TECHNISCHE UNIVERSITÄT DRESDEN

Faculty of Mechanical Science and Engineering, Bitzer Chair of Refrigeration, Cryogenics and Compressor Technology

Cryogenic refrigeration with neon-helium mixtures for FCC beam screens: Specification of Components

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Agenda

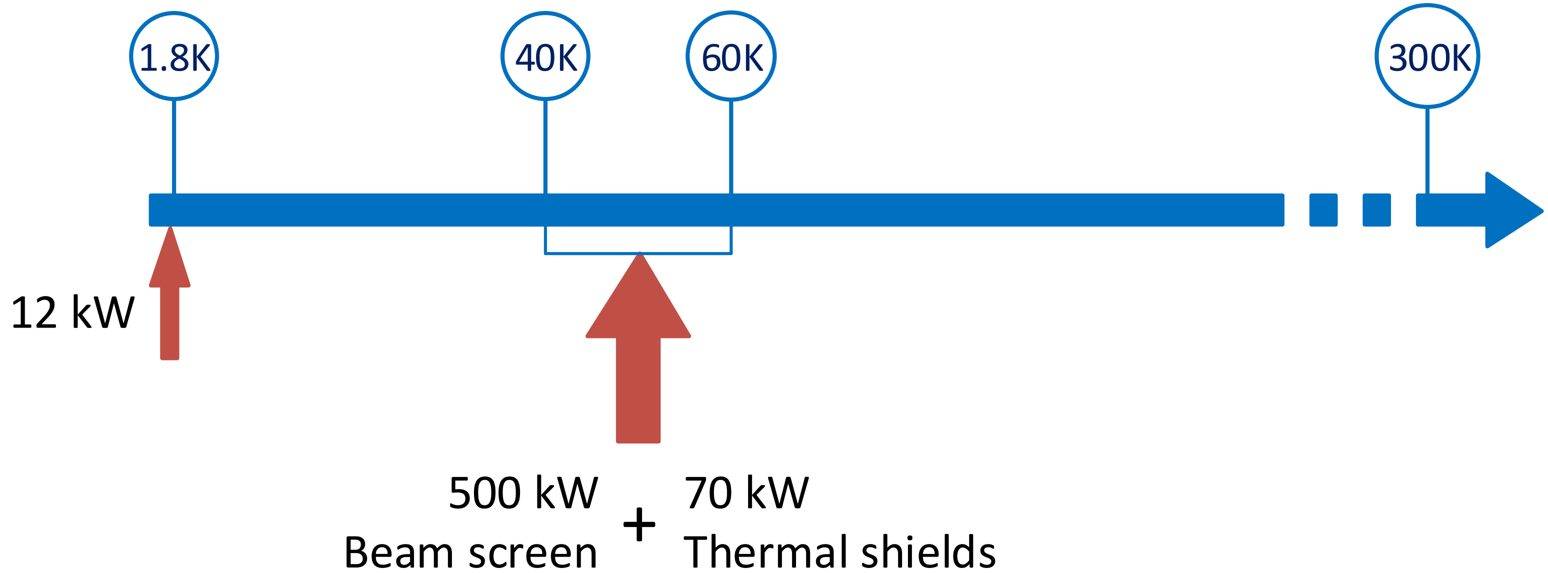
- Collaboration between CERN and TUD

- Refrigeration below 80 K / The Nelium concept
- Compressors
- Heat Exchangers

- Summary and next steps

Collaboration between CERN and TUD

Anticipated heat loads for FCC-hh per sector



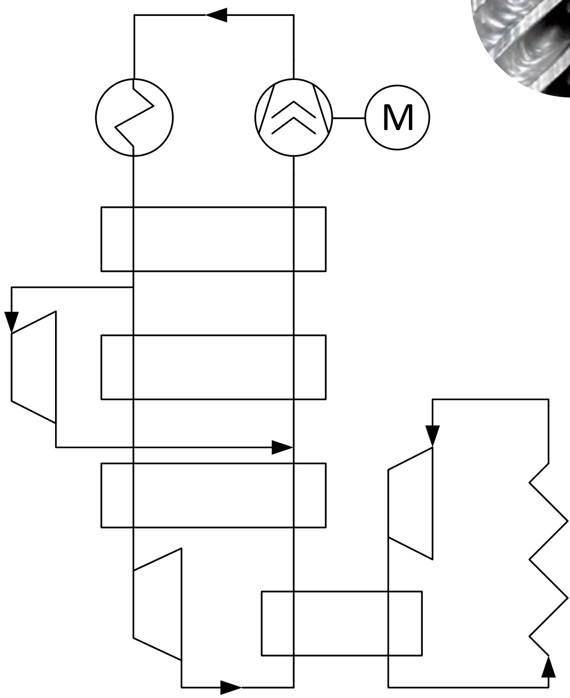
➔equivalent cooling power for beam screens is two times that for magnet cooling

➔efficient refrigeration is mandatory!

Refrigeration Cycle

Conventional He cycle

Screw compressor

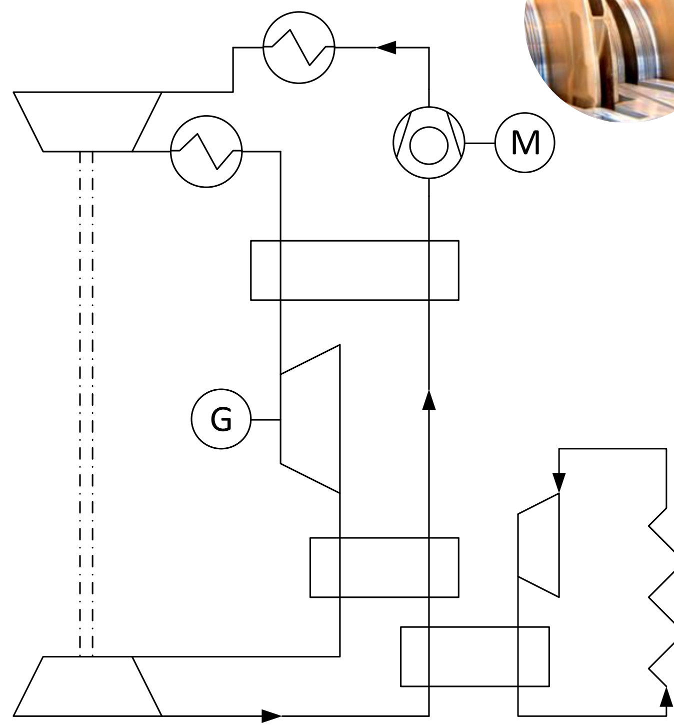


≈30 % of Carnot efficiency

➔ 13 MW input power

Alternative Ne He cycle

Turbo compressor



≈45 % of Carnot efficiency

➔ 8.7 MW input power

Photo courtesy : MAN Diesel and Compressor

Turbo compressor

Required pressure ratios in the cycles: ≈7

Achievable pressure ratios per stage:

Pure helium: 1.05 ➔ 39 stages

Pure neon: 1.27 ➔ 8 stages, but large HXs

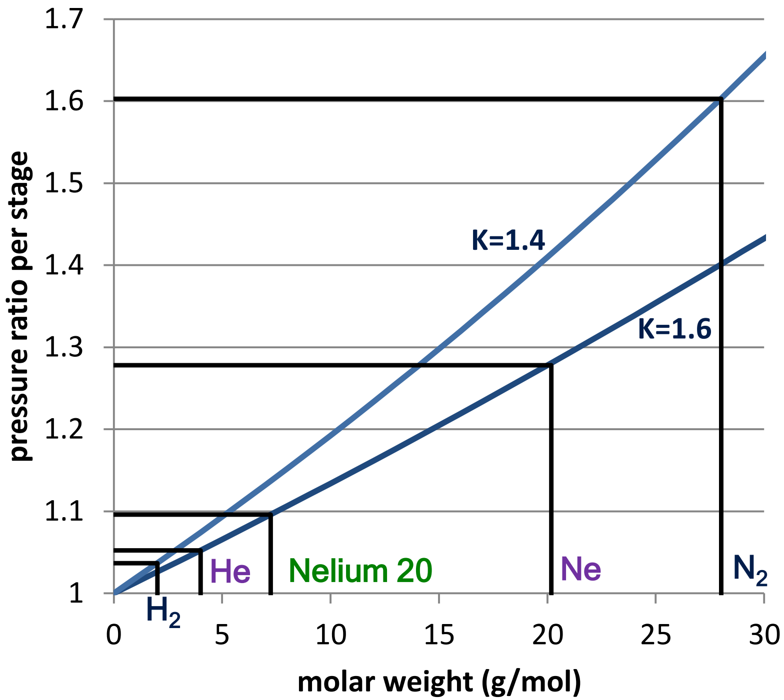
Compromise:

20 mol-% Ne + 80 mol-% He,

Pressure ratio per stage: 1.1

➔ 20 stages

$$\Delta h = 45\,kJ/kg$$



Requirements main compressor

Machine parameters

Mass flow	11 kg/s
Pressure ratio	7
Inlet pressure	5.1 bar
Volume flow at inlet cond.	6.7 m^3/s
Th. isothermal power	6.1 MW

Working fluid

20-% Ne + 80-% He

Light weight

Cost-intensive (neon)

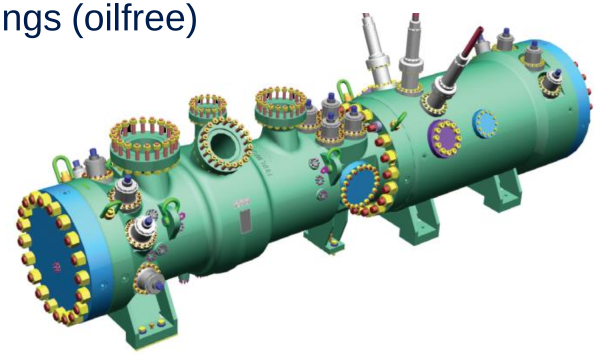
Small molecules

<u>Compressor:</u>

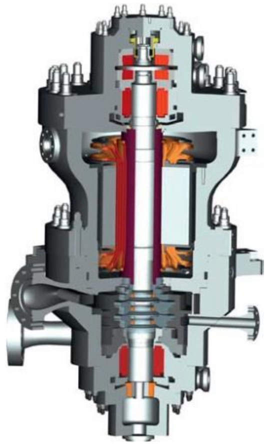
- Centrifugal
- High speed
- Hermetic

Available compressors

Commercially available:
Compressors for natural gas storage and transport
with active magnetic bearings (oilfree)

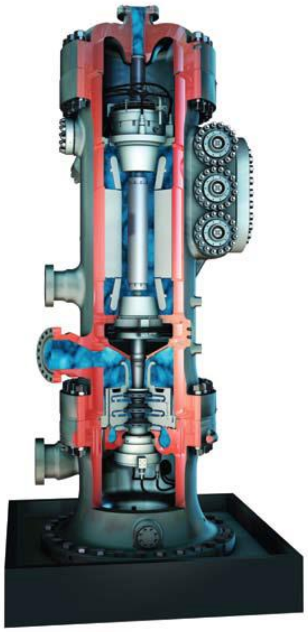


Dresser-Rand
Datum I



Siemens
STC-ECO

MAN
Hofim



GE
Blue-C

Image courtesy: resp. companies

MAN design

Technical restrictions:

- speed
  - max 12500 rpm with MAN motor
  - strength of motor windings (copper)
  - shaft-impeller joint (shrinking)
- Wheel diameter
  - max 630 mm outer diameter
  - Installation by human workers (arm length)
- Stiffness of the rotor
  - High flow coefficients require thin shafts

General: energy increase limited to ≈45 kJ/kg per stage for economical reasons

MAN design

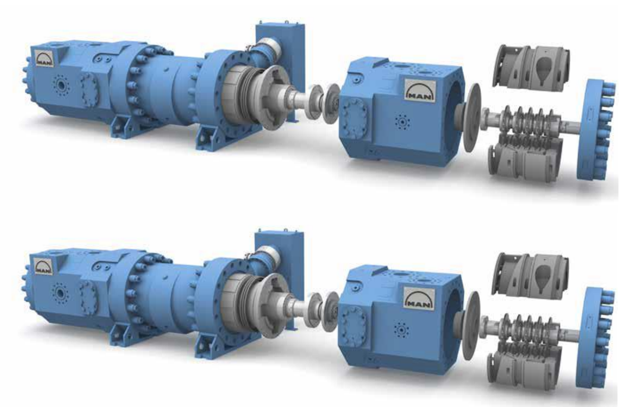
Multi shaft design (by MAN):

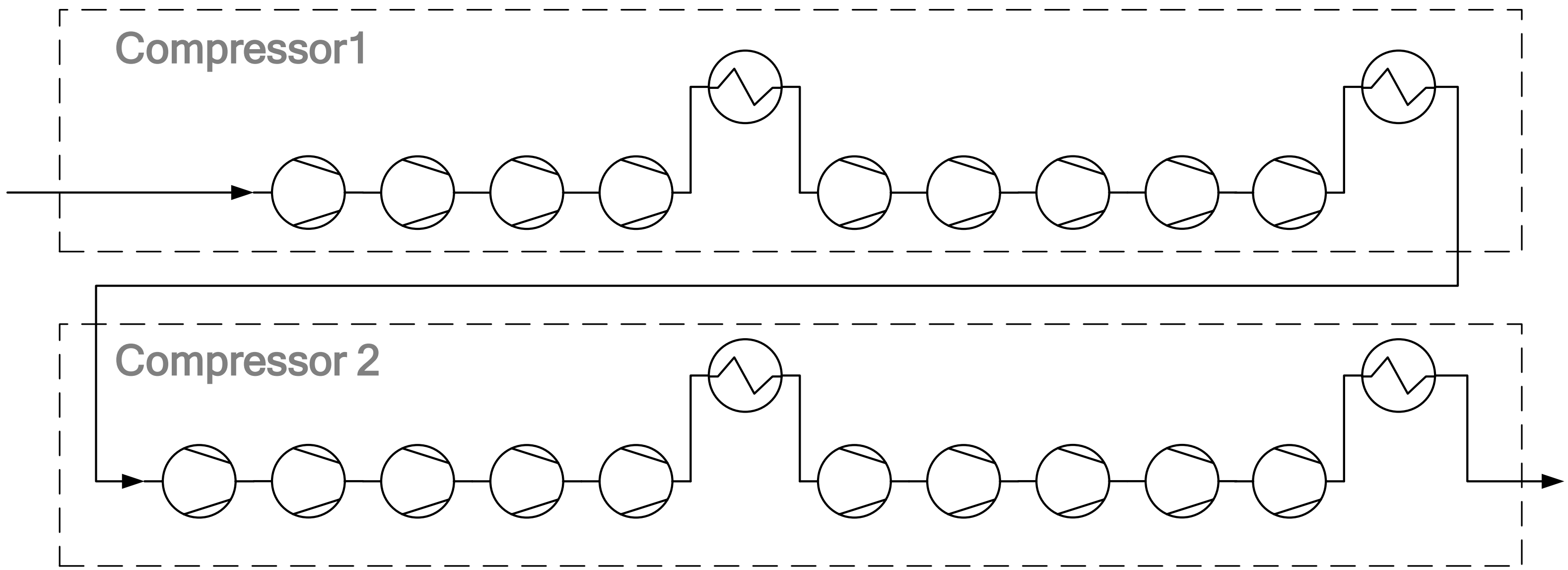
19 stages

4 inter/after-coolers

Stages 1..9: n=9000 RPM

Stages 10..19: n=11300 RPM





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New starting point: MAN calculations

- Reverse calculation of MAN compressor:
  - Pressure drop in inter and after coolers: 200 mbar
  - Isentropic efficiencies: $\eta_{is} \approx 92\%$
  - Outlet flow angle: $\beta_2 = 40..50°$ ➔ $\psi \approx 1$
  - Flow coefficient: $\varphi^* = 0.6$ (1st stage)

➔ starting point for different designs/optimizations

Further development of compressors

- The market for compressors for very light gases is quite small
- compressors from natural gas business can be adopted

  Such compressors are available for the FCC Ne-He cycle, but not optimal

Lesser stages = lower CAPEX

Optimal would be a configuration with a single machine

➔(1 motor, 1 AMB, 1 VFD)

Possible improvements to increase the head per stage:

- Larger impellers ➔ change in assembly routine
- Aluminium instead of steel ➔ impeller shaft connection
- Increased flow angle β_2 ➔ decreased stall margins
- Redesign of motor ➔ …

  Low incentive of industry for these changes

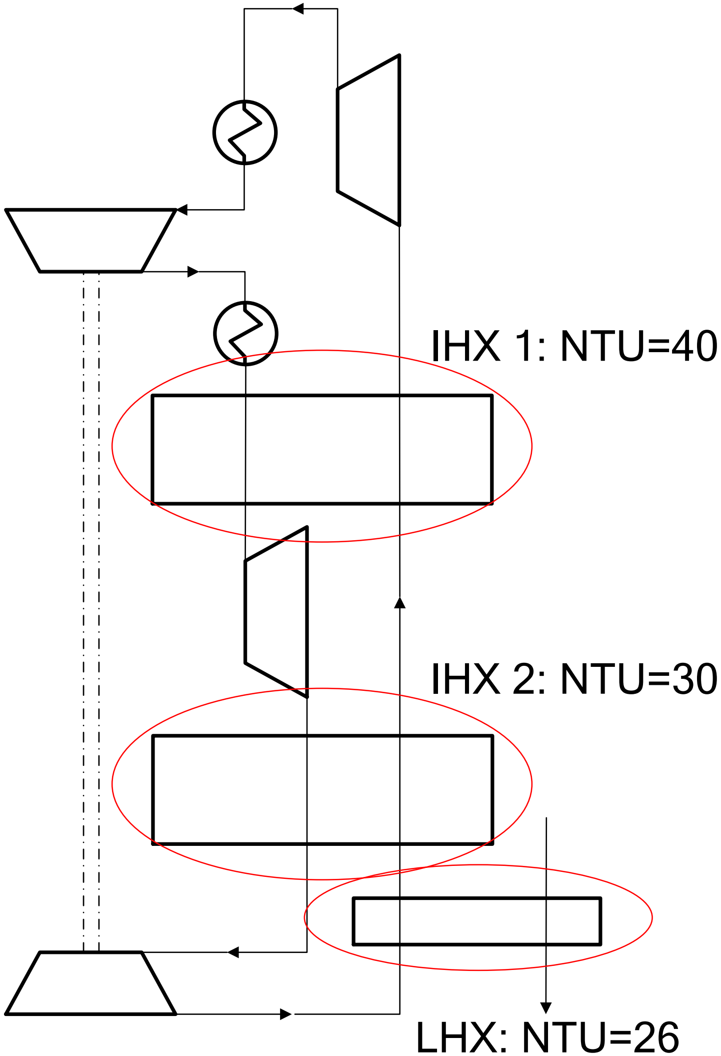
Refrigeration Cycle: HX

➔Why not use pure neon?

Neon has inferior heat exchange properties compared to helium:

	Neon	Helium
λ [W/mK]	48	156
c_p [kJ/kg]	1.0	5.2
ρ [kg/m³]	0.81	0.16
η [µPa s]	31	20

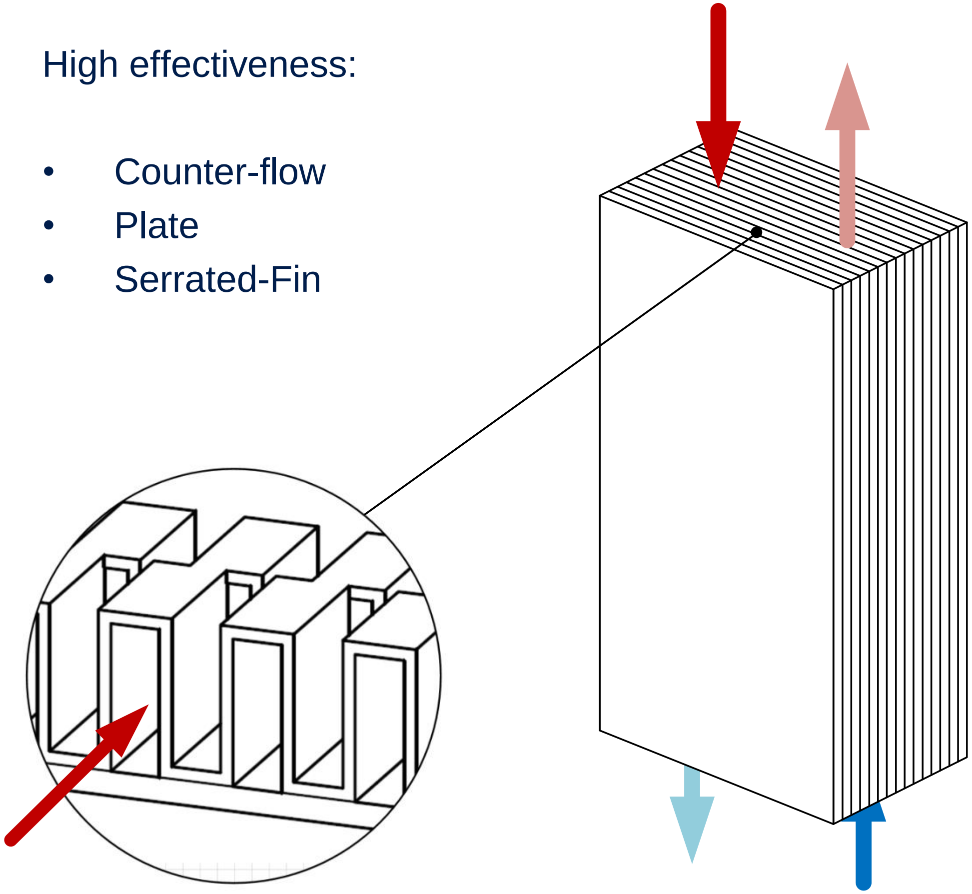
Heat exchangers (HX) with neon will be bigger, less efficient and/or have higher pressure drop

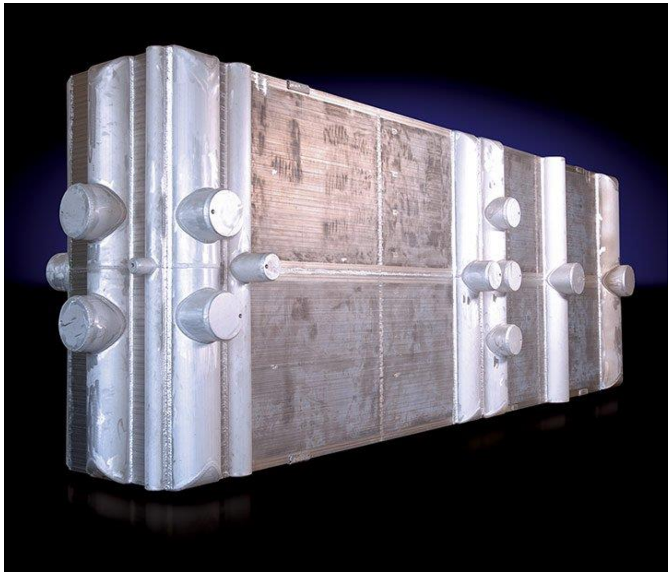


Heat exchanger selection

High effectiveness:

- Counter-flow
- Plate
- Serrated-Fin





Source: http://www.chartindustries.com

Heat exchanger sizing

Volume:

$$V = \frac{\dot{m}Pr}{\beta}\left(\frac{f^{1/2}}{j^{3/2}}\right)\left[\left(\frac{NTU_i}{\eta_0}\right)^3 \frac{1}{2\Delta p \rho}\right]^{1/2}$$

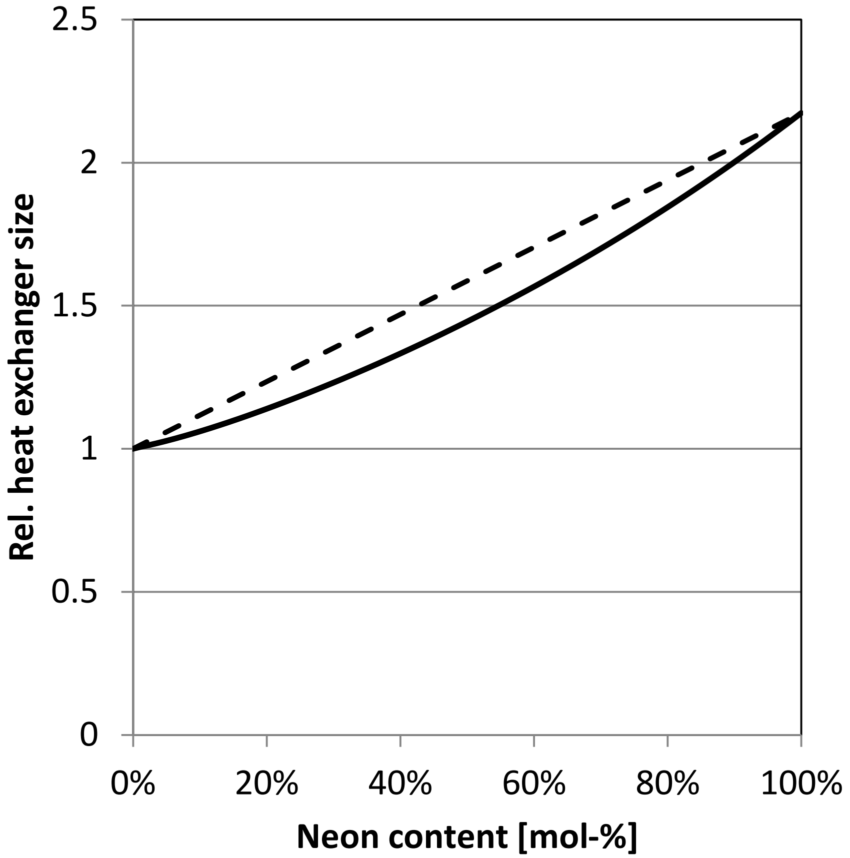
Fluid-dependent properties:

$$V \propto \frac{Pr}{\rho^{1/2} c_p}$$

$$V \propto \frac{\mu}{\lambda \rho^{1/2}}$$

Heat exchanger volume scales less then linearly with neon content

➔ Low neon content (up to 50 %) favorable



Heat exchanger sizing

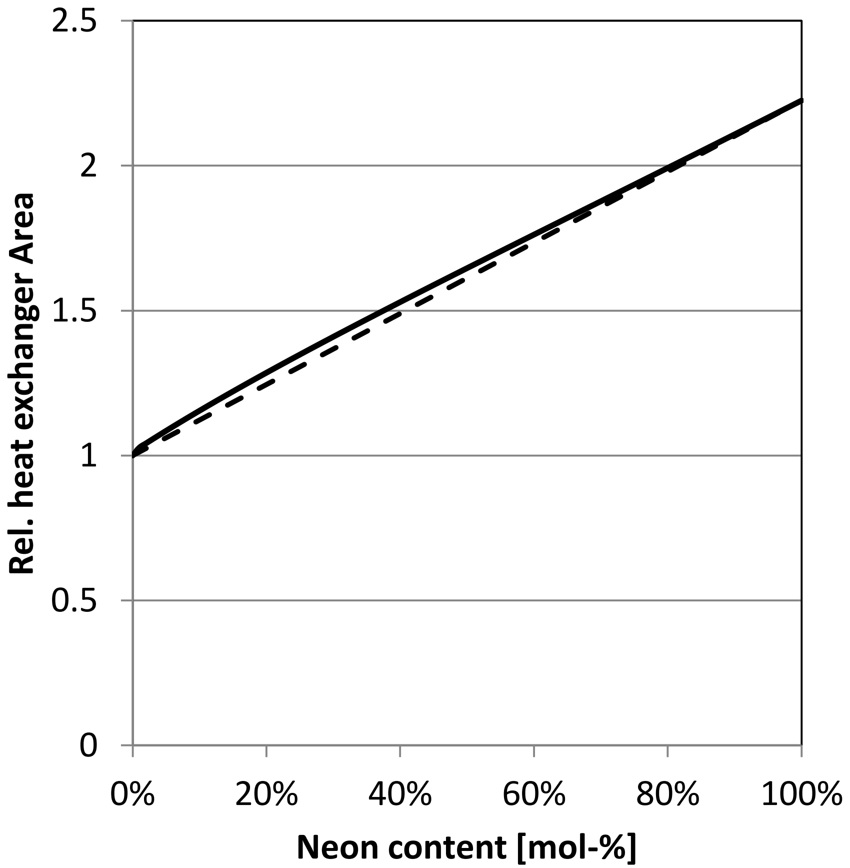
Frontal area:

$$A_c = \dot{m} \left[\frac{f}{j} \left(\frac{Pr^{2/3}}{2\bar{\rho}} \frac{NTU_i}{\eta_0 \Delta p} \right) \right]^{1/2}$$

Fluid-dependent properties:

$$A_c \propto \frac{Pr^{1/3}}{c_p \rho^{1/2}}$$

Heat exchanger frontal area increases more then linearly with neon content

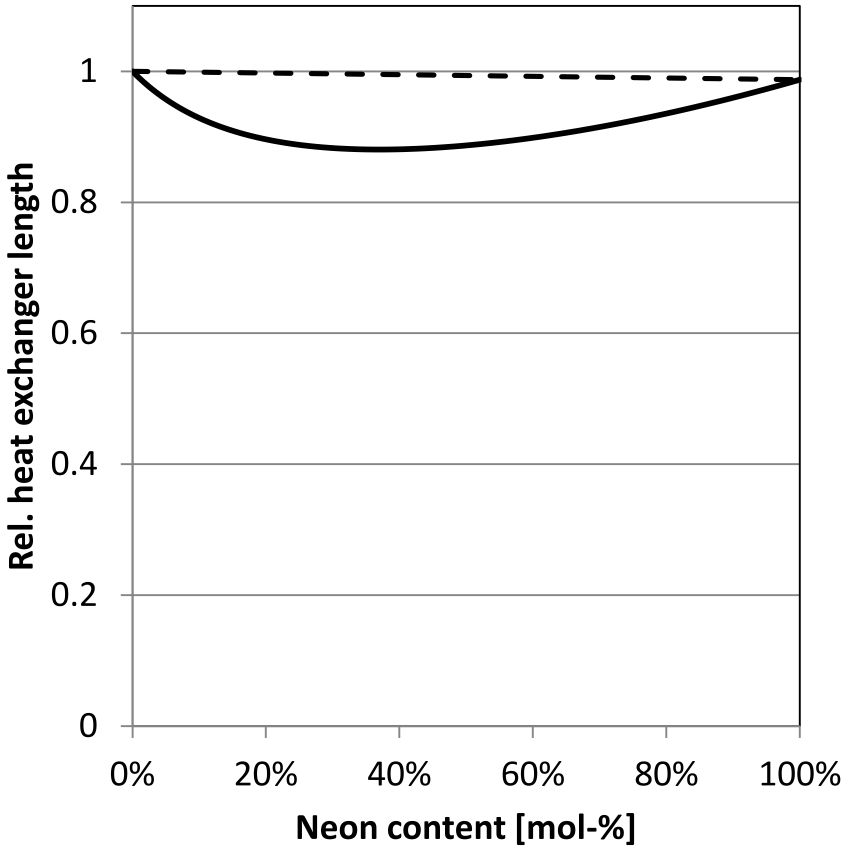


Heat exchanger sizing

Length:

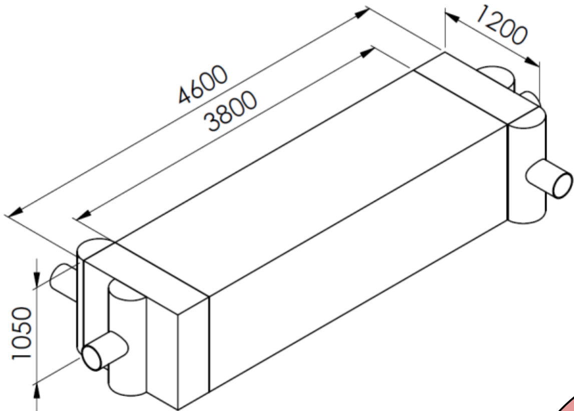
$$L = \frac{V}{A_c} \propto Pr^{2/3}$$

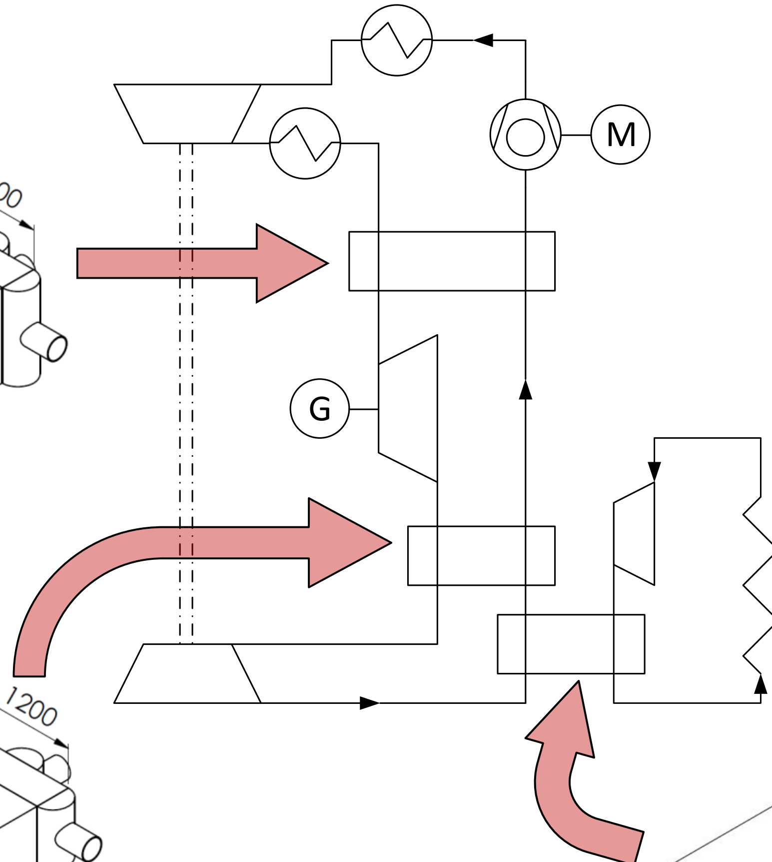
➔ Overall heat exchanger size:
shorter, but wider compared to pure helium



Heat exchanger sizing

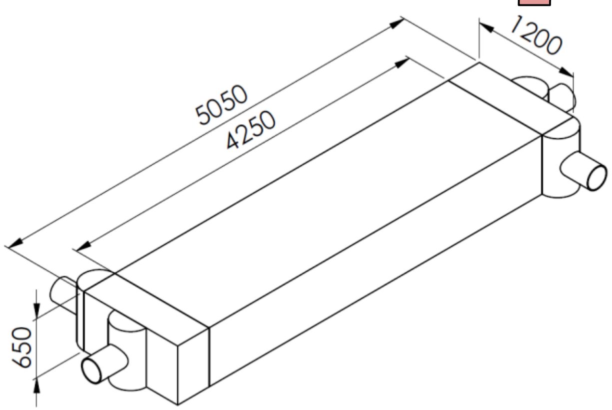
Design for 20 % neon

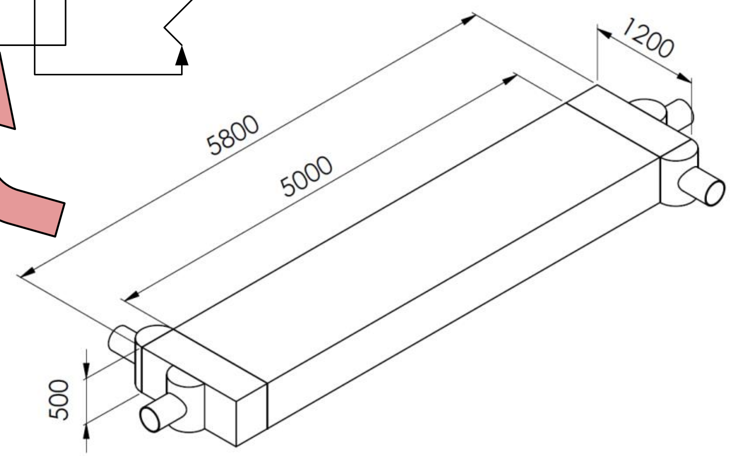




Maximum size:
Width: 1500 mm
Height: 3000 mm
Length: 8200 mm

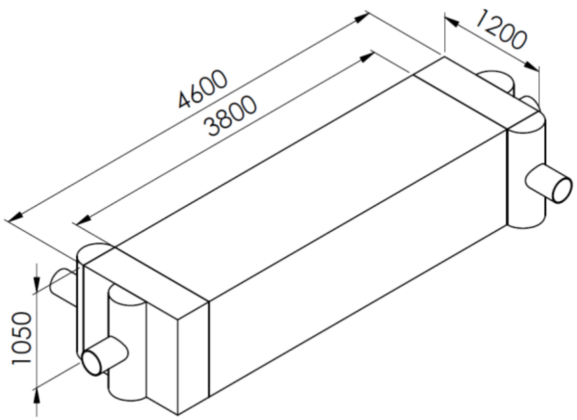
Sizes are well below limits!



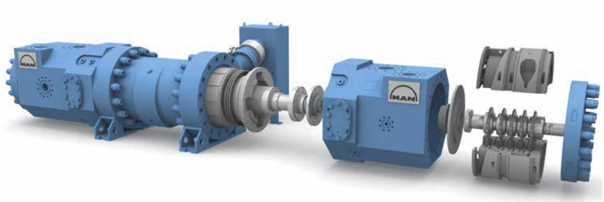


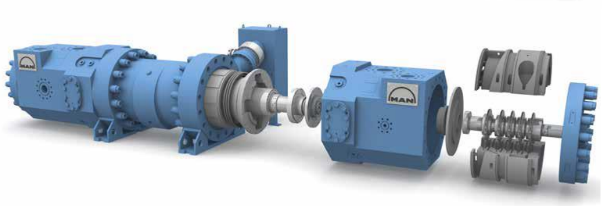
Influence of neon content

Design for 20 % neon



Compressor: 19 stages





Optimal system is defined by lowest cost

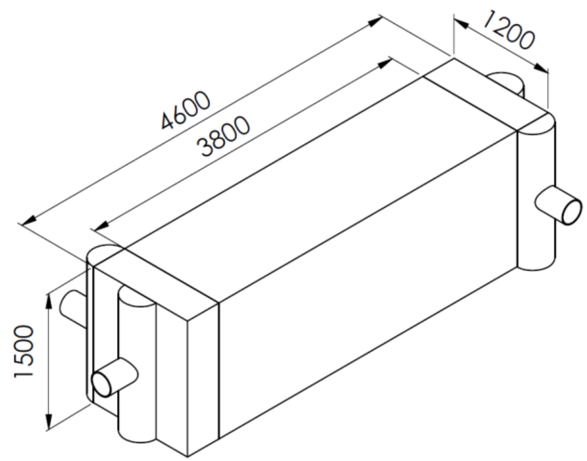
CAPEX:

- compressor
- HX
- coldbox
- Initial neon filling
- ...

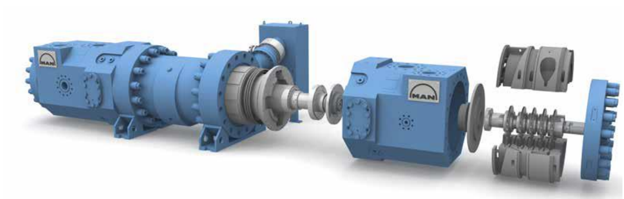
OPEX:

- input power
- neon losses
- ...

Design for 40 % neon



Compressor: 12 stages



Summary and outlook

- Using Ne/He mixtures makes centrifugal compression feasible
- Such compressors are available, but not optimal
- Heat exchangers are readily available

Next steps

- Develop model for expansion turbine/booster compressor
- Optimize total cost based on neon content
  - Define cost functions for compressors, heat exchangers, coldbox and refrigerant
  - Estimate refrigerant leakage rates
- Investigate transient operation