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Improved concept of the Nelium Turbo-Brayton cycle for the FCC-hh beam screen cooling

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EASITrain – European Advanced Superconductivity Innovation and Training. This Marie Sklodowska-Curie Action (MSCA) Innovative Training Networks (ITN) has received funding from the European Union's H2020 Framework Programme under Grant Agreement no. 764879

Outline

- ✓ Cycle requirements & former baseline
- ✓ Limiting factors
- ✓ Comparison of cycle arrangements
- ✓ New baseline
- ✓ Upper heat exchanger design
- ✓ Natural Nelium mixture

Baseline cryogenic cycle

Cooling power requirements:

680 kW for beam screens cooling (60 to 40 K)

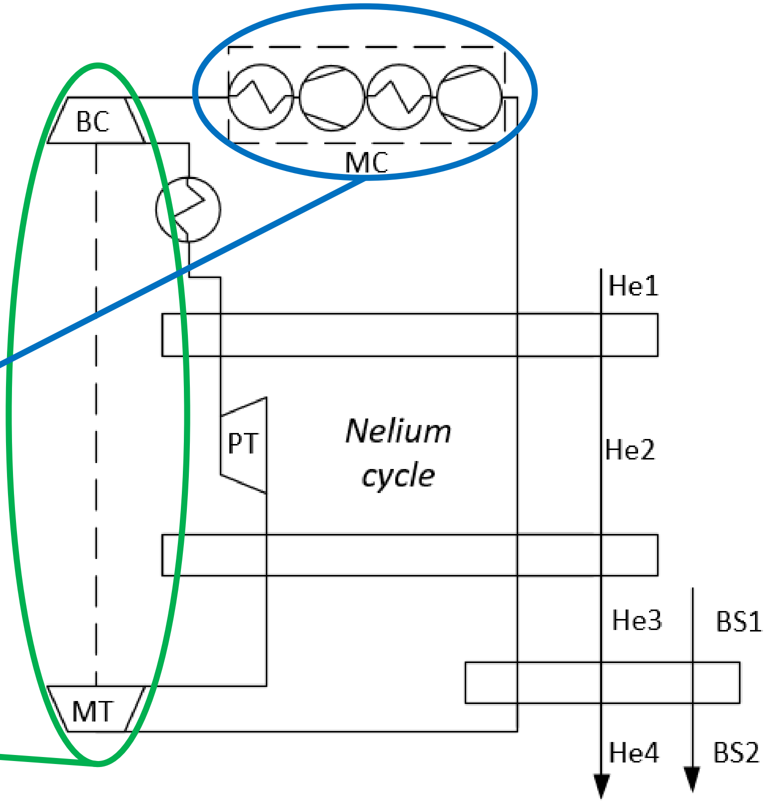
270 kW for Helium cycle pre-cooling (300 to 40 K)

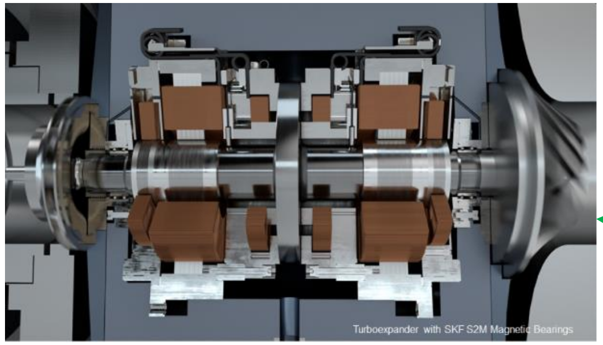
Key components:

- multi-stage centrifugal compressor (~10 MW range)
- turbo-expander ~700 kW ⟶ power recovery in compressor

Considered Nelium composition: 33 vol. % of neon

*Nelium Turbo-Brayton cycle: **former baseline** cycle layout*





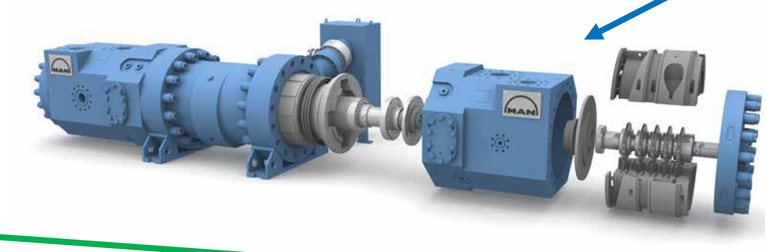


Image courtesy: MAN Diesel and Turbo

Image courtesy: SKF

Limiting factors

1. Turbo-compressor design

Design inputs: first cycle baseline parameters

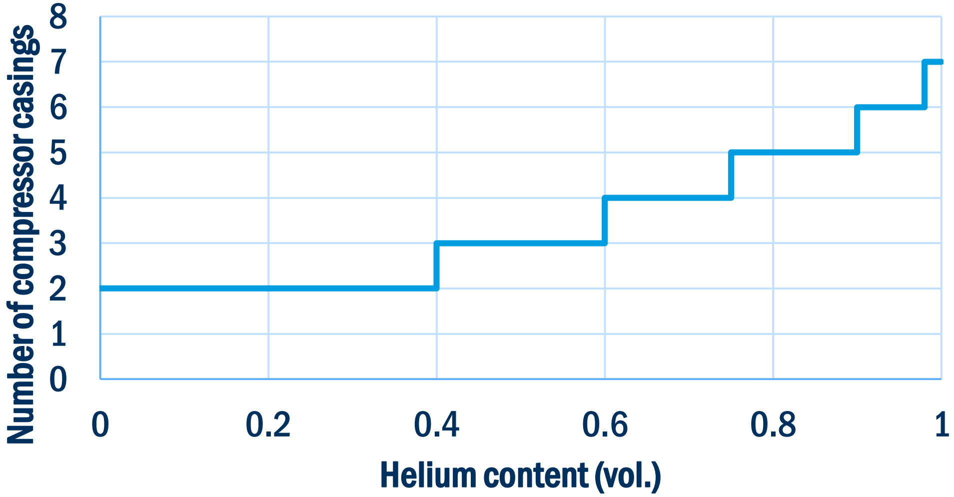
Design limitations:

- maximal impeller diameter,
- rotor dynamics,
- shaft length, etc.

Currently developed **1-tandem design**:

- up to 40 vol. % He;
- total compressor isentropic efficiency: ~73 %

Number of required compressor casings depending on the helium content
(M. Podeur, University of Stuttgart; MAN)

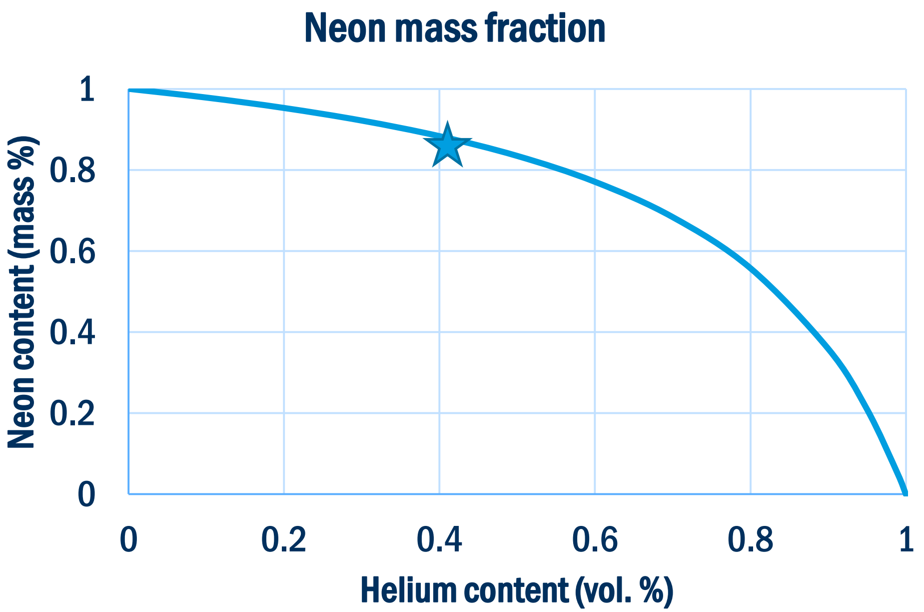


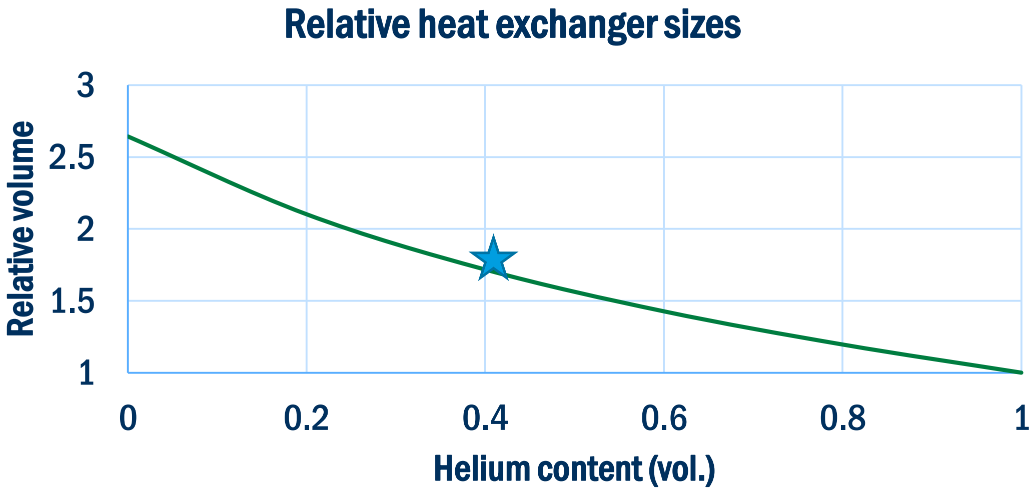
Poster session (25.06.19 15:30):

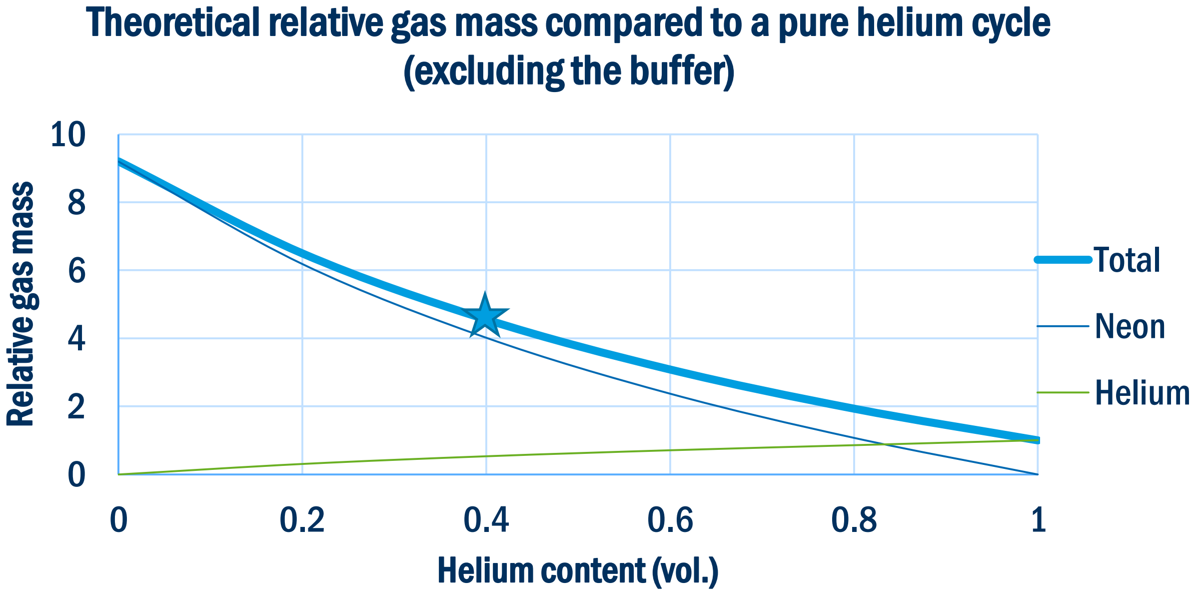
- *M. Podeur, D. Vogt, "Optimisation of a multi-stage turbocompressor architecture operating with a neon-helium gas mixture";*
- *M. Podeur, D. Vogt, S. Savelyeva, S. Kloeppel, Ch. Haberstroh, H. Quack, "Test rig for the experimental evaluation of turbo-compressor impeller designs for light gases"*

Limiting factors

2. System size and gas mass





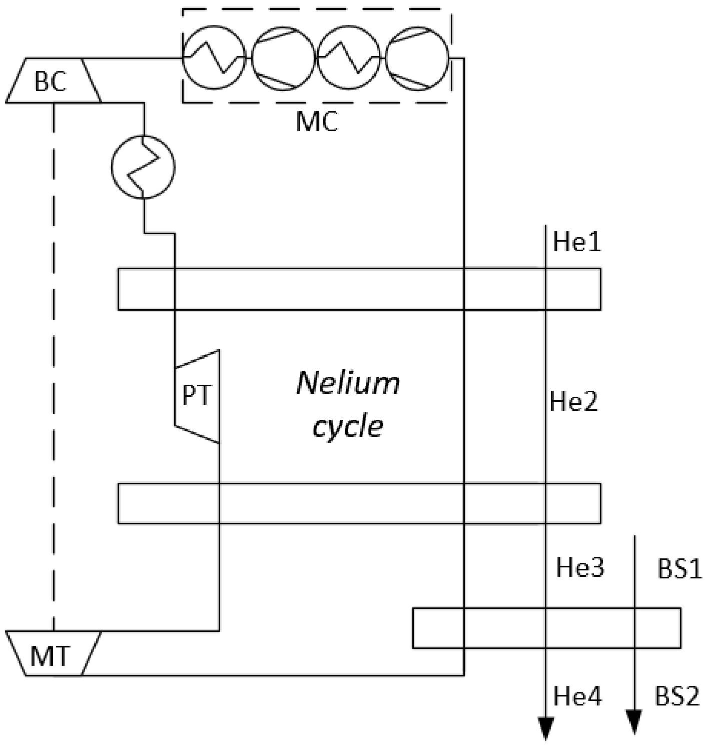


Example:

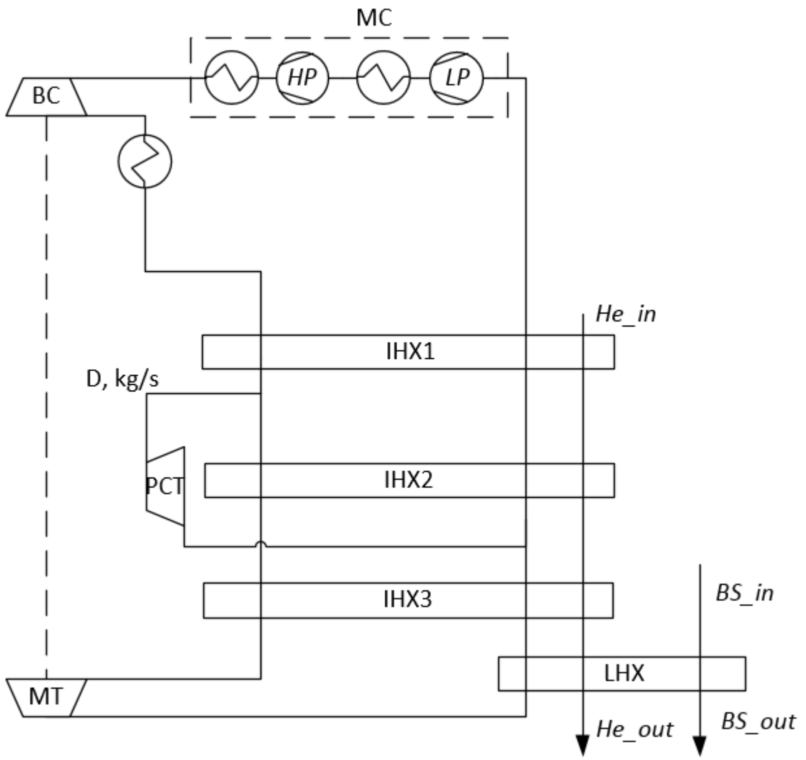
67 vol. % helium - 240 kg of gas

30 vol. % helium - 510 kg of gas

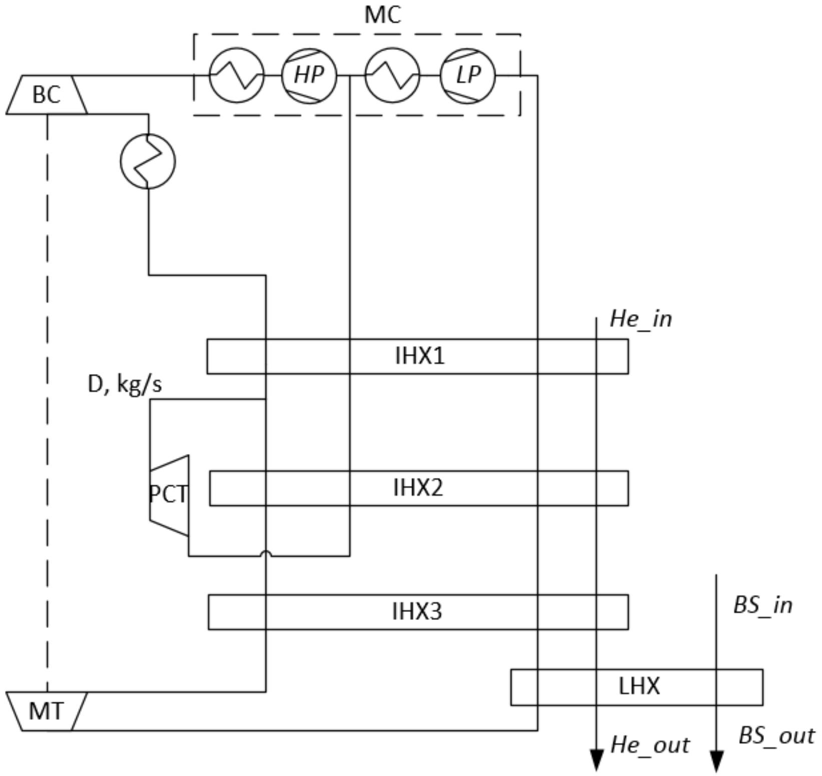
Compared cycle arrangements



Cycle A (baseline)

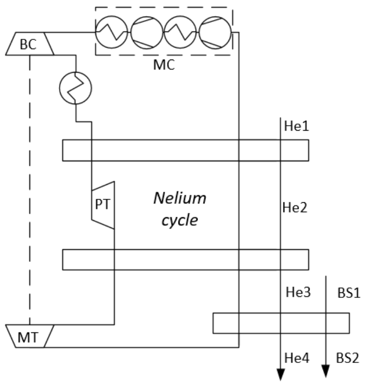


Cycle B



Cycle C

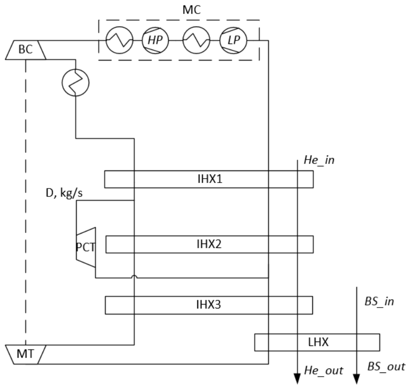
Compared cycle arrangements



✓ 2 inner heat exchangers

× higher pressure ratio

Cycle A (baseline)



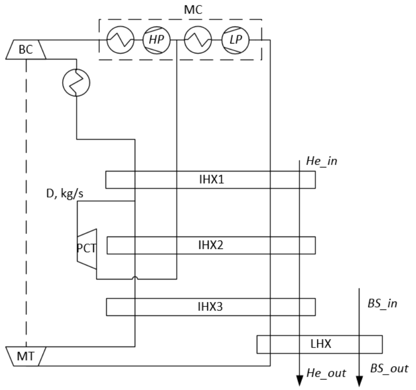
✓ reduced pressure ratio

✓ easier pressure control

× additional heat exchanger

Cycle B

× high speed of the pre-cooling turbine (high pressure ratio)



✓ reduced pressure ratio

✓ higher volumetric flow to the second compressor casing

✓ reduced pressure ratio of pre-cooling turbine compared to cycle B

× additional heat exchanger

Cycle C

Chosen arrangement

Compared cycle arrangements

Cycle C - > new baseline

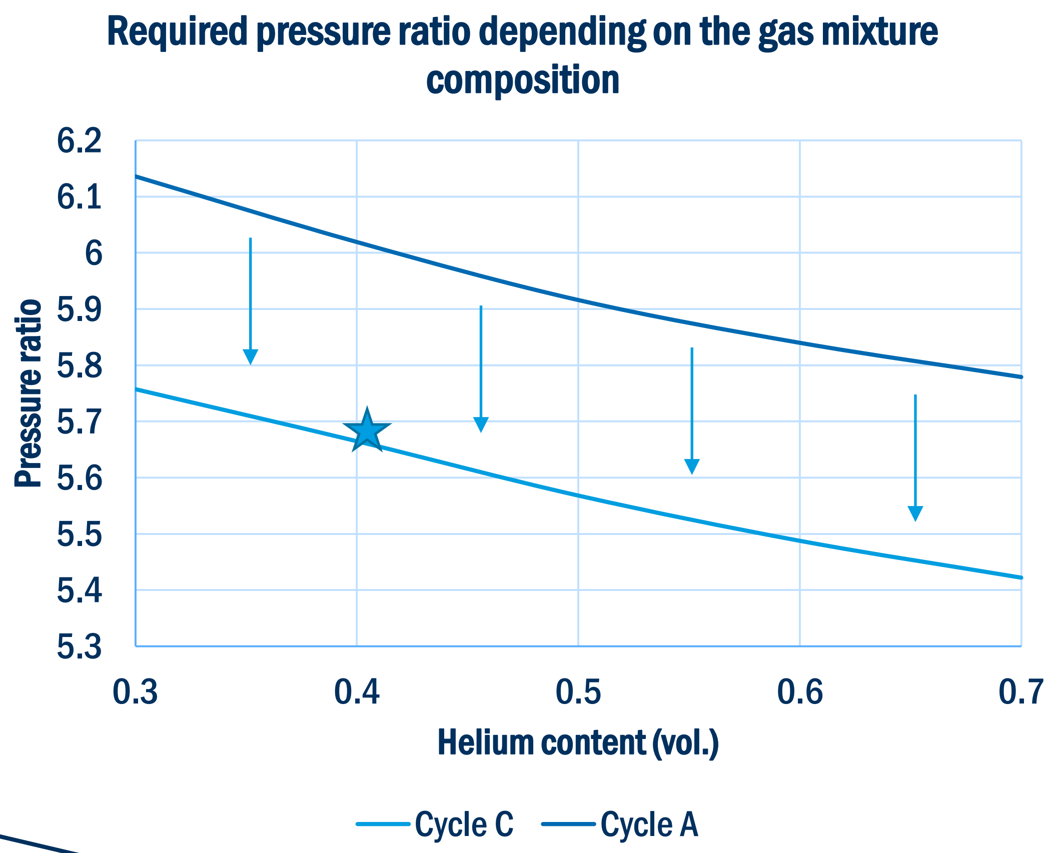
Advantages:

- Reduced pressure ratio
- Higher volumetric flow on the inlet of the second casing

Thus, for 40 % helium:

Cicle A: $\frac{V_{1\ casing}}{V_{2\ casing}} \sim 2{,}4$

Cycle C: $\frac{V_{1\ casing}}{V_{2\ casing}} \sim 1{,}9$ (var)

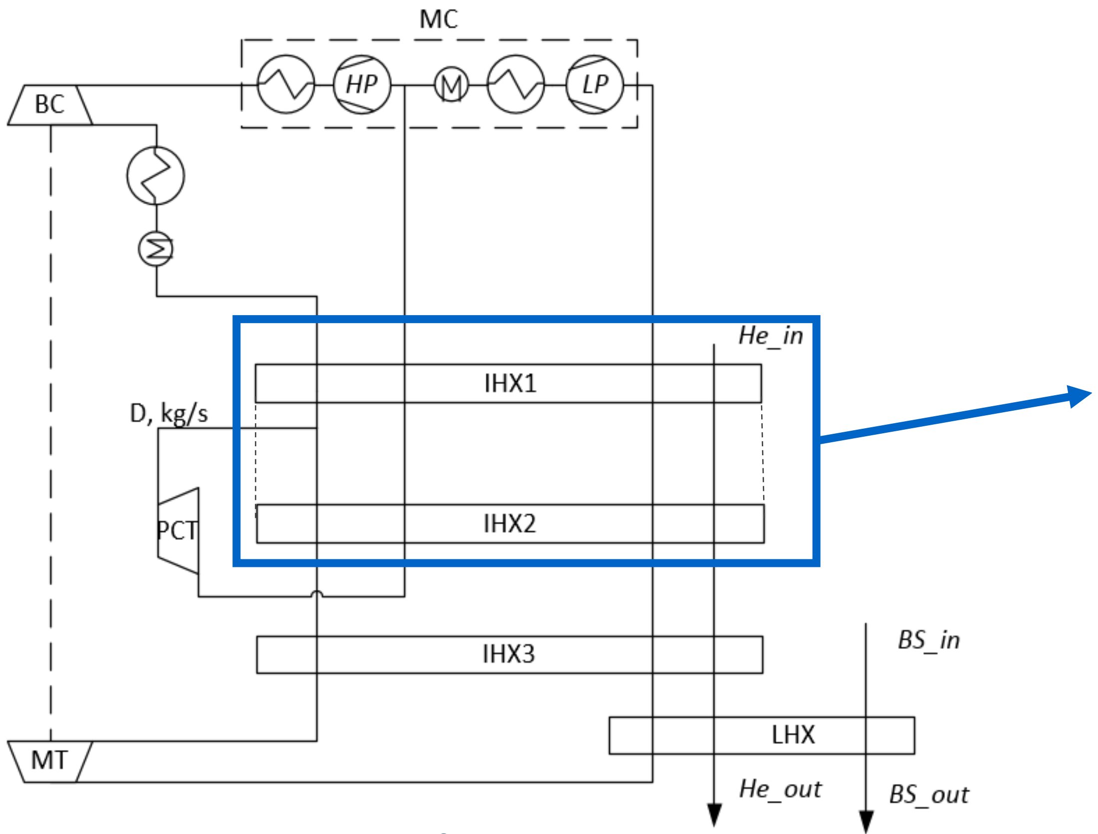


Increase helium content up to 60 vol. % He

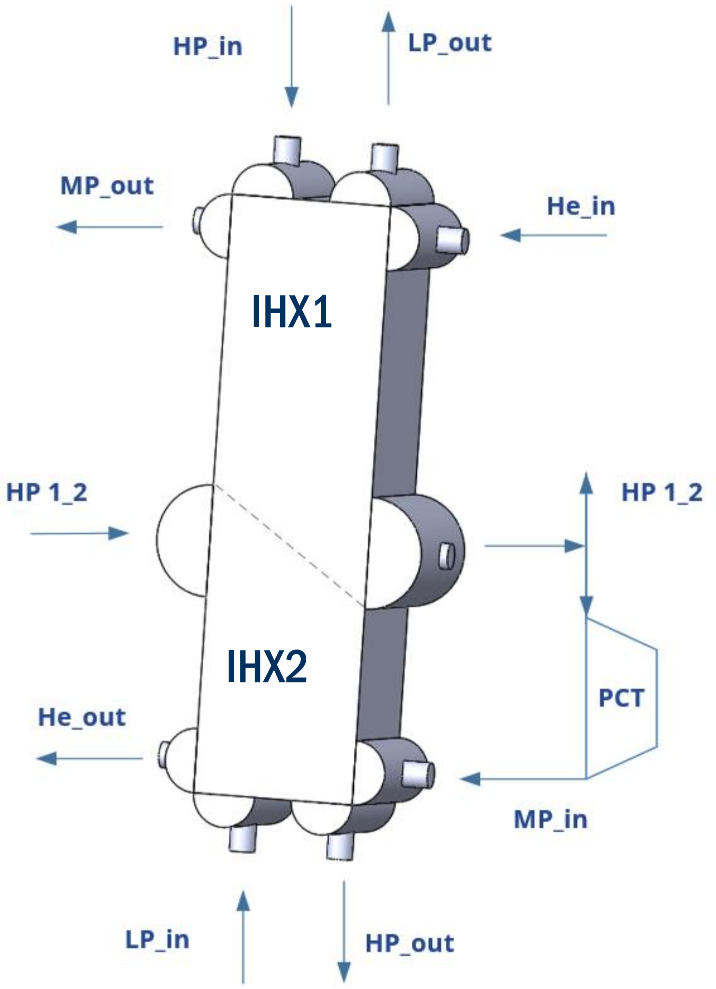
or

- 1 compressor impeller → +4..5 % to the total compresor η_s↑

Upper heat exchanger design



New baseline cycle flow diagram



Reduction of the heat exchanger cross-section area and the cold box diameter

Cold box size

Upper heat exchanger (IHX1+IHX2):

L x W x H: ~4.7 x 1.3 x 1.2 m

↓

Within maximal industrially possible size: 8 x 1.5 x 3.4 m

Cold box:

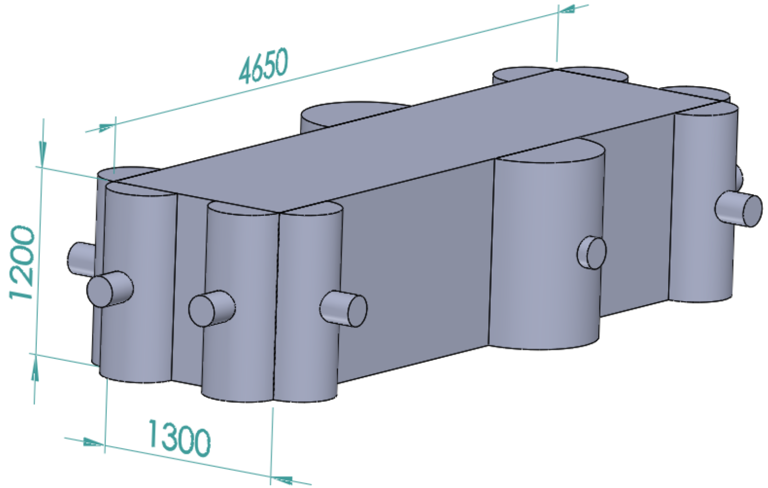
Length: 5.6…6 m;

Diameter: 3.6..3.8 m

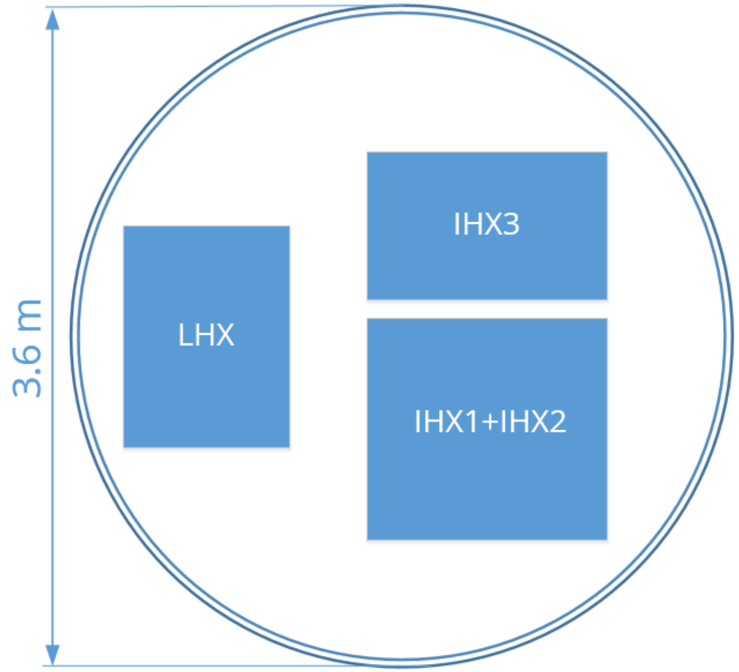
↓

Transportable

Upper heat exchanger

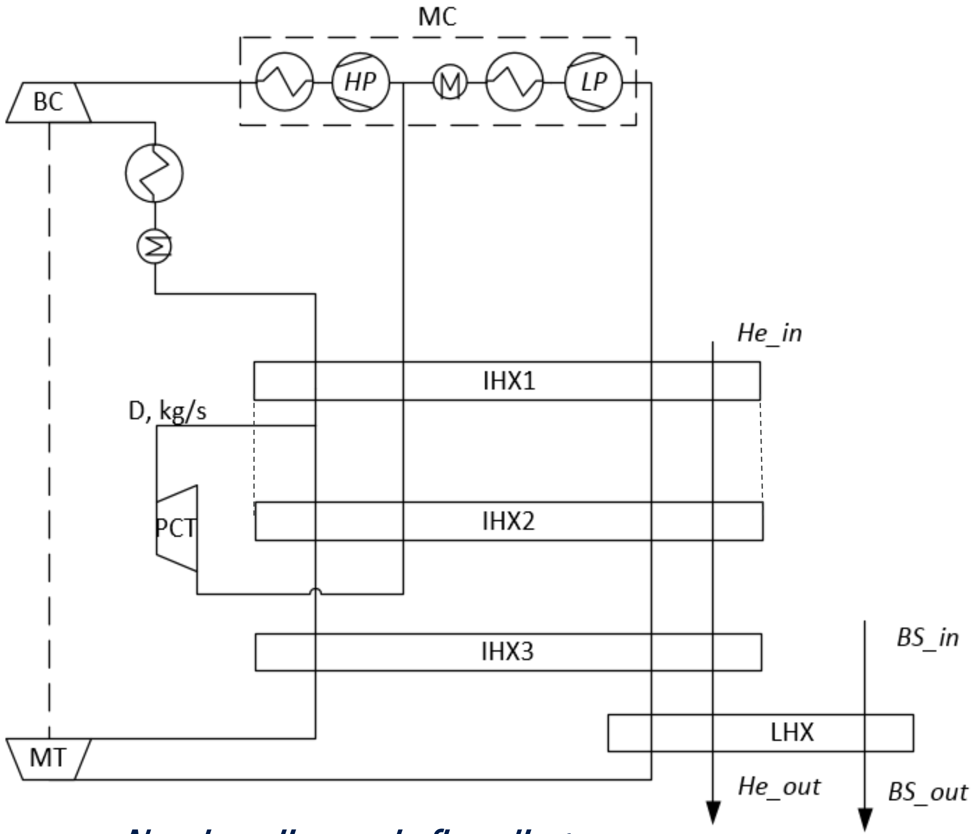


Cold box cross section



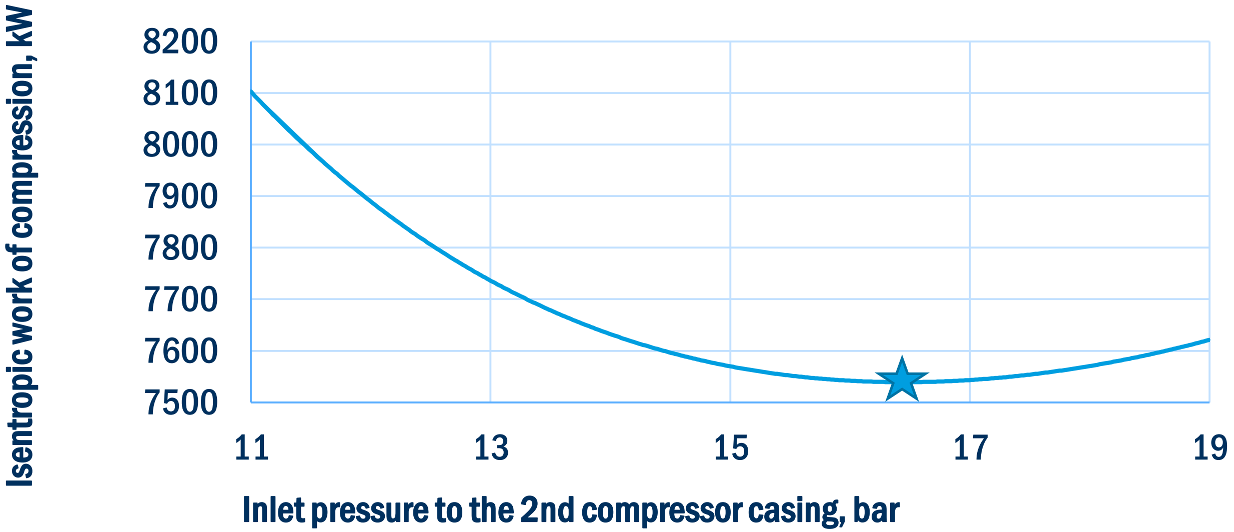
IHX 1 + IHX2 – upper heat exchanger,
IHX3 – inner heat exchanger,
LHX – load heat exchanger

Improved cycle concept



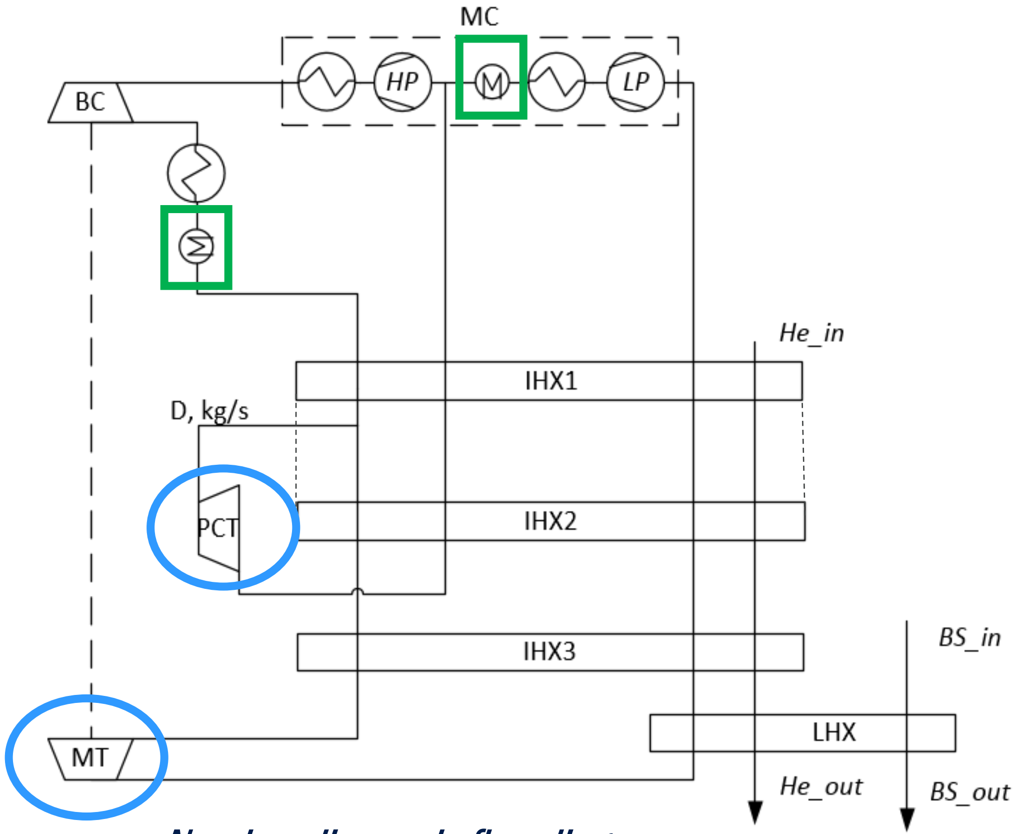
New baseline cycle flow diagram

Total isentropic power of the compressor depending on the middle pressure (for NTU1=18)



- NTU of the upper heat exchanger reduced from 40 to 30;
- Optimal NTU of IHX1: 17...18
- Case study (under progress): matching the turbo-compressor middle pressure with the cycle parameters
- Estimated total power for the chosen case: ~9.7 MW

Improved cycle concept



New baseline cycle flow diagram

✓ Preliminary check of the turbines design:

	Power, kW	D, m	N, rpm	Ns
MT	789	0.18	23000	0.57
PCT	362	0.10	54000	0.61

↓

no limitations observed

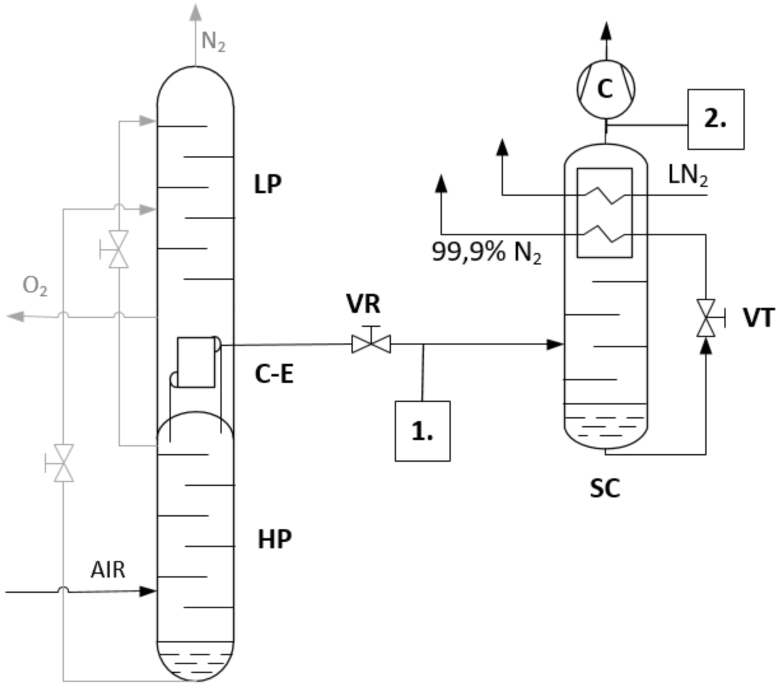
✓ Possible chillers implementation

Poster session (25.06.19 15:30):

H. Quack, F. Holdener, S. Savelyeva, S. Kloeppel, C. Haberstroh

"Cooling of the refrigerant with chilled water before the inlet of the compressor"

Natural Nelium concept

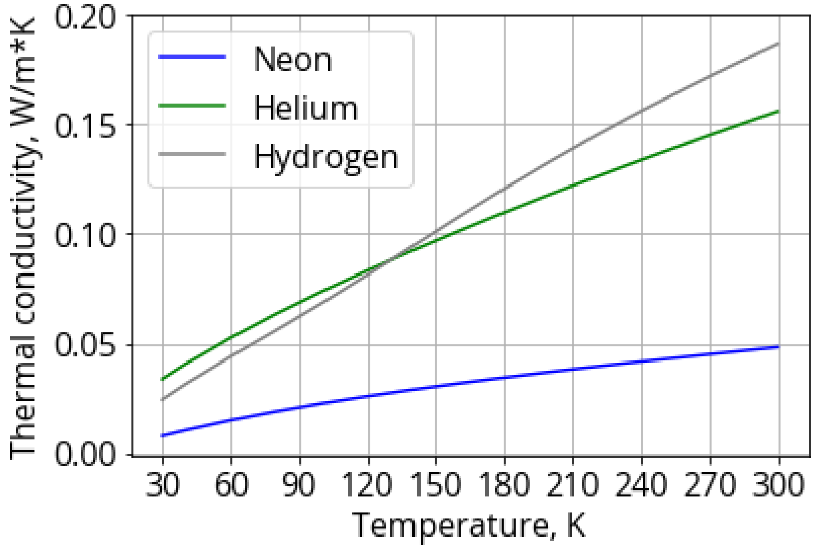


Crude nelium mixture production flow diagram

- Corresponds to the neon-helium ratio in the air:

  Natural Nelium: 68.8 % Ne, 23.4 % He, 7.8 % H2 (3…8 %)

- Economically advantageous
- Current target composition: 60 % neon, 40 % helium → cheaper helium can be added
- Hydrogen presence in the mixture: good thermophysical properties
- Problem: instability of composition



Next steps

- Case study for the turbo-compressor and cycle parameters matching
- Transient operation modes for the improved cycle
- Detailed cool-down investigation using the improved cycle
- Further study of the Natural Nelium concept

Thank you for your attention!

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