International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Low Charge Ammonia Refrigeration System

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Accepted 01 Oct 2016, Available online 05 Oct 2016, **Special Issue-6 (Oct 2016)**

Abstract

Ammonia is widely preferred refrigerant for large cold storage facilities due to it's multiple advantages. Ammonia is a natural refrigerant with no Global Warming Potential and Ozone Depletion Potential. From economical point of view ammonia is inexpensive for large size parts than HCFCs. But problem arises with ammonia system when ammonia leakage takes place. Exposure to high concentrations of ammonia in air causes immediate burning of the eyes, nose, throat and respiratory tract and can result in blindness, lung damage or death. Inhalation of lower concentrations can cause coughing, and nose and throat irritation. 5 ppm quantity of ammonia in air is said to be self alarming and more than 1300 ppm quantity is perilous. More over it, ammonia is flammable in ambient air. Hence, the focus is made on reducing the quantity of ammonia in refrigeration systems.

Keywords: *Ammonia, GWP, ODP, PPM, Quantity.*

1. Introduction

Ammonia, Hydrocarbons (HC) and Carbon-dioxide (CO_2) were the early 19th century refrigerants used for producing ice, even prior to the year 1900. These were natural refrigerants available in plenty, and their use at its peak during 1920-40. Around the 1930s and 40s, as the air conditioning and refrigeration industry grew in size and the application of mechanical refrigeration became the wide-spread in many applications, safety and energy efficiency consideration became the prime drivers for refrigerant selection. With the introduction of CFCs (R11, R12, R13, etc.) and HCFCs (R21, R22, R23, etc.) which were non toxic, non-toxic, non flammable, had lower operating pressure and many other flexibility in operation, use of CO_2 (high operating pressures), and HC refrigerants (highly flammable) dwindled. Use of Methyl Chloride and Sulphur-dioxide simply vanished. The only exception was ammonia, which has remained a very widely used refrigeration application for over 100 years, not withstanding its toxicity. In 15-28% concentrations in air, ammonia is inflammable. In low charge ammonia system, the absolute, minimum amount of ammonia is used to ensure reliable operation. Various technologies used to reduce the ammonia charge. The key amongst this is to increase the efficiency. In the low pressure receiver system aluminum coil evaporator is used, which enhance the surface and ensures very low ammonia charge. These packages are completely factory built. Low pressure receiver systems have 10 – 20% less charge compared to High pressure receiver systems. The low charge ammonia system has a gas charge of approximately 200-300 grams per TR, whereas a conventional standard Ammonia chiller has a charge of excess of 1.5 kg per TR. A chiller that utilizes ammonia as the refrigerant and consists of a compressor package, microprocessor ,condenser, plate heat exchanger evaporator and oil cooler ,surge drum all assembled and wired in factory controlled environment (R. Raghvan,2015).

2. Types of low charge ammonia refrigeration system:

2.1 Pumped Recirculated Liquid system

It is designed as a conventional two stage pumped recirculated liquid system. In its simplest form, the PRL refrigeration system works in a closed loop cycle as follows:

a. Refrigerant vapor is sent to a compressor which pressurizes it to a much higher pressure and temperature.

b. Once the desired pressure is achieved, heat is rejected from the vapor through a heat exchanger known as a condenser where it eventually becomes all liquid. It is then "stored" in a vessel known as a high pressure receiver.

c. The high pressure liquid is then sent to an expansion device where both the Temperature and the Pressure

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of the liquid are reduced and in the process, some of the liquid is vaporized. This mixture of liquid and vapor is then "stored" in a vessel known as a recirculator. For the system under consideration in this report, a second vessel operating at an even lower temperature receives and stores colder refrigerant.

d. The liquid from the recirculator's is then pumped and sent to heat exchangers known as evaporators. Heat from the room passes through the evaporators, into the refrigerant liquid, and vaporizes the liquid. Due to some of the unique characteristics of ammonia, more liquid is sent to the evaporator than is needed to meet the refrigeration load and, as a result, both liquid and vapor pass out of the evaporator and are sent back to the recirculator. The vapor in the recirculator is separated from the liquid and then sent back to the compressor while the liquid drops to the bottom of the recirculator where it can be pumped back to the evaporator to provide additional cooling.

This particular system would best be described as a "soft" optimized pumped recirculated liquid system. For the purposes of this report, it shall be referred to as the Baseline System or PRL. The ammonia charge for this design is estimated at 15,147 pounds or 20.1 pounds of ammonia/ton of refrigeration. As a result of the conservative nature of the industry, a more typical scenario for this type of system would be 17, 314 pounds or 23 pounds of ammonia/ton of refrigeration (Terry L. Chapp, PE, 2014).

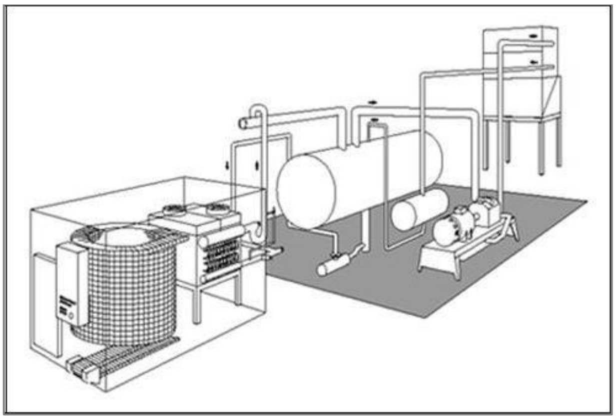

Fig. 1 PRL System

2.2 Direct Expansion Refrigeration System

Direct Expansion (also known as Dry Expansion or DX) systems have been in use in refrigeration and air conditioning for decades. Until recently, the use of DX in ammonia based industrial refrigeration systems has been quite limited.

There are a number of technical reasons behind the historical lack of DX systems in industrial refrigeration however; the topic is beyond the scope. Rather, the focus on DX systems will be its reemergence as a solution to the problem of high ammonia inventories. This revival has come primarily as a result of recent technical advancements. For the purposes of this discussion, the Direct Expansion (DX) system considered in this document will focus on incorporating the latest advancements related to:

- Heat transfer
- Liquid distribution
- Electronic control
- System optimization

As noted, the DX system falls into the category of a central system. However, the very nature of a DX system leads to a much more prudent use of ammonia than in the baseline pumped ammonia system. The result is a dramatic reduction in ammonia charge.

A properly designed DX system will;

- Utilize fewer vessels
- Utilize fewer pipes
- Utilize smaller pipe diameters
- Require no pumps

The key difference between the two systems is that the high pressure liquid in a DX system is fed directly to each evaporator via an expansion device at the evaporator inlet. The heat transfer objective of the evaporator is to vaporize all of the liquid before it leaves the evaporator. While there are many differences in terms of ammonia inventory between the two systems, the three main components in a pumped system which hold excess refrigerant are:

- The recirculator vessel
- The evaporator
- The piping system entering and leaving each evaporator from/to the recirculator vessel

As will be seen, these 3 components are major contributors to the excess ammonia inventory in a pumped. A properly designed DX system will;

- Utilize fewer vessels
- Utilize fewer pipes
- Utilize smaller pipe diameters
- Require no pumps

In order to fully exploit the benefits of an advanced DX system, there are a number of concerns which must be addressed in order to achieve optimum performance:

2.2.1 Water removal – while the presence of water is detrimental to evaporator performance in any type of ammonia refrigeration system, it is particularly troublesome in DX systems because it not only raises the boiling point of the ammonia but it also presents a false picture of the actual superheat from a control system perspective. In order to prevent the problems associated with water in the system, it is recommended that a water still/removal device be installed in the system.

2.2.2 Subcooling – this is an important requirement for DX applications. Subcooling eliminates the formation of unwanted vapor in liquid lines, which can be extremely detrimental to the performance of the expansion device. Subcooling the liquid to a sufficient extent will normally eliminate this possibility and ensure that the expansion device and the coil perform as predicted.

2.3 Electronic Expansion Devices – there are two basic types of electronic expansion valves suitable for ammonia applications: pulse width modulating valves (PWM) and motorized valves (often referred to as EEV). For coil applications, either type is suitable, although the PWM valve has some limitations with respect to minimum required pressure differential. What is important to evaluate before selecting any expansion valve is its ability to respond as fast as the controller which is directing its action requires.

2.4 Controls and Variable Frequency Drives – The use of advanced control algorithms is essential to ensuring that liquid is metered to the coil circuits in such a way that the evaporator performance is optimized. At the same time, the control system must be able to provide a high level of assurance that little or no refrigerant liquid is carried over to the suction accumulator vessel. In order for those controls to perform reliably, steps should be taken to avoid sudden, dramatic changes in suction pressure and/or discharge pressure. The most effective means of doing this is to employ variable frequency drives on condenser fans, and compressors as a means of controlling the rate of change in these devices (Terry L. Chapp,PE, 2014).

2.5

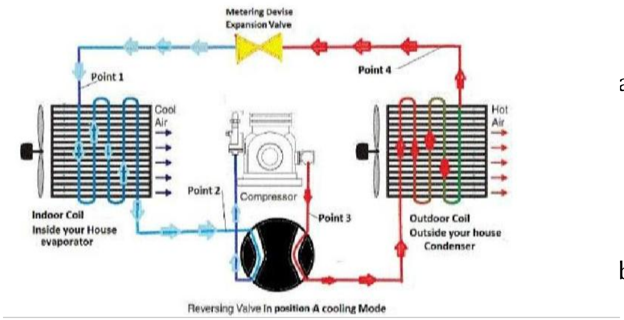

Fig. 2 DX refrigeration system

2.5 Cascade System

While the Direct Expansion system is one of the oldest alternatives to pumped recirculated liquid systems in industrial refrigeration, CO_2 systems have roots in industrial refrigeration as far back as the 19th century. Until recently, the thermo-physical characteristics of CO_2 have made it difficult to utilize CO_2 as a working refrigerant in industrial refrigeration systems in a practical and cost-effective manner. However, significant advances in materials, manufacturing, equipment designs, and controls have made it a highly viable alternative to many of the more common refrigerants and heat transfer fluids and at least one major cold storage company is using CO_2/NH_3 systems extensively throughout its organization. There are a several variations in using CO_2 refrigeration.

The type of system described as CO_2/NH_3 Cascade isolates the ammonia refrigeration part of the system to the machine room. As with all refrigerants, the higher the temperature of the refrigerant, the higher the operating pressure. In order to limit the extremely high pressures necessary for an all- CO_2 system, the ammonia part of the system provides the initial condensing for the CO_2 system and thereby limits the pressure which would exist if CO_2 were to be condensed as in a typical refrigeration cycle (95°F Condensing Temperature, typically). The evaporator for the ammonia system is also the condenser for the CO_2 system. This type of heat exchanger is referred to as a cascade heat exchanger and can be constructed in a number of different ways:

- Shell and tube
- Welded plate
- Shell and plate

The choice of style will have a direct impact on the refrigerant charge of the system with shell and tube requiring the most refrigerant and welded plate requiring the least refrigerant. There are several different approaches taken in achieving the desired temperature levels of the coolers and the freezers. The methodology for this particular configuration has been as follows:

- Cool the CO_2 down to the temperatures required by the coolers through the cascade heat exchanger and send to the CO_2 recirculator vessel.
- Move the cool liquid to the coolers and freezers

a. a. Pump some of the condensed CO_2 to the cooler coils from the cascade heat exchanger. Unlike ammonia, recirculation rates are maintained much closer to 1:1 allowing almost all of the CO_2 to be evaporated. This has the added benefit of reducing the size of the evaporator and the horsepower of the pump.

b.

c. b. Supply additional liquid from the CO_2 recirculator to the freezer coils. Each coil is equipped with an electronic expansion valve to lower the temperature and pressure of the CO_2 to the desired temperature

Return the gas/liquid mixture from the cooler coils and the freezer coils to the CO_2 recirculator.

- The vapor collected in the recirculator is then sent back to the CO_2 compressor, compressed and sent to the cascade heat exchanger to be condensed while the liquid is circulated back to the coolers and freezers.

The system is relatively simple and doesn't require much more equipment than a two stage pumped recirculated system would. As will be noted below, due to some of the thermo-physical properties of CO_2, there can be some significant savings on the equipment for this type of system. Additional advantages offered by CO_2 as a refrigerant arise from its high heat transfer coefficient at very low temperatures and favorable vapor to liquid volumetric ratios.

This leads to:

- More efficient cascade heat exchanger (reduced energy consumption due to a smaller temperature difference requirement)
- Smaller evaporators
- Lower recirculation rates
- Smaller pumps
- Reduced pumping power demands

The ultimate ammonia charge will depend on several factors:

- The type of cascade heat exchanger
- Type of condenser
- The size and amount of piping connecting the CO2 and NH3 systems.(Mosaffa, et al,2016).

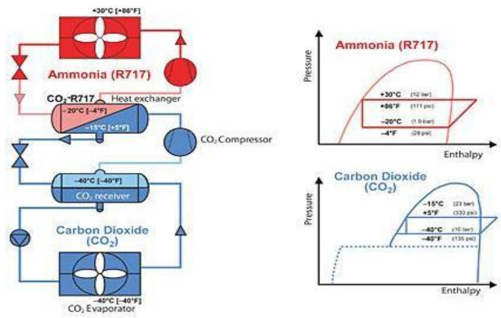

Fig. 3 Cascade system

2.6 High Pressure Float System

HFI is a high pressure float valve with internal liquid measuring device. The float valve is designed for direct flange mounting onto plate heat exchanger type condensers. HFI is direct acting; no differential pressure is required to activate the valve. HFI is sturdy and reliable owing to its simple design. The float valve is equipped with a purge valve for purging non condensable gases. E.g. air from the top of the valve housing. This facility is also useful if the valve has to be serviced.

Principle of High Pressure Float system: In installation with one application high pressure control is an effective and cost saving way of expanding liquid from the condenser to the low pressure side. High pressure refrigerant entering the condenser will start to condense; consequently condensate will accumulate at the bottom of the condenser and in float valve. When capacity demands increase, the liquid level in the float valve will rise, this will cause the valve to open and the refrigerant to expand into the separator at the low pressure side.

At first the valve is closed. When the liquid in the float valve rises to a level, the slide will move approximately half of its total travel, however the valve has only reached approx. 25% of its maximum capacity. At this position the valve is fully opened, relatively larger as the slide moves, due to nozzle design. This ensures perfect regulation throughout the whole capacity area from part load to full load. When the valve is closed, there will still be a small bypass over the seat, so any remaining liquid will equalize slowly to the low pressure side, for instance during an off cycle. Therefore the systems will equilize automatically and the compressor can start up without excessive back pressure. The size of the bypass is predetermined and set in the adjustment of the float assembly. However, the bypass can, if required be set to a minimum by readjusting the position of the slide position. It follows from the above, that almost all the refrigerant will be accumulated on low pressure side under normal conditions. Therefore under normal conditions no high pressure receiver is necessary when using HFI for high pressure control (E. Korfitsen, 1998).

Conclusions

There are numbers of viable and sound technologies available which can successfully address the growing concern over high ammonia refrigerant charges in cold storage facilities. The CO_2/NH_3 cascade refrigeration systems equipped with a flash tank and flash intercooler demonstrates more benefits and profitability. Flooding system with ammonia provides an efficient thermal solution while offering ideal operating economics (E. Korfitsen, 1998).

References

A. H. Mosaffa, L. Garousi Farshi, C. A. Infante Ferreira, M. A. Rossen, (2016), Exergoeconomic and environmental analysis of CO_2/NH_3 cascade refrigeration systems equipped with different types of flash tank intercooler, *Energy Conversion And Management, volume 117, 442-453.*

R. Raghvan, (2015), The Magazine Of The Indian Society Of Heating, Refrigeration And Air Conditioning Engineers, *Air Conditioning And Refrigeration Journal.*

E. Korfitsen, A. P. R Kristensen, (1998), Ammonia High Pressure Heat Pumps In Food Refrigeration Application, *Int J. Refrig.*,21,212-218.

Terry L. Chapp,PE (2014), Low Ammonia Charge Refrigeration System For Cold Storage ,*Low ammonia charge refrigeration systems for cold storages,* version2014, 1-48.