DEVELOPMENT AND ANALYSIS OF A SMALL SCALE NATURAL GAS RELIQUEFACTION PLANT

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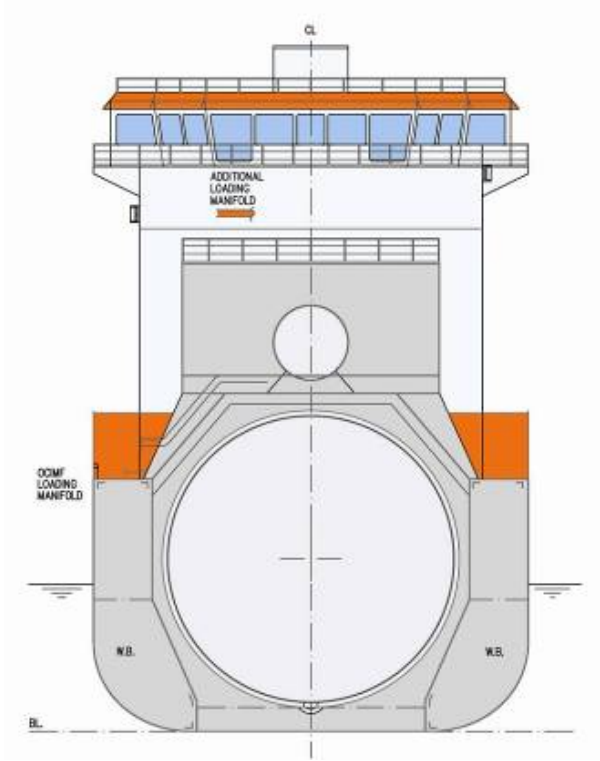
Reliquefaction of boil-off gas from a small IMS Multigas carrier using the Mini-LNG Techology

3D illustration of the tanker with the refrigeration system on the top deck

10.000 m^3
Multigas



SMALL SCALE LNG DISTRIBUTION

- Small gas tankers transport LNG to sattelites along the coast
- Reliquefaction of boil-off gas is both environmentally and economically sound
- Gives possibility to cool down the cargo during the transport period
- All cargo to the customer

NG liquefaction plants, capacity range

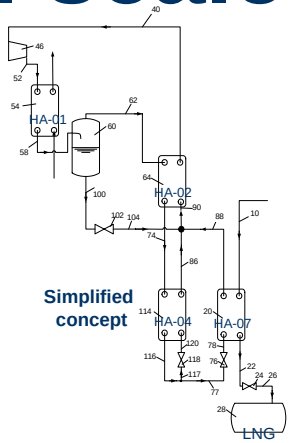
Base-load
LNG production: 1500 – 5000 kT/year
Snøhvit 4300

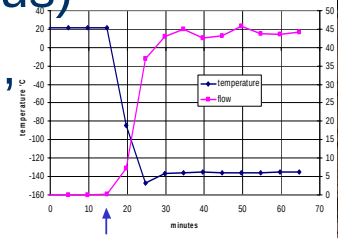
Peak shaving
LNG production: 35 – 150 kT/year

Mini-LNG
LNG production: 3.5 – 35 kT/year
(10 – 100 T/day)

Theory – laboratory - full scale

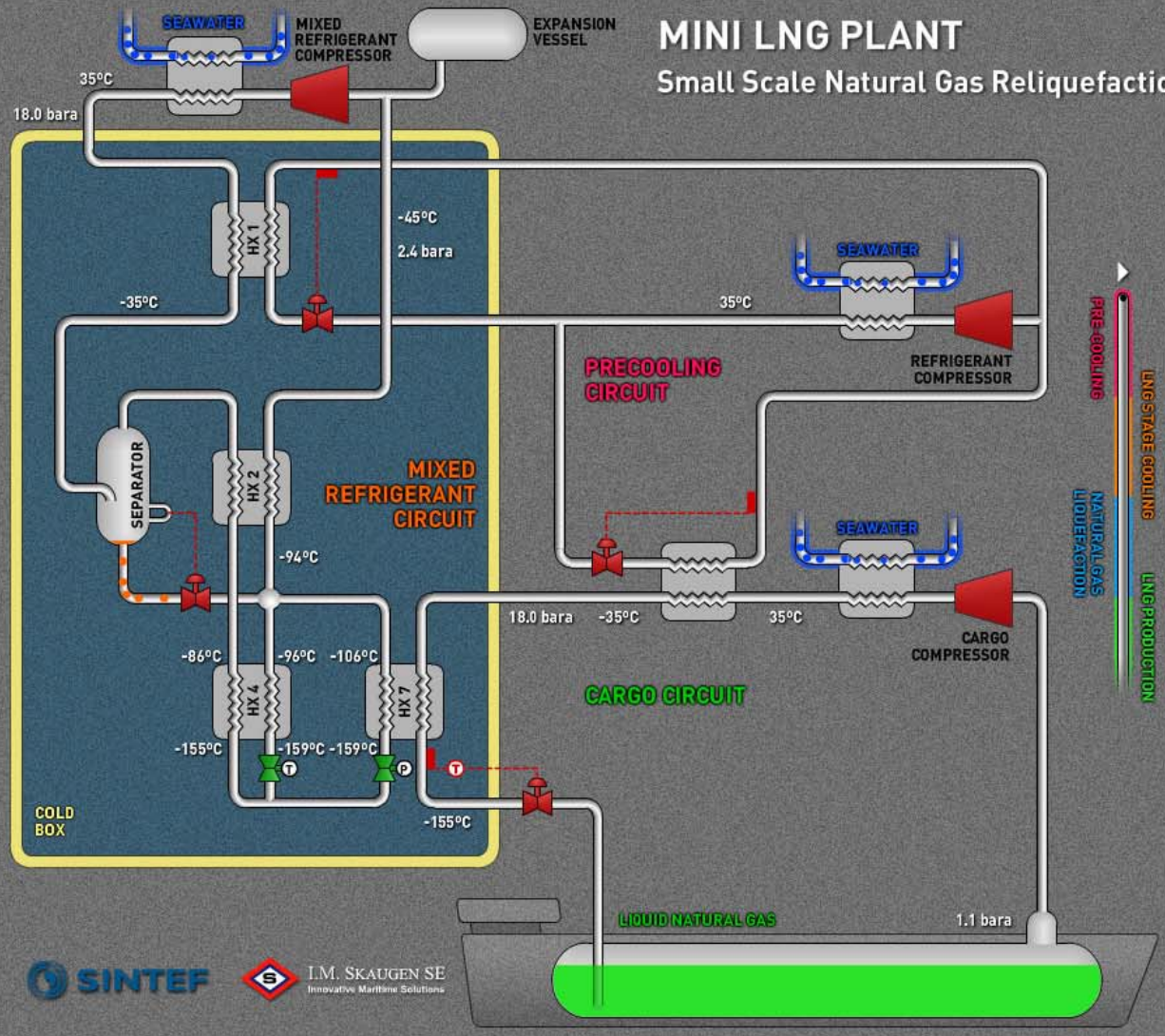
- Theoretical
  - Process development and simplification
  - Analysis
- Laboratory plant 1 tonnes$_{LNG}$/d
  - Fully instrumented lab plant at SINTEF
  - Operation since 2003, 2000 h (500 continuous)
  - Lubricant tests, various operating conditions, rapid start-up
- Full scale test, 20 tonnes$_{LNG}$/d
  - Design and construction
  - FAT test at SINTEF Tiller lab in Trondheim
  - Analysis of results
  - Installation onboard the gas carrier





The SINTEF Mini-LNG concept Liquefaction Unit

- Using standard equipment for low investment cost and fast manufacture of the liquefaction unit
  - Copper brazed plate heat exchangers, withstands very rapid temperature changes
  - Lubricant injected screw compressors
  - Proven robust oil/lubricant management
- Construction in steel frames:
  - Lower manufacturing cost
  - Faster manufacture time
  - Modular movable plant elements
- Refrigeration cycle with mixed refrigerant (N_2,C_1,C_2,C_3,C_4) for low energy demand
- Adaptation of selected equipment, MR and operational conditions to given application and NG composition


MINI LNG PLANT
Small Scale Natural Gas Reliquefaction
SEAWATER
MIXED REFRIGERANT COMPRESSOR
EXPANSION VESSEL
35°C
18.0 bara
HX 1
-45°C
2.4 bara
-35°C
SEAWATER
35°C
REFRIGERANT COMPRESSOR
PRECOOLING CIRCUIT
SEPARATOR
HX 2
MIXED REFRIGERANT CIRCUIT
-94°C
SEAWATER
18.0 bara
-35°C
35°C
CARGO COMPRESSOR
-86°C
-96°C
-106°C
HX 4
HX 7
CARGO CIRCUIT
-155°C
-159°C
-159°C
COLD BOX
-155°C
PRE-COOLING
LNG STAGE COOLING
NATURAL GAS LIQUEFACTION
LNG PRODUCTION
LIQUID NATURAL GAS
1.1 bara
SINTEF
I.M. SKAUGEN SE
Innovative Maritime Solutions

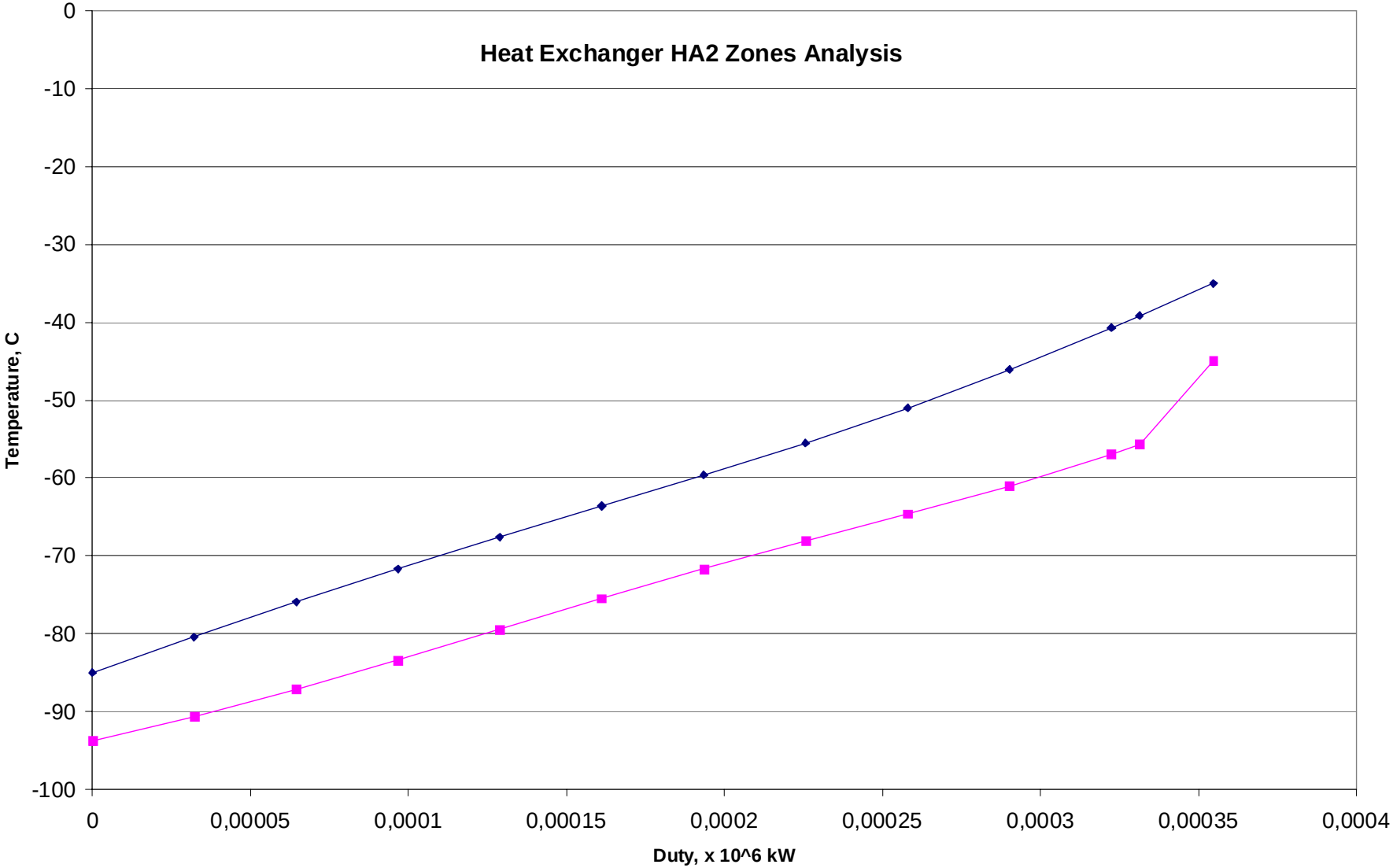
Plant design simulation results (mini-LNG)

BOG NG with 89 mol% CH4, 11 mol% N2 (18 bara)

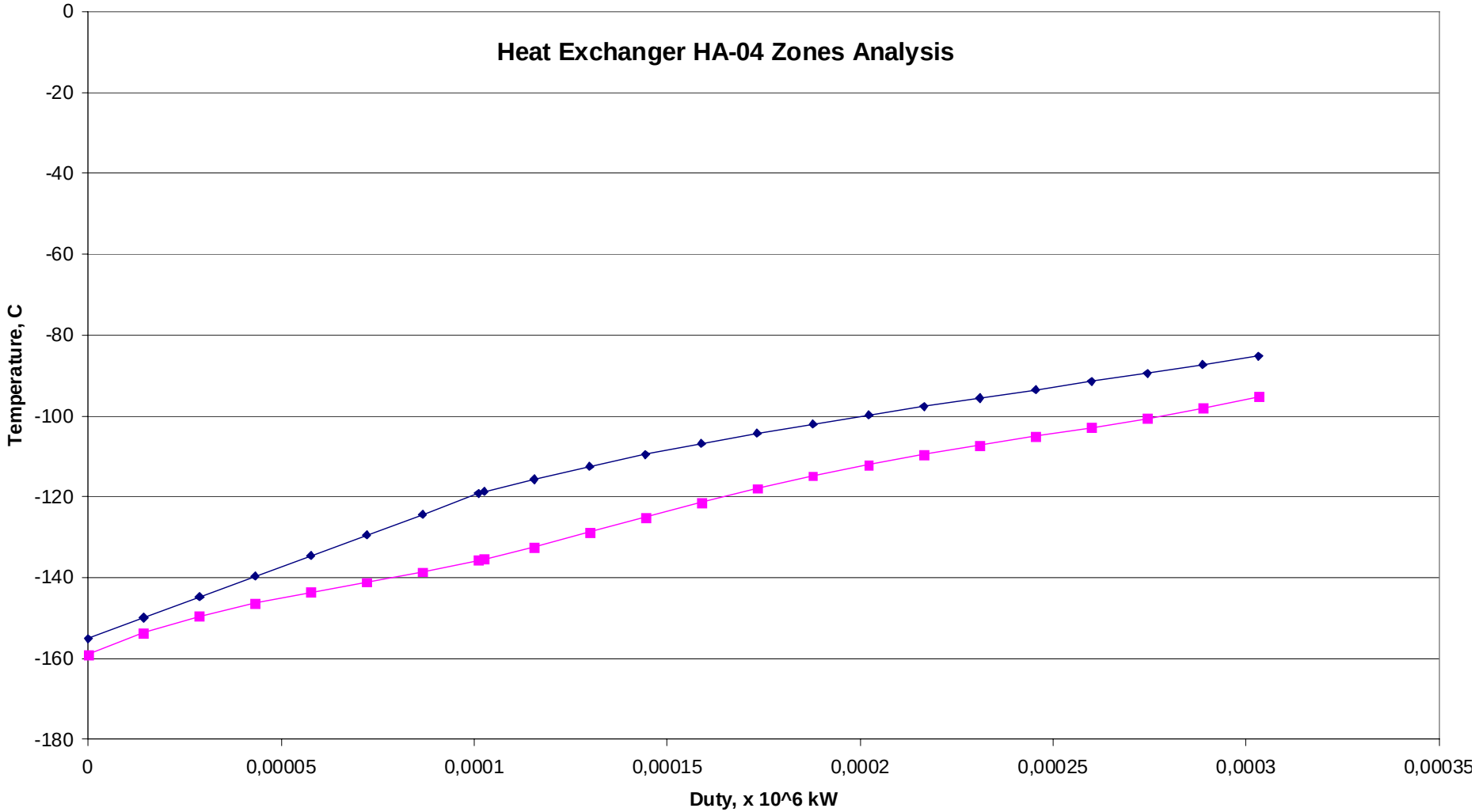
Boil-off gas liquefaction capacity	20 tonnes/d
LNG exit temperature (before throttling to tank)	-155 ^{o}C
MR (at first vapour-liquid separator inlet) and NG pre-cooling temperature	-35 ^{o}C
Mixed refrigerant compressor pressure ratio	9.3 -
Mixed refrigerant compressor power consumption	395 kW
Estimated compressor isentropic efficiency	0.65 -
Mixed refrigerant actual suction volume	1520 m^3/h
Specific suction volume	1.8 m^3/kg LNG
Specific power consumption mini-LNG	0.47 kWh/kg LNG

- Still potential for improvements

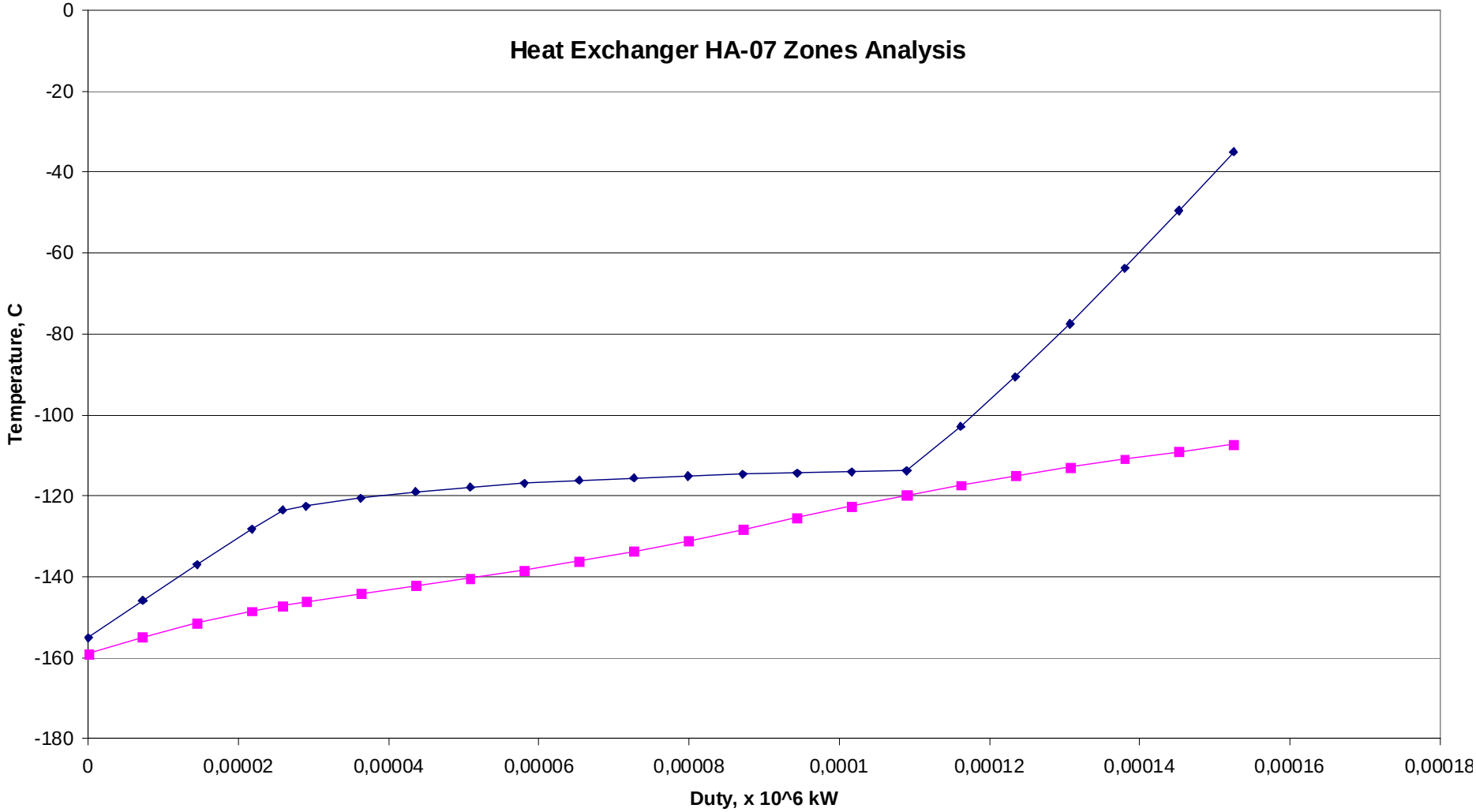
Heat Exchanger HX 2, MR-HP/MR-LP, high temp
Duty vs. Temperature



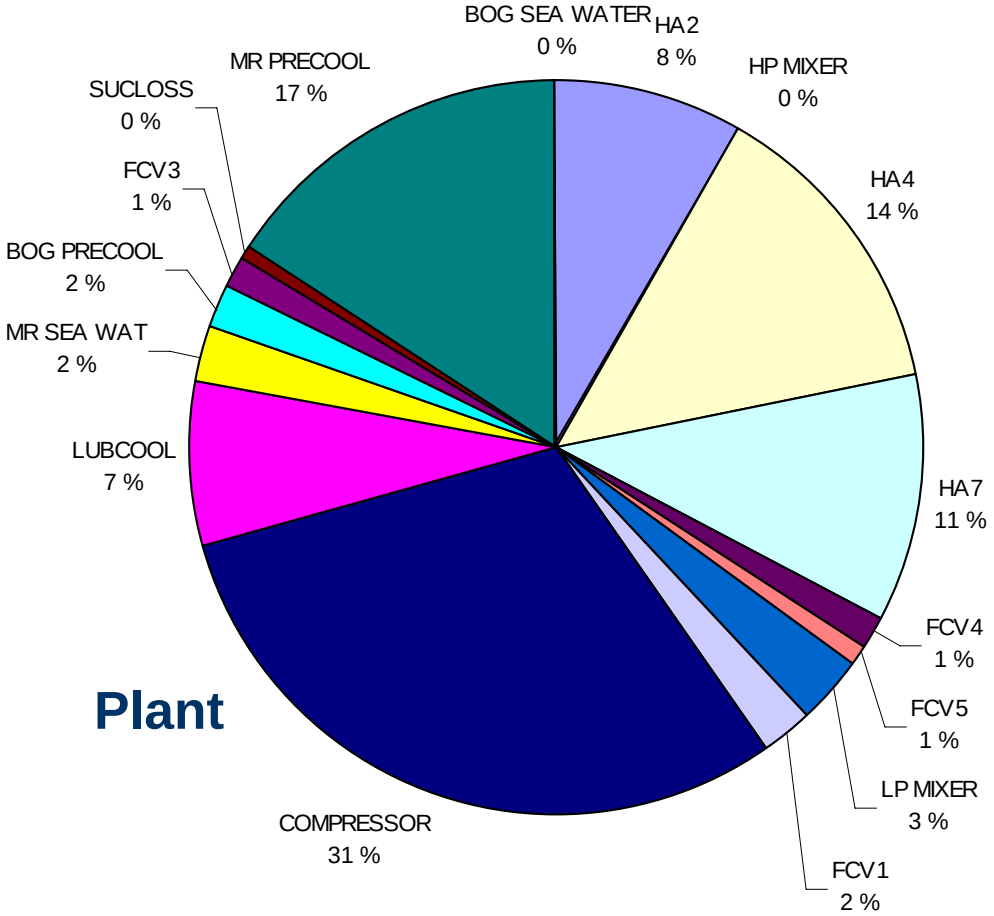
Heat Exchanger HX 4, MR-HP/MR-LP, low temp
Duty vs. Temperature



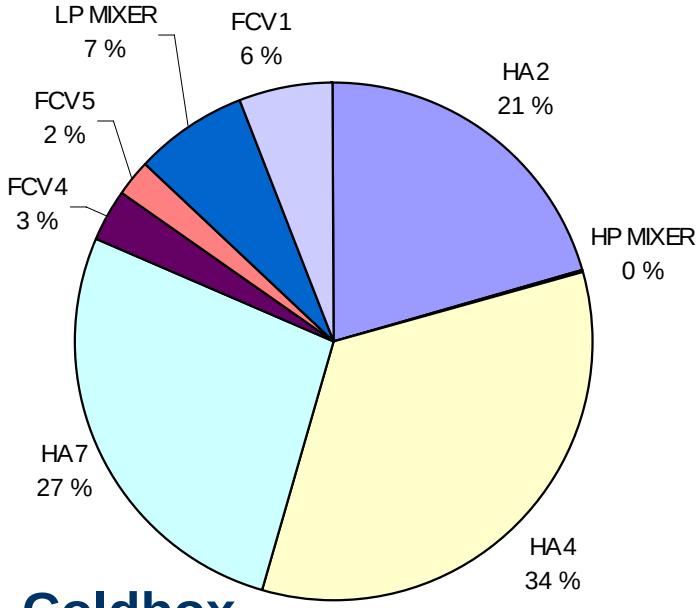
Heat Exchanger HX 7, NG/MR-LP
Duty vs. Temperature



Plant exergy analysis



Plant



Coldbox

- Still considerable potential for reducing losses
- Especially for compressor and heat exchangers
- Dependent on component availability

Comments
Possibilities and boundaries

- Some boundaries today
  - NG pressure from BOG handling system 18 bar (balance BOG compr./Mini-LNG)
  - Storage pressure in chain, carrier tanks can handle 5 bara
  - Design for high ambient temperatures - Sea water temperatures in north of Europe relatively low
  - Availability of components
- Efficiency improvements
  - Improved compressor efficiency
  - Reduced temperature differences in hx-s
  - Optimisation of MR composition
- Plant operation without pre-cooling could be possible
  - Existing refrigeration system on-board is used for precooling today

Full scale Mini-LNG for reliquefaction

FAT and performance testing, 2008

Successful tests performed

Operation on gas carrier from late 2009

Full scale test results

Results from full scale tests and simulation model verification

Including simulation results for future plant operating conditions (corrects for off-design conditions at full scale tests)

Parameter	Unit	Measured	Simulation	Simulation corrected 1) (dp and leak)	Simulation corrected 2) (precooling t)
Liquefaction capacity	tonnes/d	14,4	14,4	17,1	18,8
LNG exit temperature before throttling to tank	^{o}C	-154,1	-154,1	-155	-155
MR precooling temperature at vap-liq separtor	^{o}C	-24,9	-24,9	-24,9	-35
NG precooling temperature	^{o}C	-31,7	-31,7	-35	-35
Refrigerating capacity	kW		70,7	84,3	93,2
Volume flow LP MR out of coldbox	m^3/h		1436	1512	1517

- Capacity difference relative to nominal (18.8 tonnes/d)
  1) Corrected for leak in safety valve by-pass from high p to low p and undersized stop valve in suction tube ~ 14 %-points
  2) Corrected to nominal precooling temperature (-35°C) ~ 9 %-points
- Some maldistribution in first secondary hx (HX 2) observed
  - Estimated influence on capacity 5 - 7 %

Conclusions

- A novel concept for small scale NG reliquefaction of BOG from small gas carriers for LNG/LEG/LPG/VCM has been developed
- Enables a flexible concept with cargo cool-down and no loss of customers cargo
- Use of mixed refrigerant (mainly hydrocarbons) in combination with a lubricant injected screw compressor enables relatively high energy efficiency
- Standard refrigeration components are available off the shelf to a relatively low cost. This enables a relatively low specific plant cost and a fast manufacturing time
- The first full scale plant for marine applications has been erected and tested. Concept sucessfully proven in full-scale
- The plant is now being installed onboard the IMSkaugen's Norgas Innovation, multigas carrier. In operation from late 2009
- A continuous development is ongoing in order to further optimise the concept

Thank you for your attention!

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