NATURAL REFRIGERANTS

NH3 high pressure heat pump

hot water production for district heating

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ABSTRACT

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

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

The paper presents the results of operation in the field of NH3 high pressure heat pumps for production of hot water for district heating installations.

The plant uses high pressure reciprocating type compressors.

The heat pump produces hot water at 85°C with capacity of 4.400 kW in the winter by using

NH3 as refrigerant at 88°C.

The paper is supported with technical details and photo's of each system.

As closure for the paper a 90 GWh heat pump plant in construction is mentioned for demonstrating the importance of savings in energy needed and CO2 emissions.

FIELDCASE.

The starting point for the project was to built the heating plant using flue gas waste heat from an industrial plant as heat source.

The new plant with nominal design capacity of 4400 kW hot water of 85°C per hours, is to be used for production of hot water for district heating operation 24 hours per day per workweek in the different seasons : winter(high season), spring and autumn(mid season) and summer(low season).

The choice for NH_3 was made as it is the most suitable natural refrigerant.
To produce the water of 85°C : NH_3 is needed to condens at 88°C (49,1 bara),

To use the heat source at maximum 50°C : NH_3 is needed to evaporate at maximum 47°C (12,8bara),which must be covered by the choice of the compressor.

The NH_3 charge was to be kept with 500 kg total for this plant. NH_3 is standard application for the contractor. The timeframe for the project was order clearance till October 2016 and installation to be finalised untill February 2017. The handing over including site acceptance test was done 21-3-2017.

The system design details are shown in the table nr 1.
The hot water is heated up from 59,5°C to 85°C with capacity 4392 kW, while the heat source side cools the water from the flue gas waste heat exchaner from 50°C to 26°C with capacity of 3646 kW. 3 high pressure piston type compressors model N6HS are installed on each of the units C10, C20 and C30. The drive motors are 400kW for C10 and 315kW for C20/C30. The NH_3 charge for per unit is 150kg as individual circuit corresponding with approx. 85g per kW heating output.
Table 1.

SYSTEM DESIGN DETAILS			REF.SO78287	
HEAT OUTPUT	**HOT WATER FOR DISTRICT HEATING**			
	water	outlet	°C	85
		return	°C	59,5
	capacity		kW	4392
HEAT SOURCE	**FLUE GAS**			
	water	inlet	°C	50
		outlet	°C	26
	capacity		kW	3646
COMPRESSORS	type	**high pressure reciprocating**		
	model		**N6HS**	
	quantity		**3**	
DRIVE MOTORS	power	kW	400	C10
VFD		kW	315	C20
		kW	315	c30
NH3	charge	kg	**150**	each
		g/kW	**85**	
	circuit		individual	

Figure 1 explains the system and water flows on heat output side and heat source side.

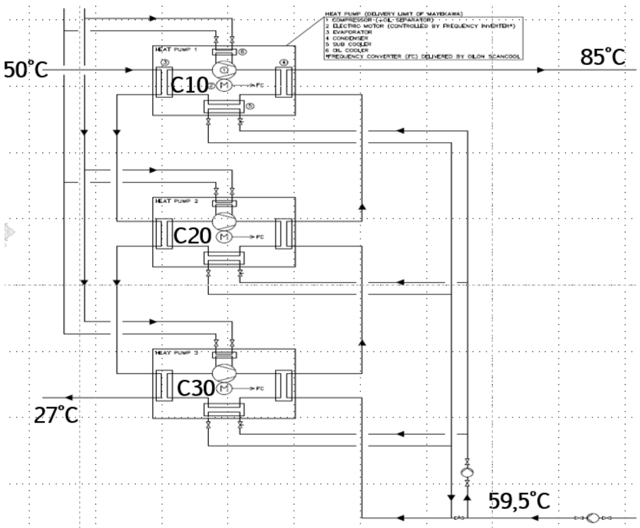


Figure 1.
Each block shows the individual heat pump unit and NH3 circuit with compressor – condensor – liquid subcooler and evaporator : C10, C20 and C30.

The heat source flow is serial starting from inlet 50°C in C10 via C20 to C30 with 27°C outlet.

The heating flow on the liquid subcoolers inlet 59,5°C goes parallel to the 3 units and is taken with the main water flow to the condensors in serial flow starting from C30 via C20 to C10 with 85°C outlet.

Table 2 shows the design data of the 3 compressors operating in serie in the heat pump installation. Using the compressors with liquid subcooling in serie results in an more optimal COP-heating.
The 6 cylinder high pressure, design presssure 66 barg, compressor is operating with variable frequency drive and individual mechanical cylinder control.

DESIGN DATA					
HEAT PUMP		C10	C20	C30	total
TC(PD)	°C(barg)	88(48,1)	79(39,5)	71(32,9)	
TE(PS)	°C(barg)	38(13,7)	30(10,7)	24(8,7)	
SC	°C	24	15	7	
HEATING	kW	1785	1423	1183	4391
BKW	kW	316	264	226	806
COPh		5,65	5,39	5,23	5,45
HEATING WATER					
OUT	°C	85	76	68,5	85
IN	°C	76,1	68,5	61,4	59,5
FLOW	kg/s				41,2
HEAT SOURCE					
IN	°C	50	40,5	32,7	50
OUT	°C	40,5	32,7	26,7	27
FLOW	kg/s				37,9

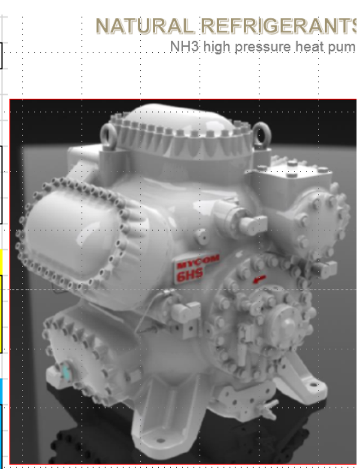


Table 2.

Figure 2.

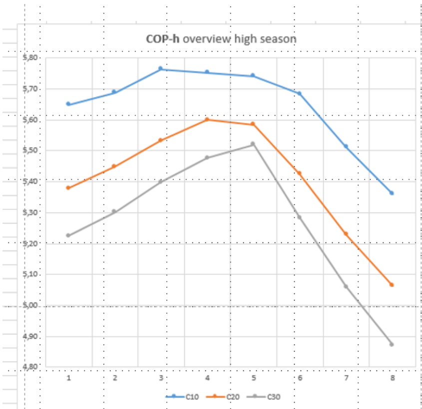
The left photo views the evaporator with suction piping to the compressor, while the right photo shows the compressor with suction line, discharge piping to the oil separator and the oil system on the skid.

Figure 3.

The different heat pump packaged have operated all together 29.320 hrs untill 5-12-2018. The picture shows the different units with their individual status of running hours done.

In table 3 an overview is shown on the COP-h in the high season. The graphs show the COP-h per compressor at different load conditions. The load is given at maximum speed 1450rpm followed by 1300, 1100, 900 and 750 as shown in the table. The last 3 columns show mechanical unload operation at 1, 2 and 3 unloaded cylinders or 83, 66 and 50% loaded clylinders.

It is clear that the COP-h increases by operating at lower speeds from 1450 to 750 rpm with full loaded cylinders. At part loaded cylinders the COP-h decreases in accordance. During the high load season the 3 compressors are always opeerating at full loaded cylinders and VFD controlled from 1450 to 1300 rpm or 50Hz to 45Hz. During the mid load season 2 compressors are running at full loaded cylinders and VFD controlled between 1450 to 1100rpm.



COP-H OVERVIEW

	1	2	3	4	5	6	7	8
%	100	90	76	62	52	43	35	26
C10	5,65	5,69	5,76	5,75	5,74	5,68	5,51	5,36
C20	5,38	5,45	5,53	5,60	5,58	5,42	5,23	5,06
C30	5,22	5,30	5,40	5,48	5,52	5,28	5,06	4,87
RPM	1450	1300	1100	900	750	750	750	750
LOAD%	100	100	100	100	100	83	66	50

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NH3 high pre

HIGH-SEASON (NOV->MARCH : 5 MONTHS)

1450rpm	C10	C20	C30	
QC	1785,5	1423,2	1182,9	4391,6
BKW	316,1	264,6	226,4	807,1
COP-h	5,65	5,38	5,22	5,44

1300rpm	C10	C20	C30	
QC	1663,8	1276,5	1060,4	4000,7
BKW	292,5	234,3	200	726,8
COP-h	5,69	5,45	5,30	**5,50**

regime :
3 compressors 100% banks & vfd 1450->1300rpm

MID-SEASON (SEP->OCT,APR.->MAY : 4 MONTHS

rpm		1429		1450	
	C10	C20		C30	
QC	0	1188,0		1081	2269,0
BKW	0	239		197	436,0
		4,97		5,49	5,20

1100rpm	C10	C20		C30	
QC	1356,6	1078,9		0	2435,4
BKW	235,4	195		0	430,4
					5,66

regime :
2 compressors 100% banks & vfd 1450->1100rpm

Table 3.

HEAT PRODUCTION ON YEARLY BASIS

season	rpm vs hours				sum	heating		BKW		COPh	
	hp	C10	C20	C30		per hour	total	per hour	total		
	rpm	hrs	hrs	hrs	hrs	kW	MWh	kW	MWh		
high 5m	1300	3600	3600	3600	10800	4000	43200	727	7852	5,44	5,50
mid 4m	1100	2840	2540	300	5680	2435	13831	430	2442	5,20	5,66
low 3m	750	2011	0	311	2322	1229	2854	224	520	5,49	5,49
	total	8451	6140	4211	18802		59885		10814	5,37	5,55

Table 4.

In table nr 4 an overview is given of the heat production of 1 year operation. The seasons are shown in the first column with 5 months operation for high season, 4 months operation for mid season and 3 months for the low season. The next columns show the running hours per season of each compressor and the total running hours per season.

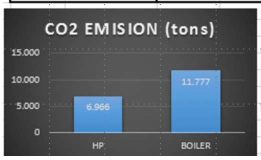
The next columns show heating capacities and compresssor shaft powers taken on the lowest operating speeds per season what means 1300rpm for high season, 1100rpm for mid season and 750rpm and cylinder part load for low season.
The COP-h's are taken at the maximum speeds(in red) as they are lower than at reduced speeds.
It shows that the final total COP-h becomes 5,37 (instead of 5,55 at lower speed).

The operation savings of this heat pumps compared to conventional gas boilers are listed up in table 5.
For the heat pump 20% losses are deducted from the COP-h shown in table 4. (5,37 x 0,8 = 4,3)
The yearly hot water production of the heat pump is increased with 10% in case of the gas boiler. The yearly energy consumption in case of the heatpumps is 13.931 MWh while 66.538 MWh for the gas boiler representing a saving of 52.607 MWh or 80% !

The energy prices for the plant are amounting to 90 €/MWh for electricity and 45 €/MWh for gas which results in an energy cost of 1.253.805€ for the heat pump versus 2.994.227€ for the gas boiler or a saving of 1.740.422€ or 58% !

The CO2 emission has been reduced from 11.777 tons for the gas boiler to 6.966 tons for the heat pump or reduction of 4.811 ton or 40% !

OPERATING SAVINGS		HEAT PUMP	GAS BOILER	NATURAL REFRIGERANTS NH3 high pressure heat pump
Performance COPh		4,30	0,90	*
Hot water (year)	mW	59.885	66.538	
Energy consumption (year)	MWh	13.931	66.538	Saving 52.607MWh or 80%
Energy prices	euro/MWh	90	45	
Energy costs	euro	1.253.805	2.994.227	Saving 1.740.422€ or 58%
CO2 emissions	tons	6.966	11.777	Saving 4.811 tons or 40%



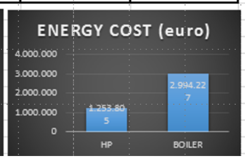


Table 5.

AND NEXT

The following district heating project is under construction but shows again the importance of the huge savings possible to realize. This is a 90 GWh heat pump installation on yearbasis based on the seasonsal loads available per hour per season.

Table nr 6 shows the design details per heat pump set each containing 2 pieces NH3 high pressure heat pump compressors and 2 pieces of NH3 heat source compressors. In total 6 sets are needed. The hot water output temperature is 80°C with total around 13.800 kW and the heat source is taken from a water purification station. In the high season the water is cooled from 15°C to 5°C with total around 10.000 kW per hour. Figure 4 gives a view on the heat pump package with 4 compressors each. The NH3 charge is 240 kg per package what corresponds with approx.100 g/kW heat output.

DESIGN DATA		PER SET			6 SETS
HEAT PUMP		1	2	subtotal	total
TC	°C	83	83		
TM	°C	30	30		
SC	°C	20	20		
HEATING	kW	1153	1153	2306	13836
BKW	kW	228	228	456	2736
COPh		5,06	5,06	5,06	
STEP CHILLER		1	2		
TE	°C	3	3		
TM	°C	30	30		
SC	°C	0	0		
COOLING	kW	839	839,0	1678	10068
BKW	kW	112	112	224	1344
COPc		7,49	7,49	7,49	
COPhtotal		3,39	3,39	3,39	3,39
HEATING WATER					
OUT	°C			80	
IN	°C			60	
FLOW	kg/s			27,54	
HEAT SOURCE					
IN	°C			15	
OUT	°C			5	
FLOW	kg/s			40.1	

NATURAL REFRIGERANTS
NH3 high pressure heat pump

Table 6.

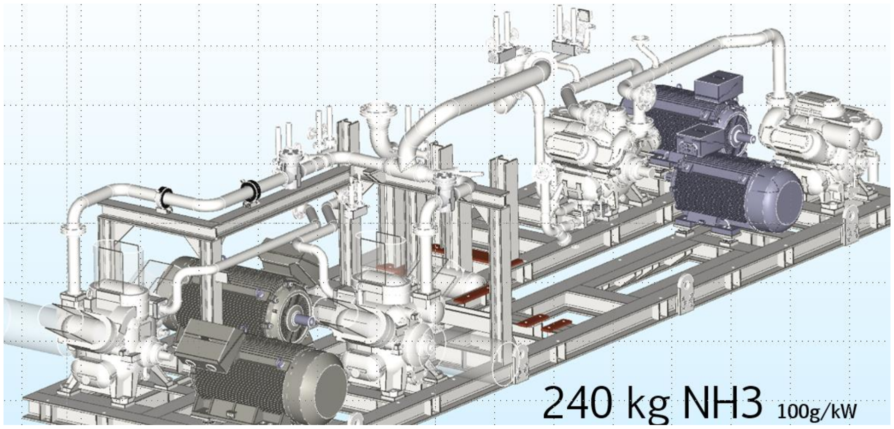


Figure 4.

In table nr 7 an overview is given of the heat production of 1 year operation. The seasons are shown in the first column with 3 months operation for high season, 6 months operation for mid season and 3 months for the low season. The next columns show the running hours per season of each compressor and the total running hours of 8.640. The total heating capacity amounts to 91.755 MWh per year and the total electrical power input amounts to 25.708 MWh corresponding with a COP-h of 3,57.

HEAT PRODUCTION ON YEARLY BASIS							
season	month	sum	heating		BKW		COPh
	qty		per hour	total	per hour	total	
		hrs	kW	MWh	kW	MWh	
high	3	2160	12098	26132	3457	7467	3,50
mid	6	4320	12722	54959	3524	15224	3,61
low	3	2160	4937	10664	1397	3018	3,53
total	12	8640		91755		25708	3,57

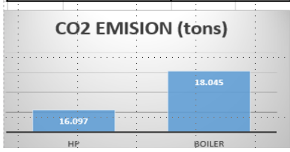
Table 7.

The operation savings of this heat pumps compared to conventional gas boilers are listed up in table 8. The yearly hot water production of the heat pump is increased with 10% in case of the gas boiler. The electrical power finally to be payd is obtained by applying 20% losses resulting to 2,85. The yearly energy consumption in case of the heatpumps is 32.194 MWh while 101.950 MWh for the gas boiler representing a saving of 69.755 MWh or 68% !

The energy prices for the plant are amounting to 65 €/MWh for electricity and 44 €/MWh for gas which results in an energy cost of 2.092.650€ for the heat pump versus 4.485.782€ for the gas boiler or a saving of 2.393.107€ or 53% !

The CO2 emission has been reduced from 18.045 tons for the gas boiler to 16.097 tons for the heat pump or reduction of 1.948 ton or 11% !

OPERATING SAVINGS		HEAT PUMP	GAS BOILER	NATURAL REFRIGERANTS NH3 high pressure heat pump
Performance COPh		2,85	0,90	
Hot water (year)	mW	91.755	101.950	
Energy consumption (year)	MWh	32.195	101.950	Saving 69.755 MWh or 68%
Energy prices	euro/MWh	65	44	
Energy costs	euro	2.092.650	4.485.782	Saving 2.393.107€ or 53%
CO2 emissions	tons	16.097	18.045	Saving 1.948 tons or 11%



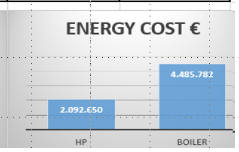


Table 8.

<u>SUMMARY</u>

To highlight once more the results obtained by applying NH3 heat pump installations against using conventional gas boilers :

1st a 60 GWh/yr HP plant to produce 85°C district heating water by using waste heat from flue gas

2nd a 92 GWh/yr HP plant to produce 80°C district heating water by using water purification station as heat source

an input energy reduction was achieved of 80 to 68%

an energy cost saving was herewith achieved of 58 to 53%

a CO2 emission reduction was achieved of 40 to 11%.

SUMMARY			SAVINGS / YR		
HEAT SOURCE	HOT WATER T° °C	OUTPUT INPUT ENERGY MWh/yr COP-h.el	ENERGY MWhr %	ENERGY € %	CO2 tons %
FLUE GAS 50°C	85	60.000 14.000 4,30	52.600 80	1.740.000 58	4.800 40
WATER STATION 5->13°C	80	92.000 32.000 2,85	69.800 68	2.393.100 53	2.000 11