AMMONIA AND CO2 APPLICATIONS IN INDUSTRIAL REFRIGERATION PLANTS

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ABSTRACT

This paper presents the results of an Ammonia/CO2 system operating in a poultry slaughterhouse installed in the Netherlands.

The initial F-gas plant with a refrigeration capacity around 600 kW was built around 1986. The R22 has been phased out and plant has been re-build in 2011 (R22->R507) and extended with a CO2 pump system for the refrigeration plant extension of 1000kW. The R507 system is designed and executed that it can be fully switched to NH3 in the future. The plant process requiring hot water is also using an NH3 heat pump using the heat rejection from the refrigeration system as heat source.

The CO2 system produces 950 kW CO2 at –7°C and is foreseen for future extension to 1500 kW.
The NH3 refrigeration system uses 2 screw compressors producing 1030 kW at –11 °C.
The hot water heat pump produces 425 kW of 68°C hot water per hour with a COP of 5,6 .

The new plant started in 2011 and operated approx. 3000 hrs per year with a return on investment of less than 5 years compared to conventional gas boiler systems.

1. INTRODUCTION

The most common applied natural refrigerants are ammonia and CO2. Ammonia is one of the oldest refrigerants in industrial use today and its use will stay and always be of interest to engineers. This is because ammonia is a natural refrigerant with benign effect on the environment and has excellent thermal properties with a potential to offer systems with high COPs. In order to increase use of ammonia in industrial refrigeration applications, a lot of effort and development have been advanced to reduce refrigerant charge, increase safety and reliability. CO2 became more popular during the last decennia and has its reputation of very performant refrigerant for refrigeration.

2. REASON FOR BUILDING AMMONIA/CO2 SYSTEM

This field case concerns a poultry slaughterhouse processing poultry meat installed by the contractor Cofely Refrigeration b.v. in the Netherlands. The slaughterhouse needs refrigeration temperatures down to -7° for tunnel coolers, coldrooms, processing rooms and expedition rooms and hot water up to 68°C.

The initial plant(dated 1986) with capacity of 600 kW needed to increase in capacity with 1000 kW.
The first installation done with R22 was retrofitted to R507 in 2010 and made suitable for implementation in the NH3 plant in the future.
Main focus was on using natural refrigerants NH3 and CO2.
Choice was made for a CO2 secondary brine pump circulation system cooled by an NH3 compression system and reduction of energy consumption and energy costs .

3. HOT WATER NEEDS AT 68°C

Initially the gas consumption of the boilers needed to be reduced.
Recovery of heat from the NH3 refrigeration system from the hot gasses and oil coolers was done by heating water from 12°C to 26°C based on a condensing temperature of 25°C.

To produce water of 68°C in an energy efficient way the choice was made for a heat pump using the refrigeration system condenser heat as heat source with ammonia as refrigerant (ODP & GWP=0) and a condensing temperature of 70°C (corresponding 32.1 barg).
This has a positive impact on the condenser load as it is decreased and ‘waste heat’ is used.
The residual heat is covered for hot water production for cleaning in the process needing 65°C.

4.DEMANDS

For the production extension in 2010 the slaughterhouse needed :

Cooling of 1000kW with CO2 at -7°C, with second extension possibility of 500 kW in future,

Heating of 70 m3/day water to 65°C with capacity of 530 kW per hour for cleaning.

5. PRINCIPLE

5.1. COOLING

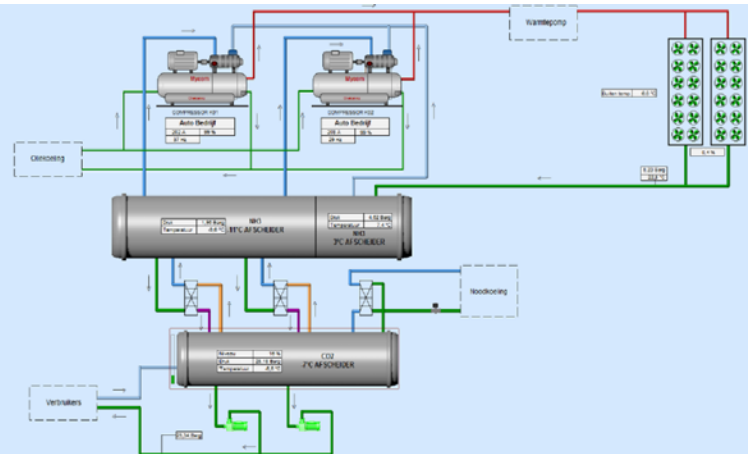


Figure 1. Scheme cascade refrigeration system NH3/CO2

The scheme shows on top the NH3 compressors connected to the NH3 suction separator divided in two temperature area’s on -11°C and +3°C.

The flooded PHE type evaporators are cooling the CO2 to -7° (at 28,8 bara) with a delta-t of
4°C (NH3< >CO2).

The CO2 flows by gravity into the main CO2 receiver feeding the 2 CO2 pumps mounted under the CO2 receiver and supplying the -7°C CO2 liquid to the users.

On the CO2 receiver an emergency cooling unit operating with propane is installed in case of power failure to keep the CO2
within the permissible pressure.

The NH3 compressors are discharging into the high pressure header to the heat pump and the condensors.

5.2.HEATING

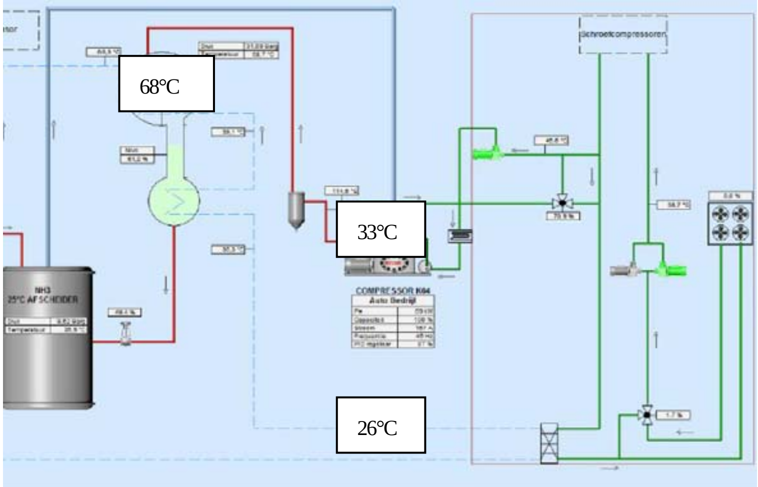


Figure 2. Scheme of hot water NH3 heat pump

The scheme shows in the middle the NH3 heat pump compressor connected to the NH3 flash tank (heat source) on the left side. In the compressor high pressure discharge line the oil separator is mounted,
followed by the condenser , the liquid subcooler and the expansion valve.
The liquid subcooler is mounted to optimize the COP of the heat pump.

On the right hand side the heat recovery circuit from the NH3 compressor hot gasses and oil coolers is shown.

The main water flow is heated up in 3 steps :
12°C to 26°C by recovering heat from hot gasses, compressor jacket and oil coolers (closed circuit with air cooler)
26°C to 33°C by heat pump liquid subcooler
33°C to 68°C by heat pump condenser.

6. EQUIPMENT

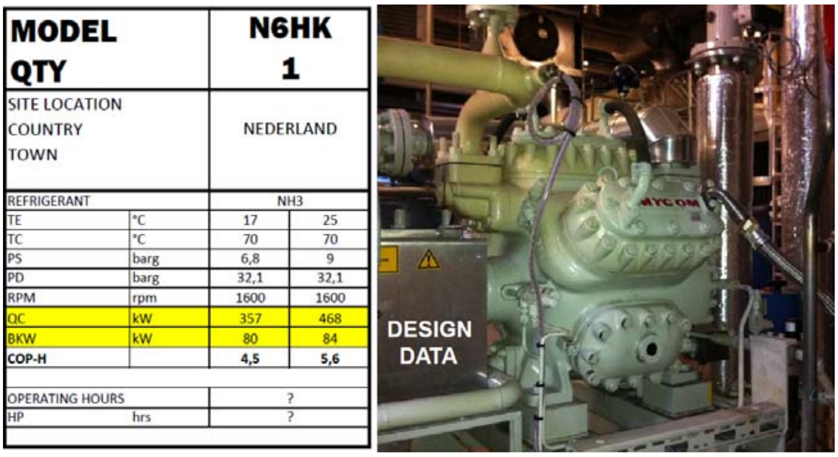
6.1 COOLING

Figure 3: View on cascade NH3 compressors & NH3/CO2 vessel skids

2 pieces of NH3 screw compressors are installed equipped with variable speed drive allowing variation in rotation from 1500 to 3600 rpm and also equipped with mechanical capacity control from 100% to 25%.
Each compressor has a displacement volume of 760 m3/hr at 3600 rpm.

On the right side the NH3 suction separator is visible on top of the PHE evaporators for cooling down the CO2 with minimized NH3 charges. On the bottom the common CO2 receiver is installed with the CO2 liquid pumps underneath.

6.2 HEATING



MODEL **QTY**		**N6HK** **1**	
SITE LOCATION COUNTRY TOWN		NEDERLAND	
REFRIGERANT		NH3	
TE	°C	17	25
TC	°C	70	70
PS	barg	6,8	9
PD	barg	32,1	32,1
RPM	rpm	1600	1600
QC	kW	357	468
BKW	kW	80	84
COP-H		**4,5**	**5,6**
OPERATING HOURS		?	
HP	hrs	?	

Figure 4: Heat pump piston compressor data

The picture shows the 6 cylinder piston compressor with data in the table.
The machine is equipped with variable frequency drive allowing compressor rotation variation from 900 rpm to 1600 rpm and the machine has also mechanical loading per bank of 2 cylinders from 100% to 33%.
For the design condition :
evaporating temperature : 25°C, condensing temperature : 70°C
the heating capacity is 468 kW with an absorbed shaftpower of 84 kW,
which corresponds with a coefficient of heating performance of 5,6.

Figure 5 : View on hot water NH3 heat pump system

The picture shows the heat pump piston compressor unit with main drive motor and oil system on the left side. In the middle the heat source flash tank is mounted with on the right hand side the condensor and liquid subcooler.

The plant is operating approx.. 3000 hours per year.
For the calculation of the power losses the efficiency of the drive motor varies between 93.7 to 93.2 at respectively

100% and 50% load.
The cos(phi) varies from 0.87 to 0.75 at respectively 100% and 50% load.
For the variable frequency drive and efficieny of 97 to 98% can be considered.

7. OPERATION SAVINGS

A comparison of the energy consumption and CO2 emission is made between the heat pump and the gas boiler.
The calculations are based on operation during 8 hours per day, 5 days per week and 51 weeks per year, or 2040 hours/year.

For the **heat pump** the design coefficient of heating performance of 5,6 is corrected with the losses on the drive motor and variable frequency drive to 4,48.
For the gasboiler an efficiency of 85% is considered.

The heat pump heats 70 m3/day water from 26°C to 68°C,
representing 425 kW heating capacity per hour.
The gas boiler heating capacity becomes 500kW/hr incl.boiler efficiency or 1.020.000 kWh/year

The yearly energy consumption is calculated for :
Heat pump : 193.526 kWh
Gasboiler : 102.000 m3 natural gas

Based on th e energy price :
Electricity : €0.06/kWh the electricity cost for driving the motor will be € 11.611,-
Natural gas : €0.50/m3 the gas cost for the boiler will be €51.000,-

The CO2 emission of 180 tons for the gasboiler will be reduced to 97 tons for the heat pump.

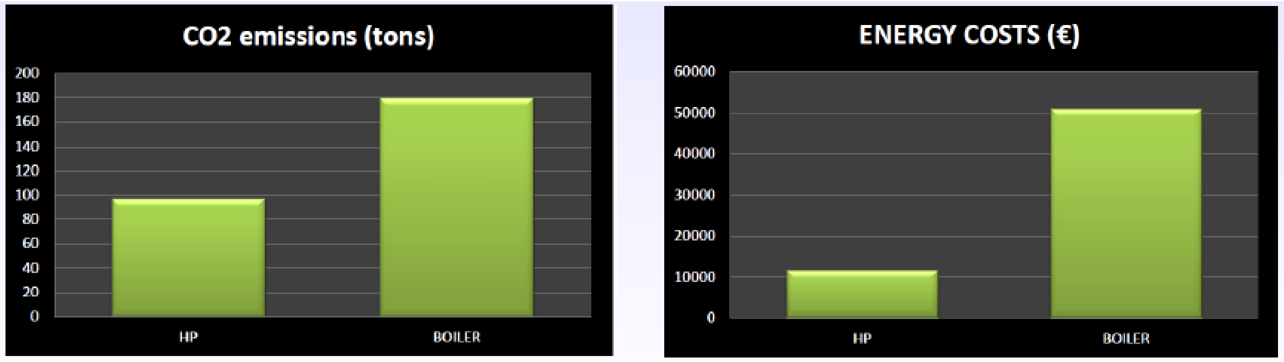


Figure 6: Energy and CO2 emission comparison heat pump versus gas boiler

For the **heat recovery from the refrigeration compressors** hot gas and oil coolers the waterquantity of 70 m3/day is to be heated from 12°C to 26°C representing a heating capacity of 142kW per hour.

In case of using the gasboiler at 85% efficiency this will be 340.800 kWh yearly heating capacity.
Which corresponds with the natural gas consumption of 34.080 m3.
Based on the energy price of natural gas of €0.50/m3 the extra gas cost for the boiler will be €17.040,-

Summarizing the heating process from 12 to 68°C means :
Total energy cost in case of :
Heat pump : €11.611,-
Gas boiler : €68.040,-
Total CO2 emmision in case of :
Heat pump : 97 tons
Gasboiler : 240 tons

The savings show
Cost : less €56.429,-
CO2 emission : less 143 tons

Figure 7 : Energy cost-/ CO2 emission reduction heat pump + system heat recovery

The investment costs for the heat pump amount to €200.000,-, while the gas boiler costs €25.000,-
Over a period of 15 years the total operating cost of the system is visualized: it shows that the heat pump investment is returned within 5 years.

7. CONCLUSION

This field case shows that the annual savings can be listed as follows :

On operation €56.429,-

On CO2 emission 143 tons

On condenser water (water + treatment) + lower condensing pressure in the refrigeration plant brings important savings on refrigeration power consumption.

Natural waste heat and condenser.

The return of investment within 5 years.

In the Netherlands, the investment in a heat pump is eligible for SUBSIDY in the form of tax reduction on the investment.

The efficiency of the heat pump is higher than when applying other comparable technologies.

The heat pump has a long lifetime (more than 25 years) and has low maintenance costs.

SPECIAL THANK-WORD :
For Mr.Willy van Leeuwen, the contractor COFELY REFRIGERATION BV Duiven, The Netherlands, who installed the plant and gave us access to all details of this NH3/CO2 REFRIGERATION & HEAT PUMP PLANT.

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