainless steel
- System refrigerant charge, 480 kg – low temperature capacity approx. 177kW, high-temperature capacity approx. 140kW, total volume facility approx. 42,600 m^3, estimated yearly energy consumption 21-23kWh/m^3*a

Use of the gas quality measurement allows optimization of the most important key factors in a refrigeration system:

- **The elimination of superheat measurement for evaporator control** can be used for reducing the temperature difference "ETD" between the ammonia and air temperature (At the plant in Melbourne is measured a "ETD" down to 2.3K) – especially in case of partial load. This reduces the system energy consumption because the compressors operate with the highest possible suction pressure in all operational situations. It also minimize the volume of the gas, thus the compressor works less and thereby uses less energy.
- **Elimination of wet suction lines in Ammonia systems and to prevent the challenges with wet return piping in industrial refrigeration systems.** Wet suctions cause large pressure drop in industrial plants which mounting of the evaporators with riser pipping and long distances to the compressor room.

"Rules of thumb" Suction pressure

1°C decrease mean approx.:

At	Capacity	COP	Power
+10°C	-3.6%	-5.0%	+5.2%
0°C	-4.0%	-4.3%	+4.5%
-10°C	-4.4%	-3.8%	+4.0%
-20°C	-5.1%	-3.5%	+3.6%
-30°C	-5.5%	-3.9%	+4.1%
-40°C	-6.5%	-4.4%	+4.6%
-50°C	-7.3%	-5.0%	+5.2%

Ex. On the increased energy consumption at -25°C:

10° superheat increases energy consumption up to 10%.

Optimal evaporator design can further improve the efficiency.

0.3bars Pressure drop in suction lines increases energy consumption by 24%.

"Rules of thump" is calculated by COOL PARTNERS.

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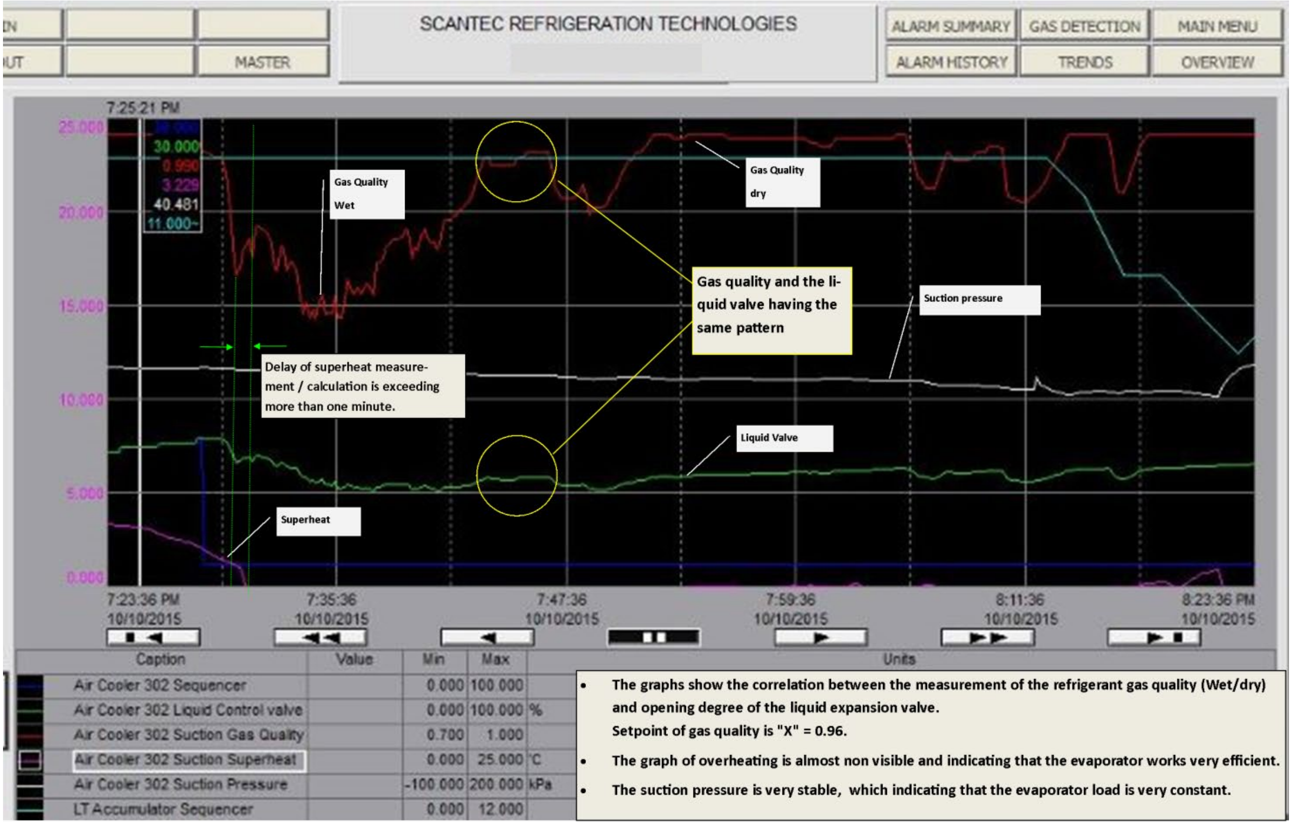
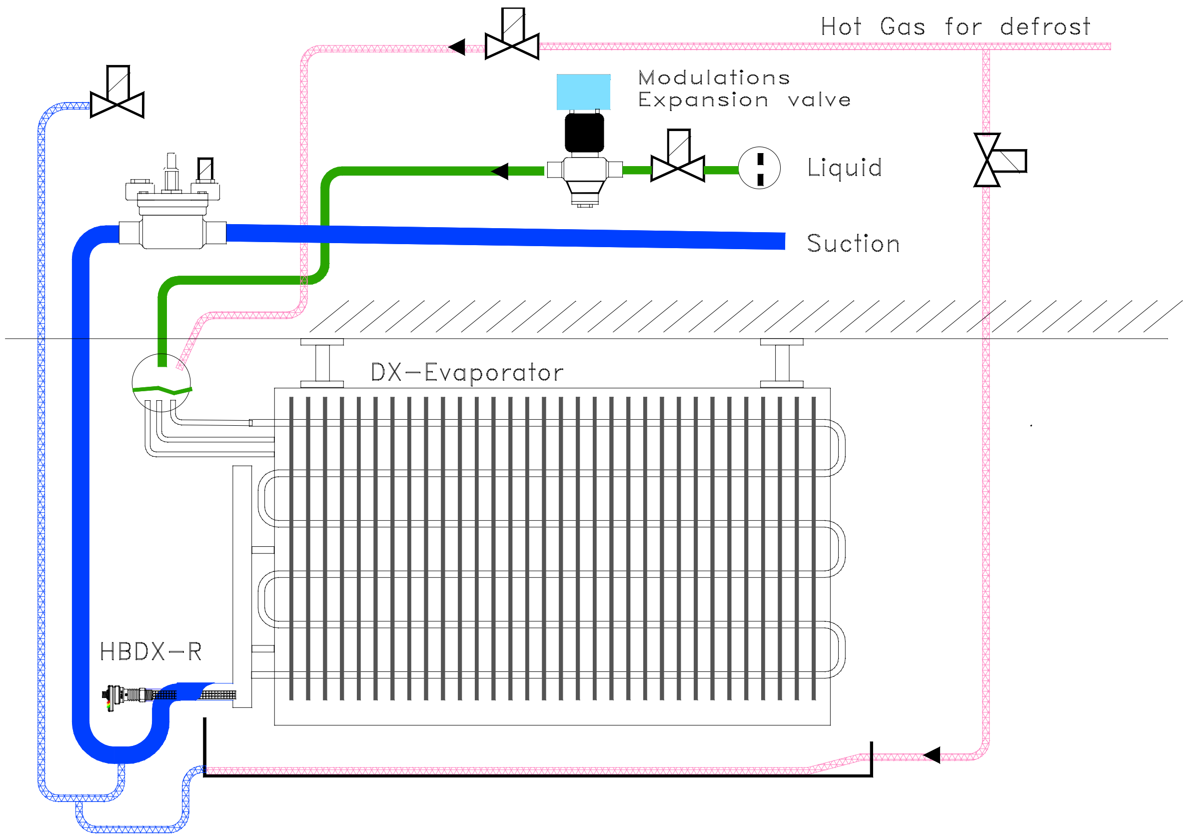


- The graphs show the correlation between the measurement of the refrigerant vapor quality (Wet/dry) and opening degree of the liquid expansion valve.
- Setpoint of gas quality is "X" = 0.96.
- The graph of overheating is almost non visible and indicating that the evaporator works very efficient.
- The suction pressure is very stable, which indicating that the evaporator load is very constant.



Stefan Jensen is the director of Australia's most innovative refrigeration company. The company has specialised in the design and delivery of highly efficient "Low Charge" ammonia refrigeration systems. Stefan is a member of various refrigeration organisations, including IIAR, and participates in conferences worldwide to ensure and to optimise the use of natural refrigerants such as ammonia and CO_2.

Michael Elstrøm is the director of HB Products A/S, where he is responsible for technical development . He has 25 years of design experience within capacitive sensors for the refrigeration industry. The idea for a gas quality sensor came about during a dialogue on improving efficiency and optimisation of the control of a liquid expansion value for use in air coolers/evaporators.