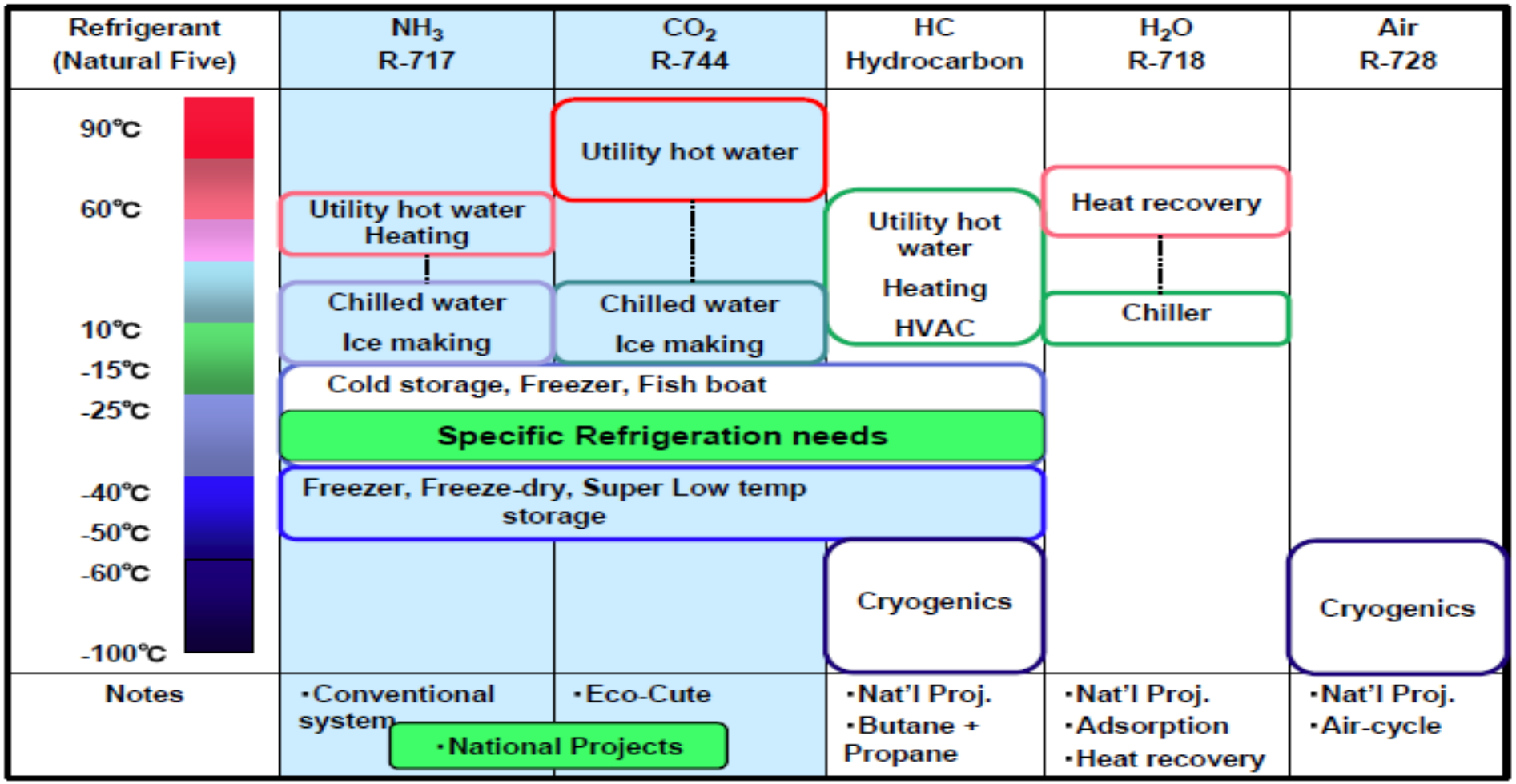
NATURAL REFRIGERANTS

AT LOWER TEMPERATURE APPLICATIONS

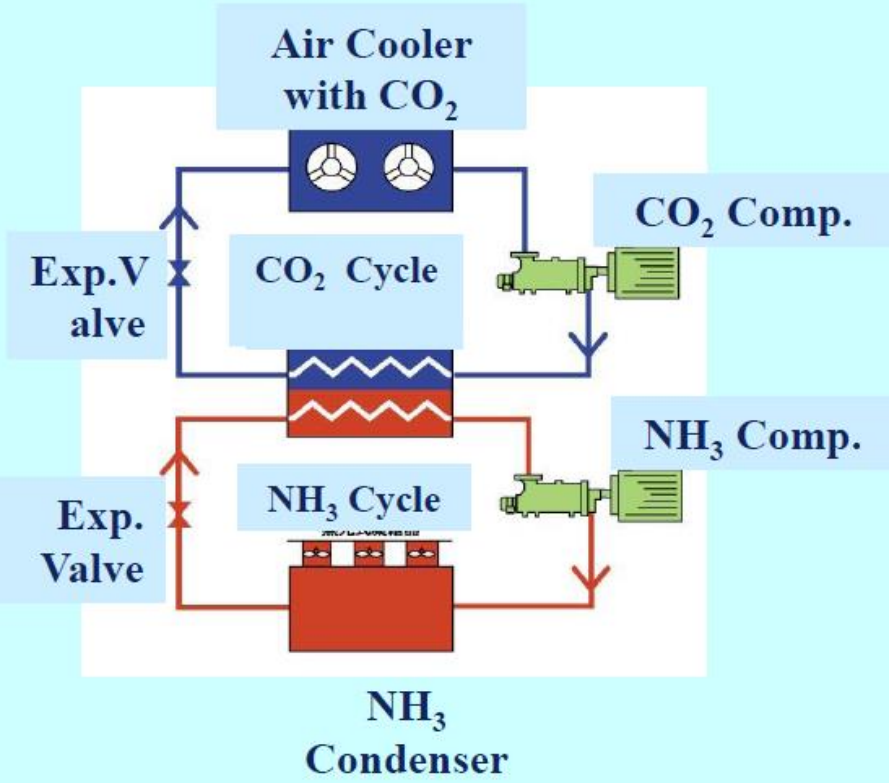
Presented by Jan Boone, MAYEKAWA

"Natural Five" Refrigerants and Product Solutions



FIELD CASE

CO2/NH3 CASCADE COMPRESSION REFRIGERATION

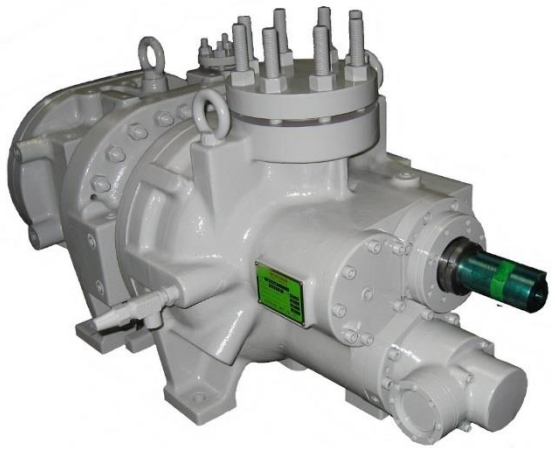


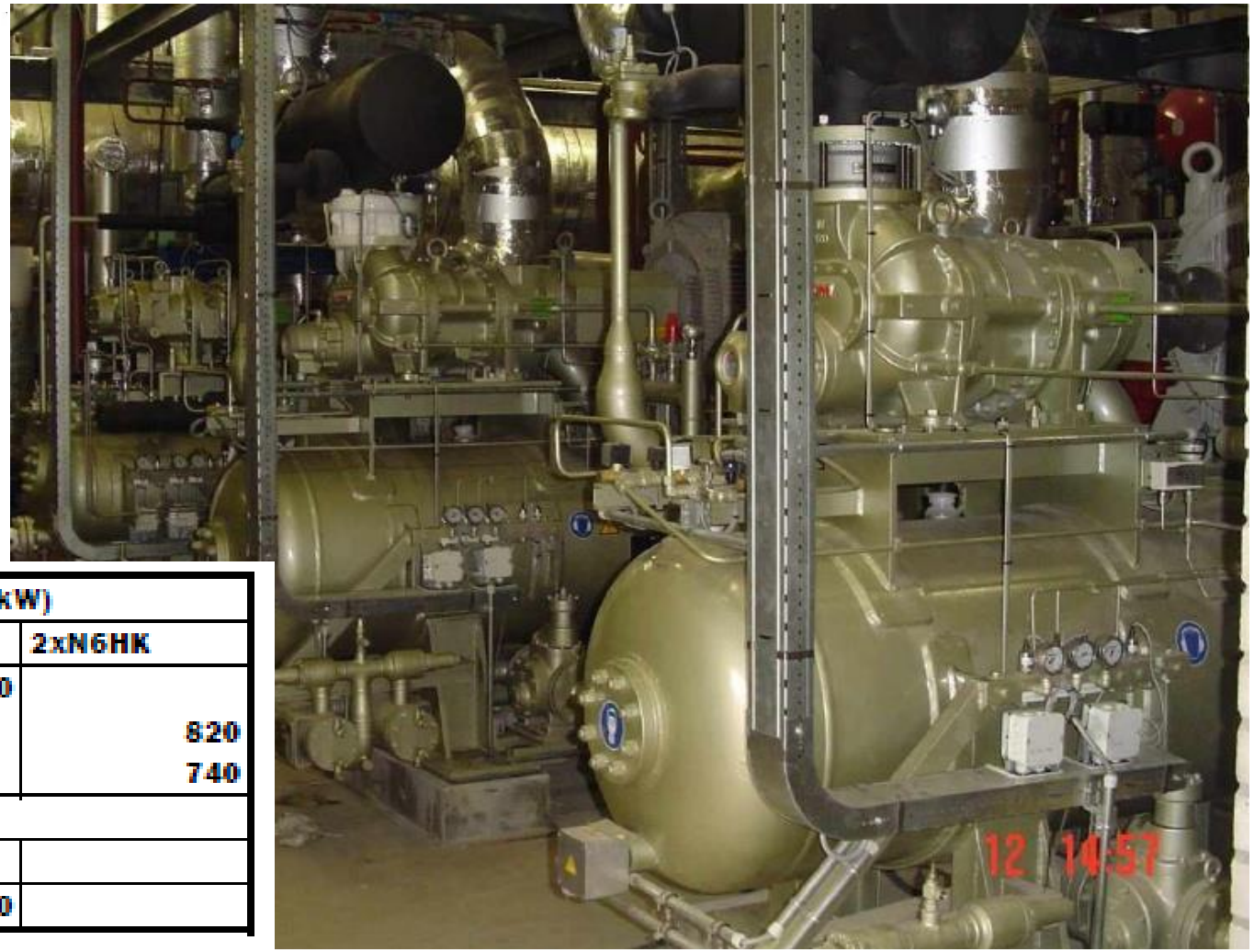
INTRODUCTION

Starting point, need? 2900kW -51°C -12°C -51°C -35°C +10°C +55°C +35°C +12->14°C TC<Twb+10°C	The contractor Engie Refrigeration bv received the request from his customer to convert & increase the refrigeration size of the plant, in use with refrigerant R22 since 1997, in capacity and freezing temperature from 1300kW at -42°C to 2900kW at -51°C. The new plant is to be used for processing meat which is frozen during the process, operating 24hrs/day per workweek by using : chilling in the process working rooms requiring -12°C, product freezing : plate freezers(4x550kW), quick freezing tunnel (1x600kW) and a spiral freezer(1x600kW) requiring -51°C, freezing in stores requiring -35°C. The freezers need to be defrosted by using the CO2 hot gas from the plant. In addition heat recovery is required to obtain hot water for : the process(55°C), floor-/office-/loaddock-/expedition room heating(35°C), bottom floor freezingrooms (12-14°C), and condensing temperature must not exceed 10°K above wetbulb-temperature (authority requirement)

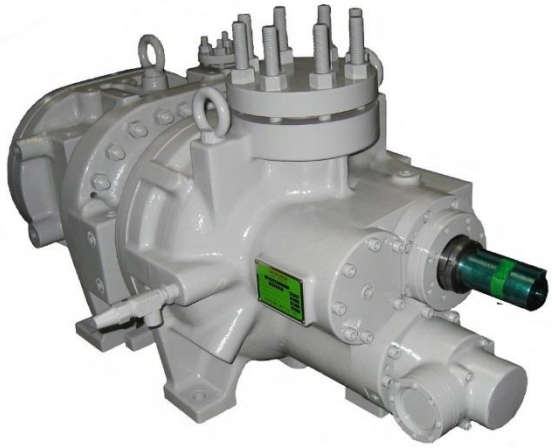
Why natural refrigerants -51°C	For the temperature of -51°C CO2 is the most suitable refrigerant for direct use on the low temperature system applied in a cascade system with NH3 as refrigerant only used for the high temperature cascade side.
Which choice & why <2000kg NH3	CO2 for low temperature side used for direct cooling on the freezers. Most suitable NF. NH3 for high temperature side for cascade purpose only as the customer's environmental licence did not allow more than 2000kg NH3 in the plant. NH3 is standard application for ENGIE Refrigeration bv.
Timeframe 2003 idea Re-built & Extend 10-2004->6-2005	In 2003, the idea came up to re-build the plant by re-using the installed compressors and to extend the plant capacity with lower process temperatures by using CO2 as NF. Plant extension had to be executed from October 2004 till June 2005, Starting with the convertion of the F250VLD units into N250VLD for use with NH3 in May 2005.

Steps to get the project running	Plant stop was scheduled from wk35-2004 to wk25-2005. Plant erection was done in 5 phases. Phase 1 : modification of R22 plant to NH3 (from wk18 to wk23-2005) Phase 2 : installation of CO2 equipment (from wk49-2004 to wk10-2005) Phase 3 : start-up of C5 & C6 (from wk10-2005 to wk14-2005) Phase 4 : start up of C7 (wk16-2005) Phase 5 : start-up of C8 & C9 (wk18-2005 to wk20-2005) Full production from wk25-2005
Funding, partner : other organisation	Yes NOVEM (ROB-program : reduction-plan other greenhouse gases-Reductieplan Overige Broeikasgassen) 450.000€ Funding in terms of reduction of greenhouse gases (program management is done by Ministry of VROM and execution is in hands of NOVEM in NL) EIA (Energy investment deduction) 636.000€ (condition : profitable cie-operation) VAMIL (free writing off) MIA (environment investment deduction)





LOW TEMPERATURE SIDE : FREEZING CAPACITIES (kW)			
CO2 LIQUID T°(°C)	1xGH160	2xC200WMD	2xN6HK
-51	630	2870	
-41	900		820
-31	960		740
HIGH TEMPERATURE SIDE (TC = 32°C)			
NH3 TE (°C)	3xN250VLD	1xN200VLD	
-18	4180	800	



GH160S 50bar SCREW

Operation
PS : 5,5->12,8 barg
PD : 23,3->45 barg

COMPRESSOR OPERATING PARAMETERS															TESTS DONE									
CUSTOMER															FILE NAME									
PLANT															SHEET NO							5		
MYCOM SO NO						27127-1									ISSUED BY							JAN BOONE		
UNIT NO						7									DATE							UNTILL 15/4/2005		
COMPRESSOR						GH160S									REVISION NO							0		
TC	°C	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9
PD	BARG	23,29	24,01	24,74	25,48	26,24	27,02	27,82	28,63	29,45	30,30	31,16	32,04	32,93	33,85	34,78	35,73	36,70	37,68	38,69	39,72	40,76	41,83	42,91
TE	PS	PRESSURE DIFFERENCE : DISCHARGE PRESSURE - SUCTION PRESSURE																						
°C	BARG																							
-31	12,80	10,49	11,21	11,94	12,68	13,44	14,22	**15,02**	15,83	16,65	17,50	18,36	19,24	20,13	21,05	21,98	22,93	23,90	24,88	25,89	26,92	27,96	29,03	30,11
-32	12,34	10,95	11,67	12,40	13,14	13,90	14,68	15,48	16,29	17,11	17,96	18,82	19,70	20,59	21,51	22,44	23,39	24,36	25,34	26,35	27,38	28,42	29,49	30,57
-33	11,89	11,40	12,12	12,85	13,59	14,35	15,13	15,93	16,74	17,56	18,41	19,27	20,15	21,04	21,96	22,89	23,84	24,81	25,79	26,80	27,83	28,87	29,94	31,02
-34	11,45	11,84	12,56	13,29	14,03	14,79	15,57	16,37	17,18	18,00	18,85	19,71	20,59	21,48	22,40	23,33	24,28	25,25	26,23	27,24	28,27	29,31	30,38	31,46
-35	11,02	12,27	12,99	13,72	14,46	15,22	16,00	16,80	17,61	18,43	19,28	20,14	21,02	21,91	22,83	23,76	24,71	25,68	26,66	27,67	28,70	29,74	30,81	31,89
-36	10,60	12,69	13,41	14,14	14,88	15,64	16,42	17,22	18,03	18,85	19,70	20,56	21,44	22,33	23,25	24,18	25,13	26,10	27,08	28,09	29,12	30,16	31,23	32,31
-37	10,20	13,09	13,81	14,54	15,28	16,04	16,82	17,62	18,43	19,25	20,10	20,96	21,84	22,73	23,65	24,58	25,53	26,50	27,48	28,49	29,52	30,56	31,63	32,71
-38	9,80	13,49	14,21	14,94	15,68	16,44	17,22	18,02	18,83	19,65	20,50	21,36	22,24	23,13	24,05	24,98	25,93	26,90	27,88	28,89	29,92	30,96	32,03	33,11
-39	9,42	13,87	14,59	15,32	16,06	16,82	17,60	18,40	19,21	20,03	20,88	21,74	22,62	23,51	24,43	25,36	26,31	27,28	28,26	29,27	30,30	31,34	32,41	33,49
-40	9,04	14,25	14,97	15,70	16,44	17,20	17,98	**18,78**	19,59	20,41	21,26	22,12	23,00	23,89	24,81	25,74	26,69	27,66	28,64	29,65	30,68	31,72	32,79	33,87
-41	8,68	14,61	15,33	16,06	16,80	17,56	18,34	19,14	19,95	20,77	21,62	22,48	23,36	24,25	25,17	26,10	27,05	28,02	29,00	30,01	31,04	32,08	33,15	34,23
-42	8,32	14,97	15,69	16,42	17,16	17,92	18,70	19,50	20,31	21,13	21,98	22,84	23,72	24,61	25,53	26,46	27,41	28,38	29,36	30,37	31,40	32,44	33,51	34,59
-43	7,98	15,31	16,03	16,76	17,50	18,26	19,04	19,84	20,65	21,47	22,32	23,18	24,06	24,95	25,87	26,80	27,75	28,72	29,70	30,71	31,74	32,78	33,85	34,93
-44	7,64	15,65	16,37	17,10	17,84	18,60	19,38	20,18	20,99	21,81	22,66	23,52	24,40	25,29	26,21	27,14	28,09	29,06	30,04	31,05	32,08	33,12	34,19	35,27
-45	7,31	15,98	16,70	17,43	18,17	18,93	19,71	**20,51**	21,32	22,14	22,99	23,85	24,73	25,62	26,54	27,47	28,42	29,39	30,37	31,38	32,41	33,45	34,52	35,60
-46	7,00	16,29	17,01	17,74	18,48	19,24	20,02	20,82	21,63	22,45	23,30	24,16	25,04	25,93	26,85	27,78	28,73	29,70	30,68	31,69	32,72	33,76	34,83	35,91
-47	6,69	16,60	17,32	18,05	18,79	19,55	20,33	21,13	21,94	22,76	23,61	24,47	25,35	26,24	27,16	28,09	29,04	30,01	30,99	32,00	33,03	34,07	35,14	36,22
-48	6,39	16,90	17,62	18,35	19,09	19,85	20,63	21,43	22,24	23,06	23,91	24,77	25,65	26,54	27,46	28,39	29,34	30,31	31,29	32,30	33,33	34,37	35,44	36,52
-49	6,10	17,19	17,91	18,64	19,38	20,14	20,92	21,72	22,53	23,35	24,20	25,06	25,94	26,83	27,75	28,68	29,63	30,60	31,58	32,59	33,62	34,66	35,73	36,81
-50	5,82	17,47	18,19	18,92	19,66	20,42	21,20	22,00	22,81	23,63	24,48	25,34	26,22	27,11	28,03	28,96	29,91	30,88	31,86	32,87	33,90	34,94	36,01	37,09
-51	5,55	**17,74**	18,46	19,19	19,93	20,69	21,47	**22,27**	**23,08**	23,90	24,75	25,61	26,49	27,38	28,30	29,23	30,18	31,15	32,13	33,14	34,17	35,21	36,28	37,36
-52	5,28	18,01	18,73	19,46	20,20	20,96	21,74	22,54	23,35	24,17	25,02	25,88	26,76	27,65	28,57	29,50	30,45	31,42	32,40	33,41	34,44	35,48	36,55	37,63
-53	5,02	18,27	18,99	19,72	20,46	21,22	22,00	22,80	23,61	24,43	25,28	26,14	27,02	27,91	28,83	29,76	30,71	31,68	32,66	33,67	34,70	35,74	36,81	37,89
-54	4,78	18,51	19,23	19,96	20,70	21,46	22,24	23,04	23,85	24,67	25,52	26,38	27,26	28,15	29,07	30,00	30,95	31,92	32,90	33,91	34,94	35,98	37,05	38,13
-55	4,54	18,75	19,47	20,20	20,94	21,70	22,48	23,28	24,09	24,91	25,76	26,62	27,50	28,39	29,31	30,24	31,19	32,16	33,14	34,15	35,18	36,22	37,29	38,37
TC	°C	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9
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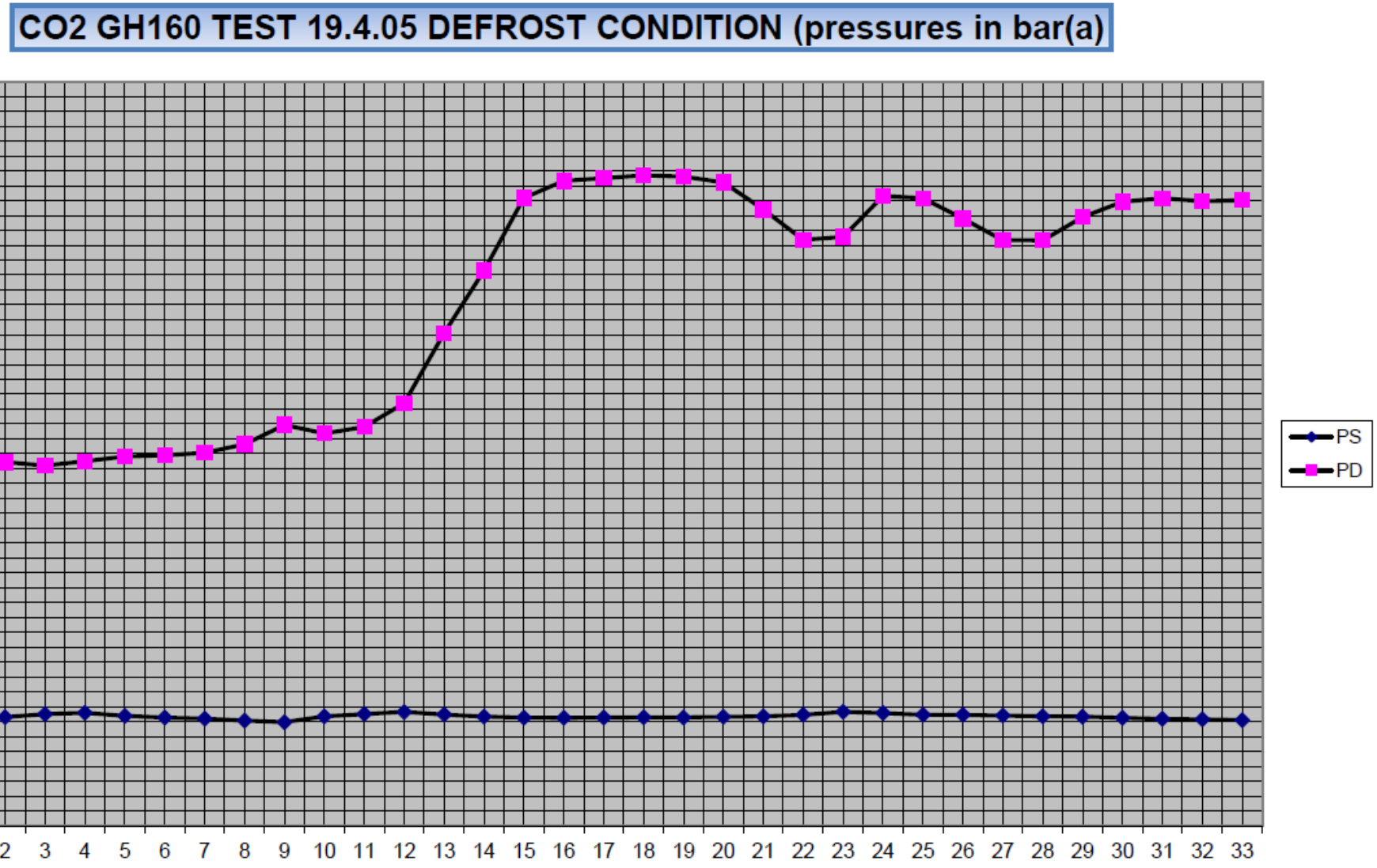
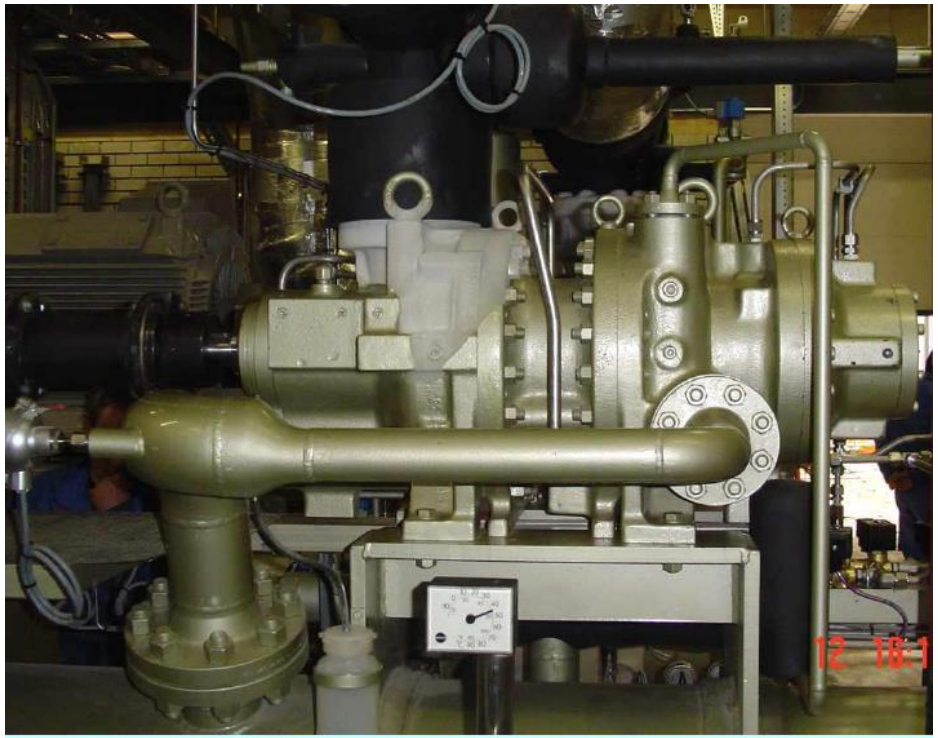

CO2 GH160 TEST 19.4.05 DEFROST CONDITION (pressures in bar(a)
50,00
45,00
40,00
35,00
30,00
25,00
20,00
15,00
10,00
5,00
0,00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
PS
PD

OVERVIEW INSTALLED COMPRESSORS

natural refrigerant	unit nr	compressor		
		type model	installation year	running hours 2/11/2017
CO2	5	C6HK	2005	92765
CO2	6	C6HK	2005	15964
CO2	7	CGH160	2005	80630
CO2	8	C200VMD	2005	68539
CO2	9	C200VMD	2005	13813
NH3	1	N250VLD	1997	98149
NH3	2	N250VLD	1997	50411
NH3	3	N250VLD	1997	48004
NH3	4	N200VLD	2005	107737



EFFICIENCY ANALYSIS

design

CO2/NH3 CASCADE		RT	BKW	THR	COPc-each	COPc-total
TE=-51°C	TC=+32°C	kW	kW	kW		
CO2 LS	GH160	629	184	813	3,4	
	C200VMD	1100	311	1411	3,5	
	C200VMD	1191	330	1521	3,6	
	total	2920	825	3745	3,5	1,61
NH3 HS	N250VLDx2	2760	723			
	N250VLDx1	987	268			
	total	3747	991		3,8	

average

CO2/NH3 CASCADE		RT	BKW	THR	COPc-each	COPc-total
TE=-51°C	TC=+25°C	kW	kW	kW		
CO2 LS	GH160	629	184	813	3,4	
	C200VMD	1100	311	1411	3,5	
	C200VMD	1191	330	1521	3,6	
	total	2920	825	3745	3,5	1,75
NH3 HS	N250VLDx2	2820	626			
	N250VLDx1	927	214			
	total	3747	840		4,5	

EFFICIENCY ANALYSIS

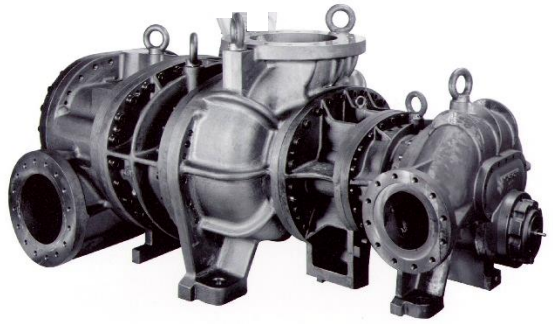
Difference planned & actual results if occured?	
If yes, why were there differences? TC:32->25°C 90600€	For the main freezing load of 5 days 24hrs operation : Average condensing temperature on the NH3 cascade compressors is reduced from design value of 32°C to 25°C, this means a compressor absorbed power reduction of 151kWh or 906 MWh based on 6000hrs operation per year. (COP-c increase of 8,7%) This represents an energy saving for the customer of 90600 € (based on 0,10€/kWh) Heat recovery . 690 MW/year (process use)
How is the process of measuring efficiency?	The freezing equipment is operating following load programs which must be covered by the refrigeration plant, which was fullfilled. Per type of compressor 1 machine is equipped with frequency convertor for speed control at part-load operation in order to keep the best COPc

COSTS INVOLVED & POSSIBLE COST SAVING OR HIGHER SPENDING FOR THIS PROJECT.	This installation represents for ENGIE Refrigeration bv a value of approx. 4.000.000 €.
Estimated price difference to conventional system	The comparison with synthetic refrigerant R507 has been considered. ENGIE Refrigeration bv concluded that this solution was much more expensive than the choosen CO2/NH3 concept.
Maintenance	For 12 years operation of the 9 compressors the costs for used parts, service works and lubrication oil amount in total to approx. 275 000€ i.e. nearly 7% of the 2005 installation investment. (incl. 1 bare GH160S)
Savings or potential savings because of existing or pending regulation	At the completation and the acceptance of the new CO2/NH3 plant, TNO reported that the CO2/NH3 plant is significantly more efficient than a comparable plant with R507. The calculated savings amount to 23% on energy, resp. 49% on CO2 equivalent emmission at that time. In addition the plant is equipped with following energy-saving options : -heat recovery -high efficiency electrical motors -hot gas defrosting -frequency controllers -energy-saving condensors

&
LAST BUT NOT LEAST

CERN (EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH)

HELIUM COOLING SCREW COMPRESSORS



The LHC (LARGE HADRON COLLIDER) in Geneva,
world's largest & most powerfull particle accelerator,
uses a 27 km ring of superconducting magnets which
are cooled down to -271,3°C to minimize the losses with
2-stage Mycom screw compressors using superfluid helium.

July 2012 : Highs boson was discovered as 1st major result of LHC research. (Brout-Englert-Higgs particle predicted 1964)

2013 : Nobel price in physics
awarded jointly to Francois Englert and Peter Higgs for theoretical discovery of mechanism that contributes to our understanding of the origin of mass of subatomic particles, confirmed by the experiments at CERN's LHC.

HELIUM COOLING SCREW COMPRESSORS

TEST PLANT

experimental campaign : crucial for advancing fusion science to prepare the way for fusion power plants to-morrow needs...

TOKAMAK

world's largest magnetic device
PLASMA 1 300 000°C
FUSION POWER 500 MW
POWER INPUT 50 MW
(10-fold return on energy!)

MAGNETS

cooling with supercritical He 4K

PLANNING : 1st plasma production 2035

THANKS FOR YOUR ATTENTION

Special thank-word to :

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ENGIE REFRIGERATION bv – NEDERLAND

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ENGIE REFRIGERATION FRANCE

MARKET AVAILABILITY

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