NATURAL 5 :

Cascade CO2/NH3 refrigeration combined with hot water NH3 heat pump in Food Industry.

Jan Boone

MAYEKAWA EUROPE S.A.,Leuvensesteenweg 605, 1930 Zaventem, Belgium Tel. 32-2-757-9075, Fax. 32-2-757-9023

ABSTRACT

This paper focuses on the natural refrigerants which strongly contribute to the reduction of energy-consumption and significant reduction of the CO2 emissions.

The different system applications are presented in the 'NATURAL 5 LINE-UP'.

The second part presents the use of natural refrigerants in an industrial food production company installed in Lithuania by the contractor GREEN GROUP in 2012.

The main activities are the production of fish bites and culinary fish products (dumplings processing with seafood, salmon, cottage cheese, jam, etc.).

The cascade system produces CO2 930kW freezing capacity with 5 tons CO2 at -40°C and ammonia 2700kW with 3 tons NH3 at -8°C, in addition 500kW hot water at 60°C is produced by applying a high pressure NH3 heat pump compressor.

The CO2 part uses 3 reciprocating compressors with frequency drivers (VFD) and the NH3 part 3 screw units with VFD. The hot water NH3 heat pump compressor is installed as second stage heat pump on the refrigeration plant as heat source. All machines are equipped with Siemens control and monitoring.

In 2015 plant extension added 900kW on NH3 system with 1 VFD screw compressor unit.

The freezing cascade performance coefficient is designed at 2 to 2,5 - while for the heating performance coefficient it is 5,9.

The paper evaluates the results of operation of this plant and is supported with technical details obtained mainly via remote monitoring and photo's of the system in operation.

(Note : the indicated figures are subject to revision after that full details will be generated)

REASON FOR BUILDING NH3/CO2 SYSTEM.

Main focus was to use natural refrigerants NH3 and CO2.

Choice was made for CO2 for direct use on freezers, process cooling and storage which is very performant refrigerant for use at -40°C (10 barg).

The NH3 system is used to take the heat rejection from the low temperature CO2 system via a cascade heat exchanger and to produce glycol at -5°C and higher for refrigeration of the cold stores.

HOT WATER NEEDS AT 60°C.

In order to reduce the gas consumption of the boilers recovery of oil cooler heat from the NH3 screw compressor packages is done by heating water to approx. 50°C.

To produce water of 60°C in an energy efficient way the choice was made for a heat pump using the refrigeration system condenser heat as heat source with NH3 as refrigerant (ODP & GWP=0) and a condensing temperature of 65°C (corresponding 28,1 barg).

This has a positive impact on the condenser load as it is decreased and 'waste heat' is used.

DEMAND.

In 2012 the freezing capacity of 930 kW at -40°C was needed with CO2.

With 2700 kW at -8°C NH3 refrigeration for taking the heat rejection from the CO2 system and additional approx..1500 kW refrigeration.

In 2015 an extension of 900 kW at -8°C NH3 was added on the NH3 system.

PRINCIPLE

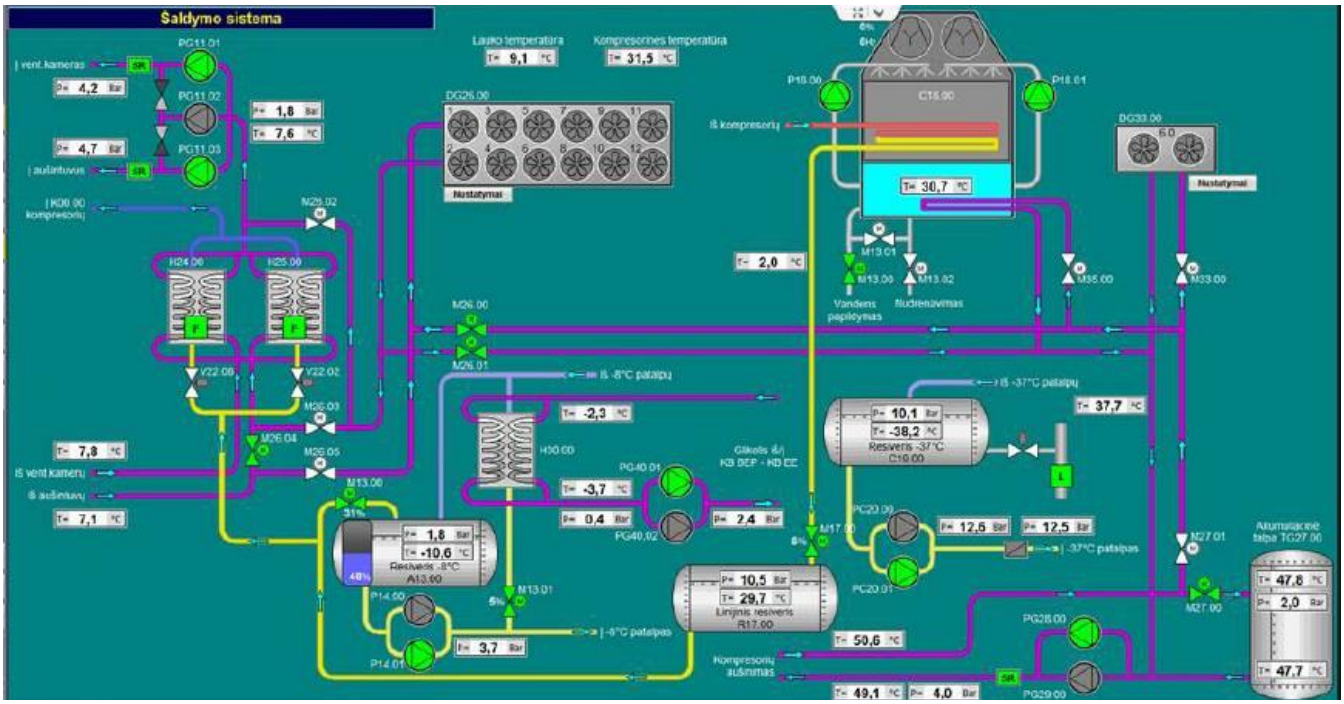


Figure 1. NH3/CO2 system

NH3 system : the scheme shows the evaporative condenser(rightside top) with high pressure receiver(bottom).

The high pressure liquid feeds the -8°C low pressure receiver and liquid pumps to the system and is also used to produce glycol at approx.. -4°C and +7°C.

CO2 system : the scheme shows the -37°C low pressure CO2 receiver at right side under the condenser.

The heat recovery tank is shown on the right bottom side.

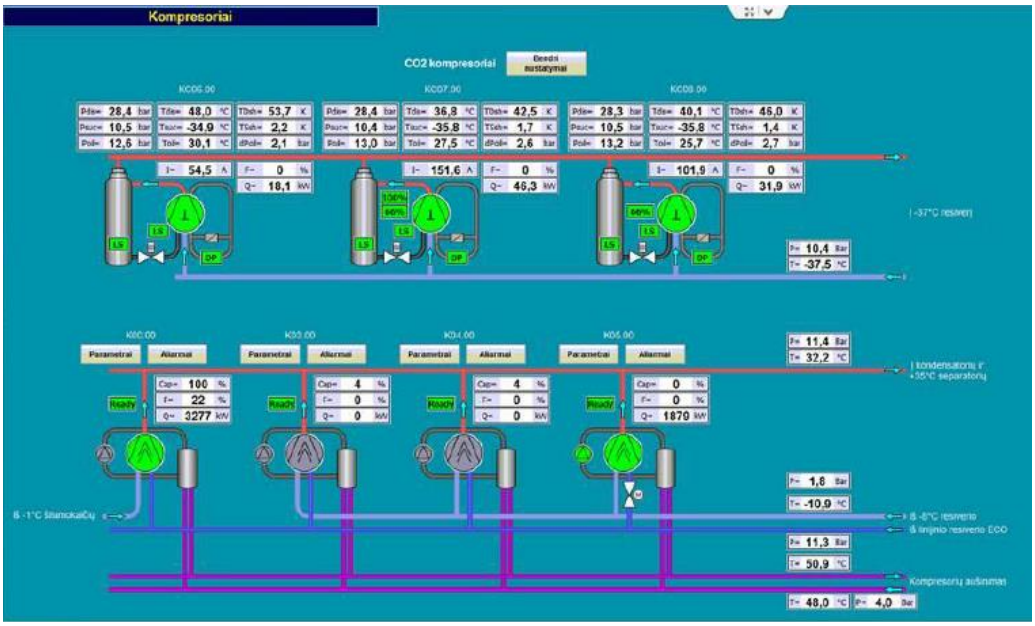


Figure 2. NH3/CO2 compressors

The scheme shows on top the 3 CO2 compressors with suction- and discharge gas headers. On the bottom side the NH3 compressors are shown.

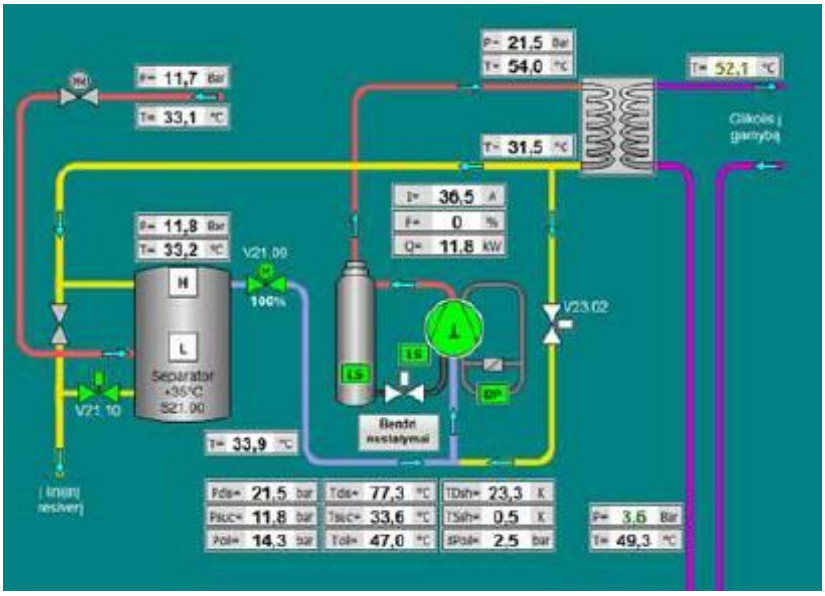


Figure 3. hot water NH3 heat pump

The scheme shows the high pressure separator from the refrigeration system used as heat source for the heat pump. The heat pump produces the hot water of 52°C on this view.

EQUIPMENT

Figure 4. view on machine room

LEFT : 3 pieces of NH3 screw compressors with VFD(variable frequency drive) range 1500 to 3700 rpm (slide valve 100%-25%).

RIGHT : front 3 pieces of CO2 6 cylinder piston compressors VFD range 900 to 1500 rpm (cylinder bank 100-33%), back 1 piece NH3 6 cyl. heat pump piston compressor (VFD & BC)

SYSTEM		NH3			CO2	NH3 HP
MODEL		N170JL	N220JS	N220JM	C6HK	N6HK
QTY		1	2	1	3	1
INSTALLED		2012	2012	2015	2012	2012
RPM	rpm	3650	3700	4500	1500	1450
TE	°C	-1	-10	-10	-37	35
TC	°C	35	35	35	-7	65
RT	kW	825	843	1335	343	437
BKW	kW	147	199	318	66	68
QC	kW				408	504
COP		5,64	4,24	4,2	5,2	7,45
HRS	hrs	12749	10487		10273	6880
28/09/2015			11784			

Figure 5. overview table

The table shows the installed units and the number of operating hours on 28/9/15.

SYSTEM OPERATION

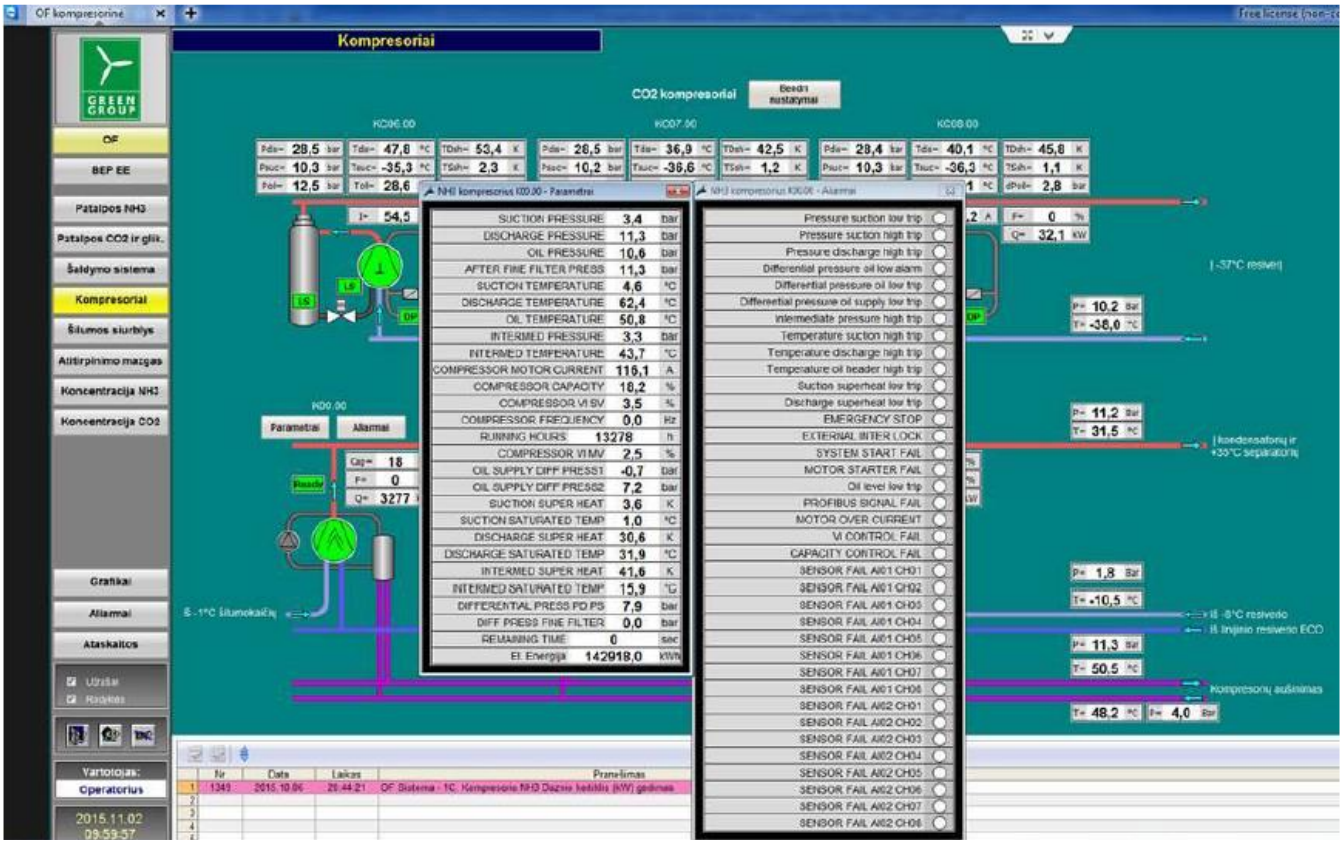


Figure 5. system operation

All installed compressor packaged units are equipped with Siemens PLC S7-300 with profibus communication allowing to follow, verify and optimize the operation of the equipment.

The screen shows as example the operation of NH3 screw compressor unit nr 1.

All pressures, temperatures, motor currents, capacity positions, energy consumptions, operating hours and all parameter alarms and trips are continuous visible.

The supervision can be done from the office or similar locations so that necessary interventions can be done by remote or by intervention at site by qualified personnel.

Figure 6. system condition trends

This example is taken from the CO2 compressor operation and shows the trend of the temperatures and pressures on 2/11/2015 from 06:15 till 10:00hr. This information can be used for fine-tuning of the operation to obtain stability in the plant.

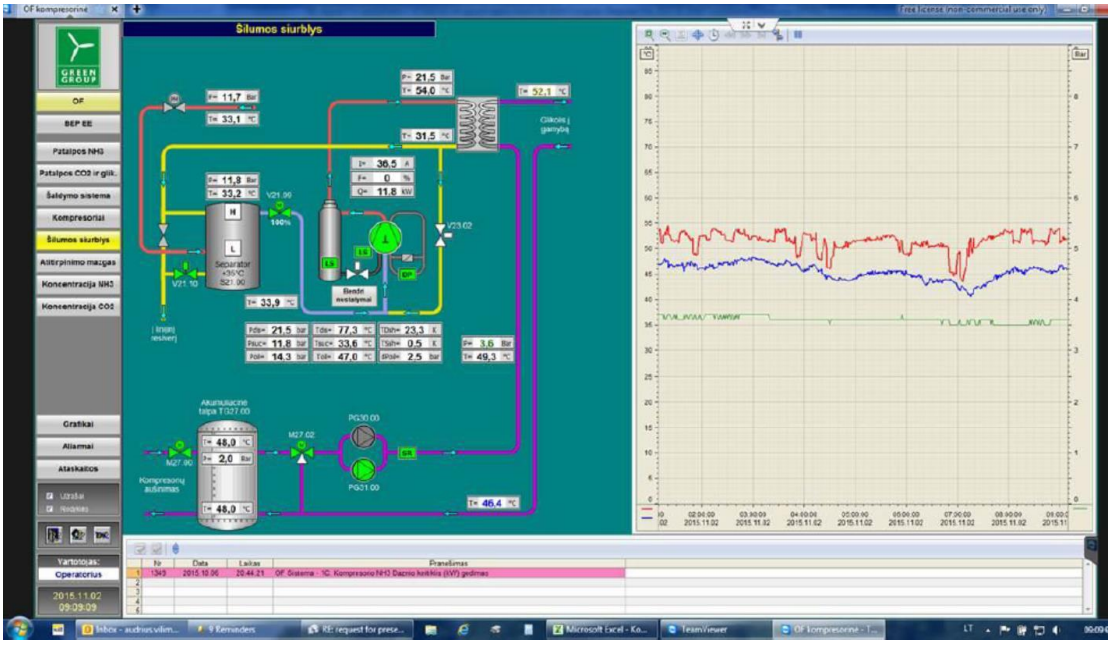


Figure 7. heat pump system & trend supervision

The screen shows the compressor in operation with indication of all conditions. The trends are selected and shown for the hot water inlet and outlet-temperatures on 2/11/2015 from 01:00 till 09:00 hr together with the heat source saturated evaporating temperature.

OPERATION SAVINGS

CO2/NH3 SYSTEM

In addition that the use of natural refrigerant, and a minimized CO2 emission, compared to a non-CO2/NH3 solution the COP-cooling is more than 20% better with this installation concept

HOT WATER HEAT PUMP.

A comparison of the energy consumption and CO2 emission is made between the heat pump and the gas boiler.

The calculations are based on 4600 hrs operation per year.

For the heat pump the design coefficient of heating performance of 7,45 is corrected with the losses on the drive motor and variable frequency drive to 5,9.

For the gas boiler an efficiency of 85% is considered.

The heat pump heats 35 m3/hr with 10°C to 60°C representing 406 kW heating capacity per hour.

The gas boiler capacity becomes 477 kW incl.boiler efficiency or 2.194.200 kWh/year.

The yearly energy consumption is calculated for :

Heat pump : 317.400 kWh (electrical power input : 69 kW x 4600hrs)

Gas boiler : 219.420 m3 natural gas.

Based on the energy price :

Electricity : €0.06/kWh the electricity cost will be € 19.044.

Natural gas : €0,50/m3 the gas cost for the boiler will be € 109.710.

The CO2 gas emission of 387 tons for the gas boiler will be reduced to 159 tons for the heat pump.

HEAT RECOVERY NH3 REFRIGERATION COMPRESSORS

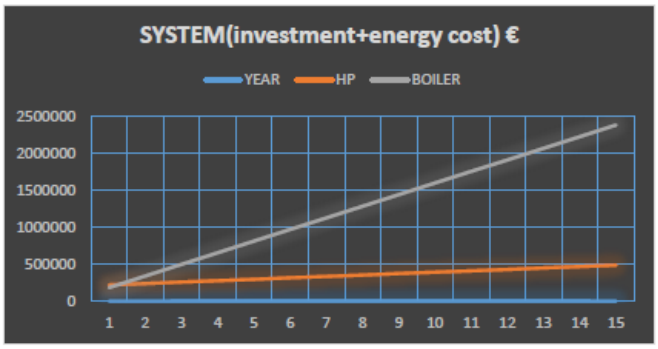
For the heat recovery of the refrigeration compressor oil coolers the water quantity of 35 m3/hr is heated up to 50°C representing a heating capacity of 175 kW per hour.

In case of the gas boiler at 85% efficiency this will be 947.058 kWh yearly heating capacity, which corresponds with a natural gas consumption of 94.705 m3.

Based on the energy price of natural gas of € 0.50/m3 the extra gas cost for the boiler will be € 47.352.
Summarizing the heating process from 45 to 60°C means :

Total energy cost :	Heat pump	:	€ 19.044
	Gas boiler	:	€ 157.062
Total CO2 emission :	Heat pump	:	159 tons
	Gas boiler	:	547 tons
The savings :	Cost	:	less € 138.018
	CO2 emission	:	less 388 tons

The investment costs for the heat pump amount to €200.000, while the gas boiler costs €25.000.



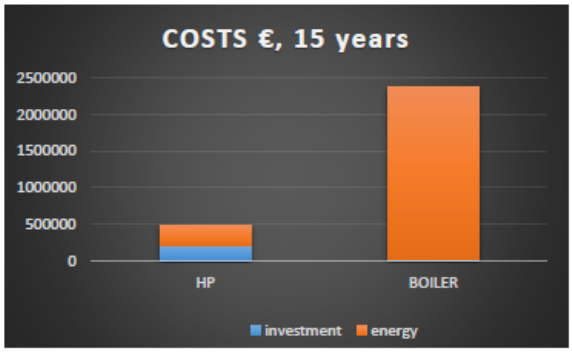


Figure 8. system cost overview

Over a period of 15 years the total operating cost of the system is visualized :
it shows that the heat pump + heat recovery investment is returned within 3 years.

For 15 years of operation the energy cost is :			& maintenance cost is :	
Heat pump	:	€ 285.660		€ 300.000
Boiler	:	€ 2.355.930		-

Total cost 15 years operation

Heat pump	:	€ 785.660	Boiler	:	€ 2.385.930
or a saving of	:	€ 1.600.270			

Return of investment + operating cost < 3 years !

TRAINING

Product : organized by Mayekawa to the contractors

System : organized to Contractors, with Mayekawa-support, to the users.

COMMISIONING

Installation and commissioning of the compressor units is done by the contractor with support from Mayekawa if necessary. Fine tuning of the operation is very important in order to obtain stability and long lifetime of the equipment. Necessary registrations of all conditions and settings are done in logbook for each machine to be used as reference for further evaluations in the future. Every event will be registered per compressor with related action done.

SERVICE & MAINTENANCE

Daily and routine checks are done by qualified personnel (operators & contractor service persons).
The J type screw compressors will receive the main service every 5 years, while the HK type compressors will be serviced every 2 years. Mayekawa recommends that lubrication oil needs to be checked regularly by preventive analysis. Preventive particle filtration prolongs the life time of compressor parts and lubricants.

All service and maintenance activities are registered in each machine logbook.

SPECIAL THANK-WORD :

For Mr.Egidijus Vilkauskas , the contractor GREEN GROUP, who installed the plant and gave us access to all details of this NH3/CO2 REFRIGERATION & HEAT PUMP PLANT.

UAB Green group

Kalvariju g. 272A, LT-08339, Vilnius, Lietuva, Tel. +370 5 2030024

info@greengroup.lt, egidijus@greengroup.lt, www.greengroup.lt

LOCAL REPRESENTATIVE :

Mr.Zikica Andrejevic & Mr.Srdjan Andrejevic

d.o.o. KLIMA

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