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

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Agenda

- Collaboration between CERN and TUD
- Refrigeration below 80 K / The Nelium concept
  - Compressors
  - Heat Exchangers
  - Coolant circulation
  - Cycle variants
- Summary and next steps

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Collaboration between CERN and TUD

Scenario:

For the FCC-hh, 12 cryogenic plants are planned, each should provide refrigeration for:

- beam screens
  - 500 kW @ 40..60 K
- thermal shields
  - 70 kW @ 40..60 K
- current leads
  - 2000 kA per plant (1000 kA in and out)
  - additional stream @ 40 K

In comparison to LHC, refrigeration in the temperature range 40..60 K became a new challenge ➔ more than 50 % of the equivalent refrigeration capacity are needed in this range

Restrictions:

- hydraulic impedance beam screen: 230 parallel pipes, length 30 m, inner diameter 5.55 mm
- hydraulic impedance thermal shields: straight pipe, 16 km length, inner diameter 100 mm
- pressure is limited to 50 bar

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Collaboration between CERN and TUD

Scope of the study:

Design of a highly efficient refrigeration cycle to provide the refrigeration capacity

Focus on:

- cooling of beam screens, thermal shields and current leads
- refrigeration cycle, efficiency
- requirement and characteristics of specific hardware
- proposals of a reference cycle
- recommendations and inventory of specific developments

Refrigeration Cycle: Compressor

For refrigeration below 80 K the standard is an oil flooded *screw compressor* with an isothermal efficiency of 50..60 %

➔ Is there a more efficient alternative?

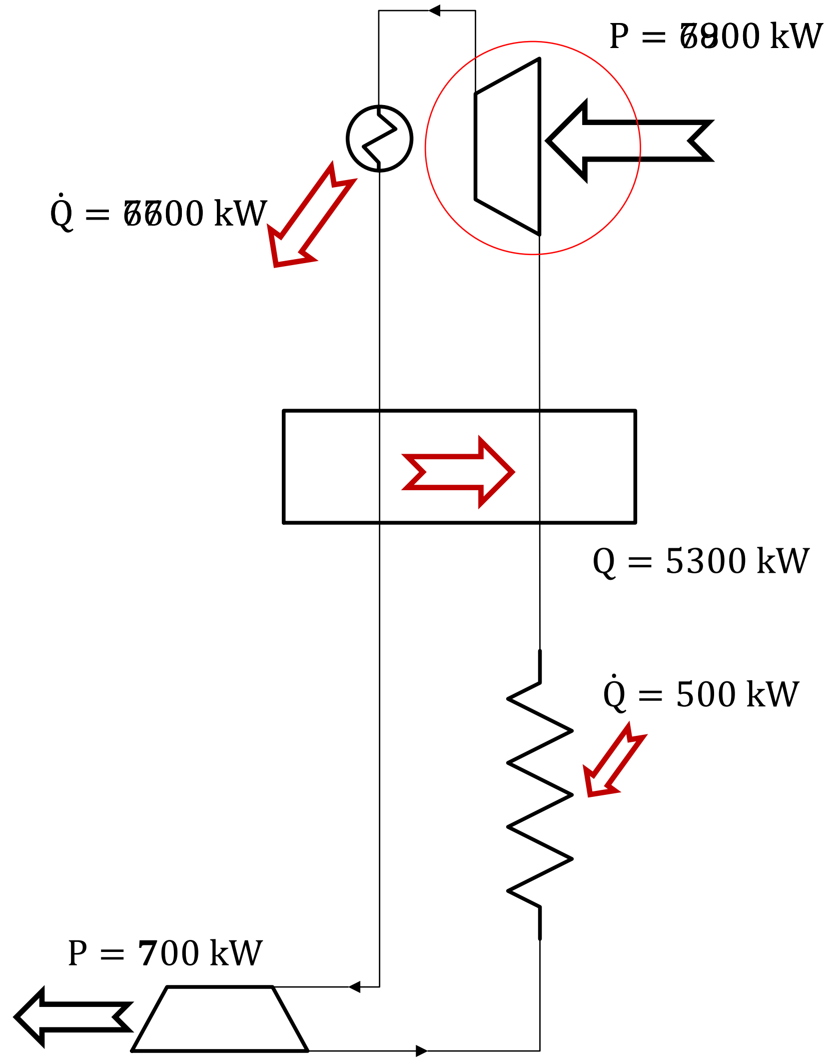
A *centrifugal compressor* with isentropic efficiency of 83 % with an aftercooler can reach a isothermal efficiency of 70 %.

➔ Why not use a centrifugal compressor?

Optimal compressor, $u_2 = 340$ m/s, $\psi = 0.65$

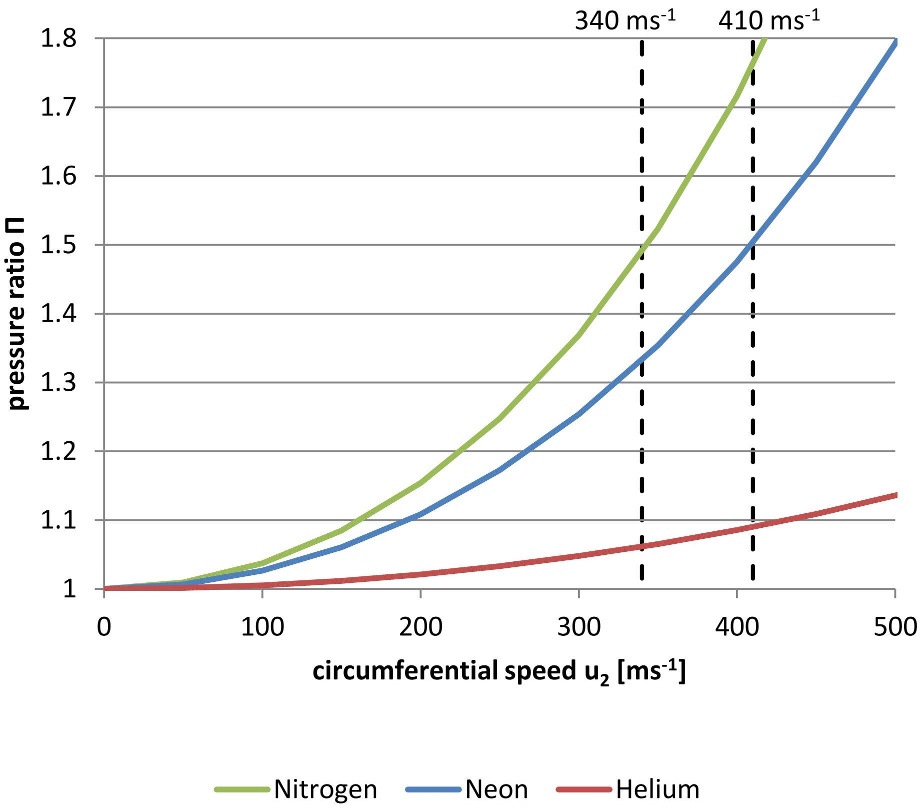
	Pressure ratio
Helium	1.06
Nitrogen	1.49

➔Very low pressure ratio per stage with helium, high number of stages



Refrigeration Cycle: Compressor

- ➔ Is it possible to increase the pressure ratio per stage?
- A higher circumferential speed allows a higher pressure ratio
- Limitations due to structural robustness, rotor dynamics etc.
- The other possibility is to use a gas with a higher molecular weight
- Only alternative useable gas in the respective temperature region is neon



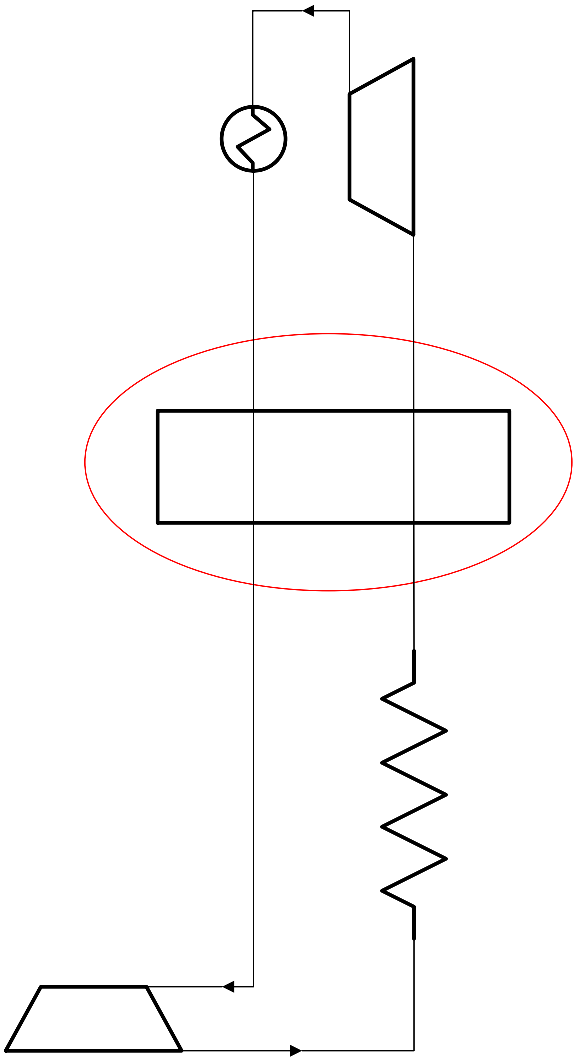
Refrigeration Cycle: HX

➔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



Refrigeration Cycle: Compressor

➔ Is it possible to increase the pressure ratio per stage?

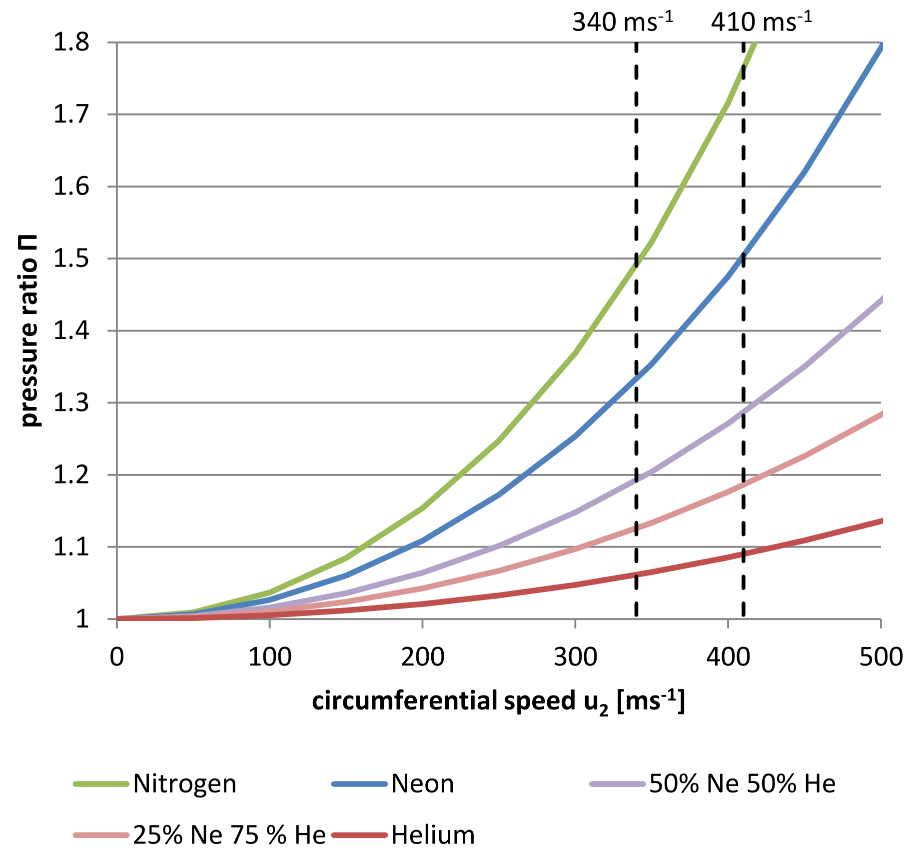
A higher circumferential speed allows a higher pressure ratio

Limitations due to structural robustness, rotor dynamics etc.

➔The other possibility is to use a gas with a higher molecular weight

Only alternative useable gas in the respective temperature region is neon

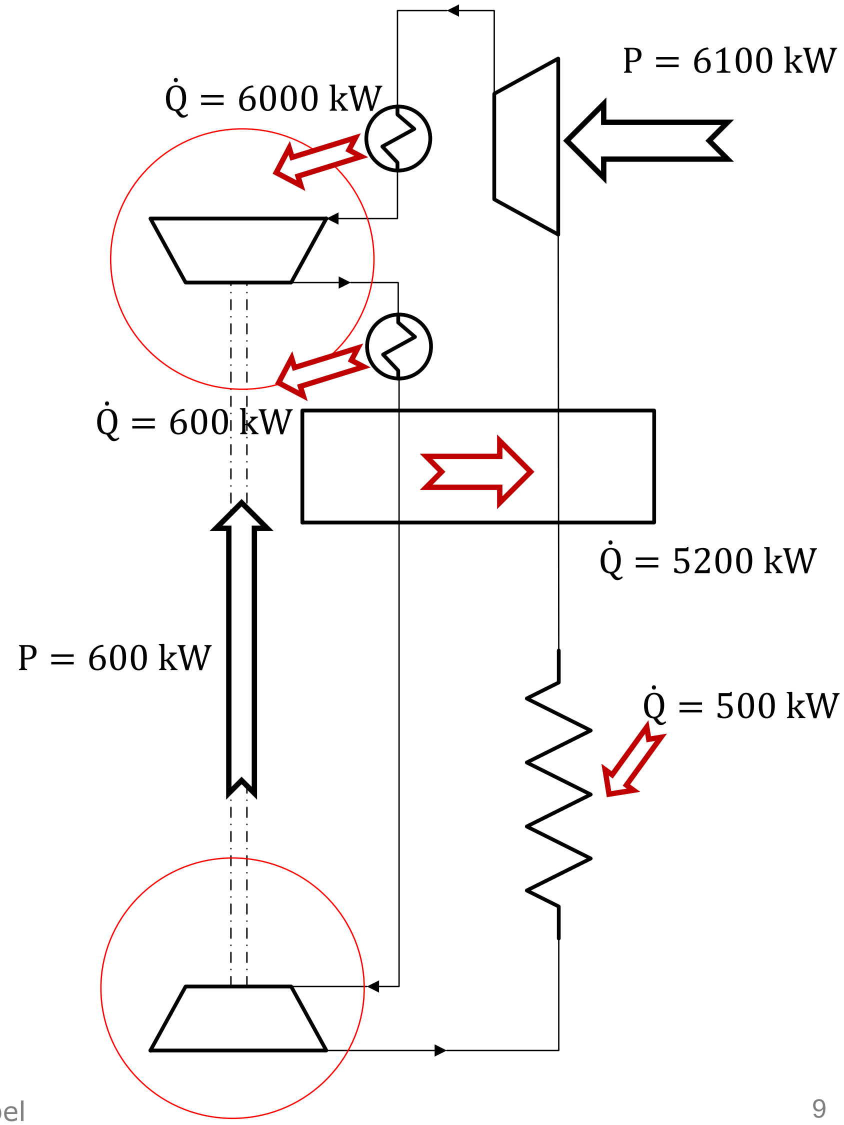
➔ A mixture of neon and helium (*Nelium*) can be compressed in a centrifugal compressor and has moderate pressure losses in the HX



Refrigeration Cycle: Expander

With pure helium, the work of the expansion turbines is dissipated:

Using a mixture of helium and neon allows to recover the mechanical energy of the turbines



Refrigeration Cycle: HX

- ➔ Is it possible to use the refrigerant directly in the beam screen?

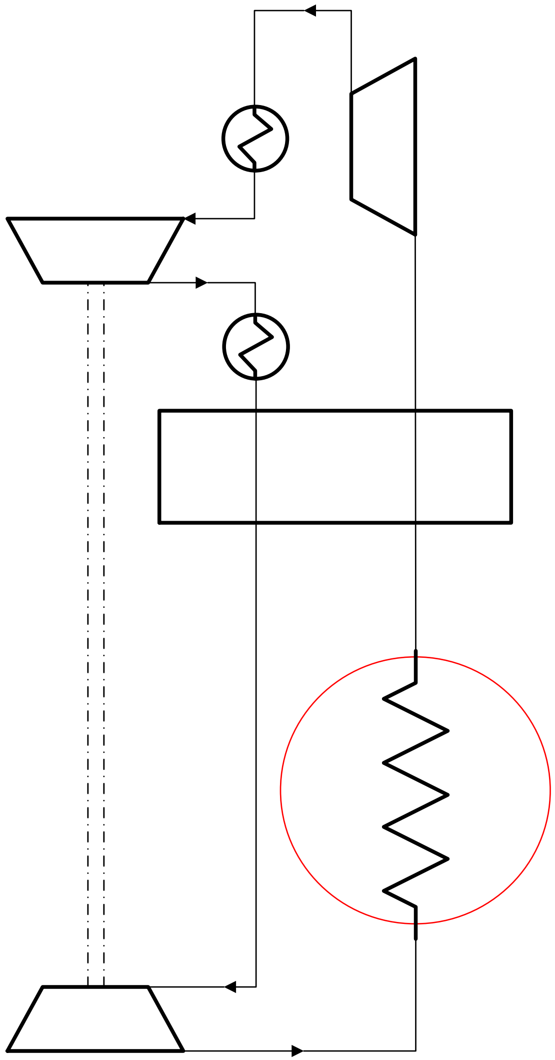
Capillaries in the beam screen are long and narrow: necessary inlet pressure for exhaust pressure of 1 bar:

	p [bar]
Helium	26
Nelium 25 (25 mol-% Ne)	34

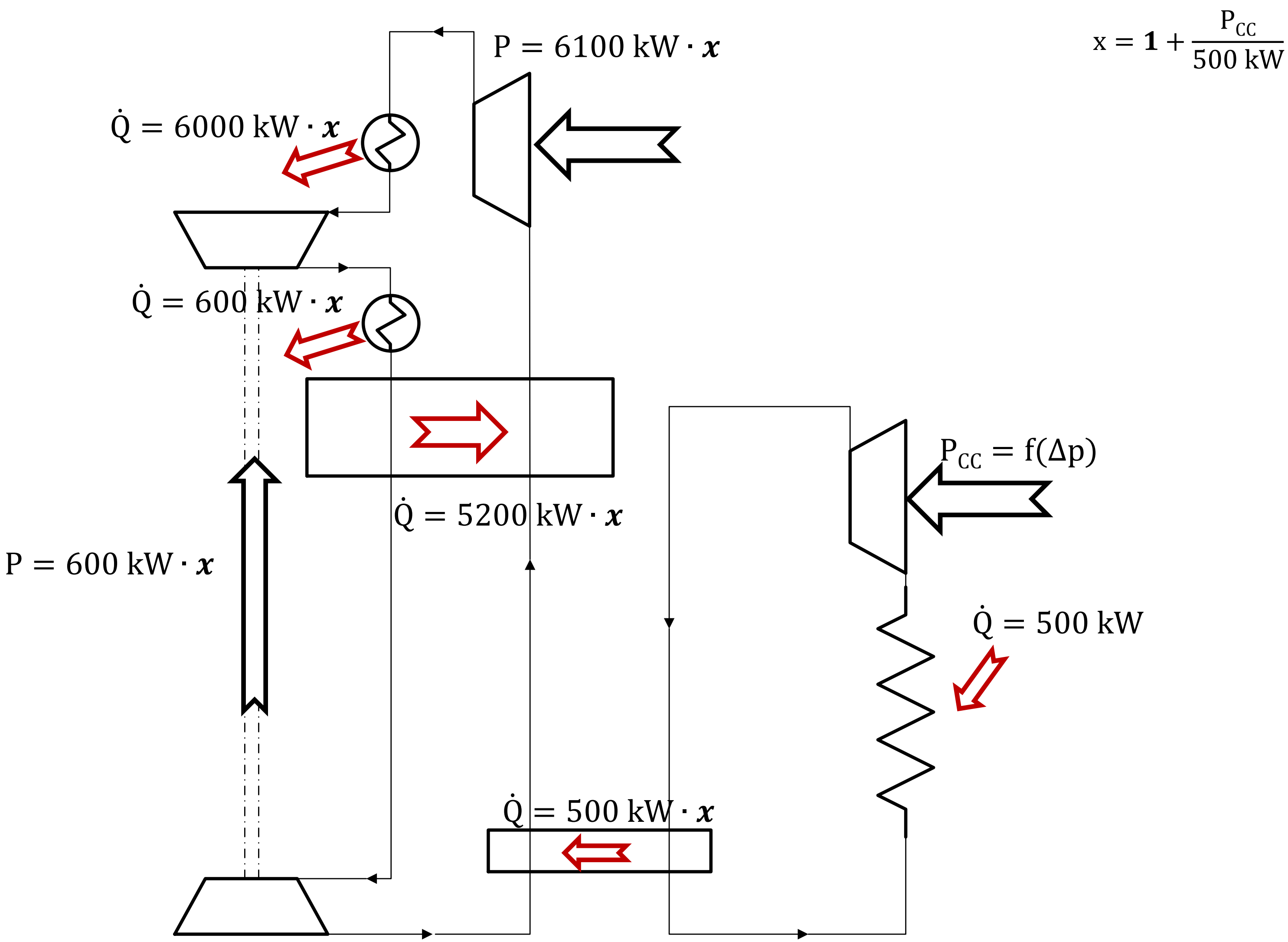
Pressure ratio of the expansion turbine is about 5

- ➔ The pressure at the outlet of the main and booster compressors would be very high

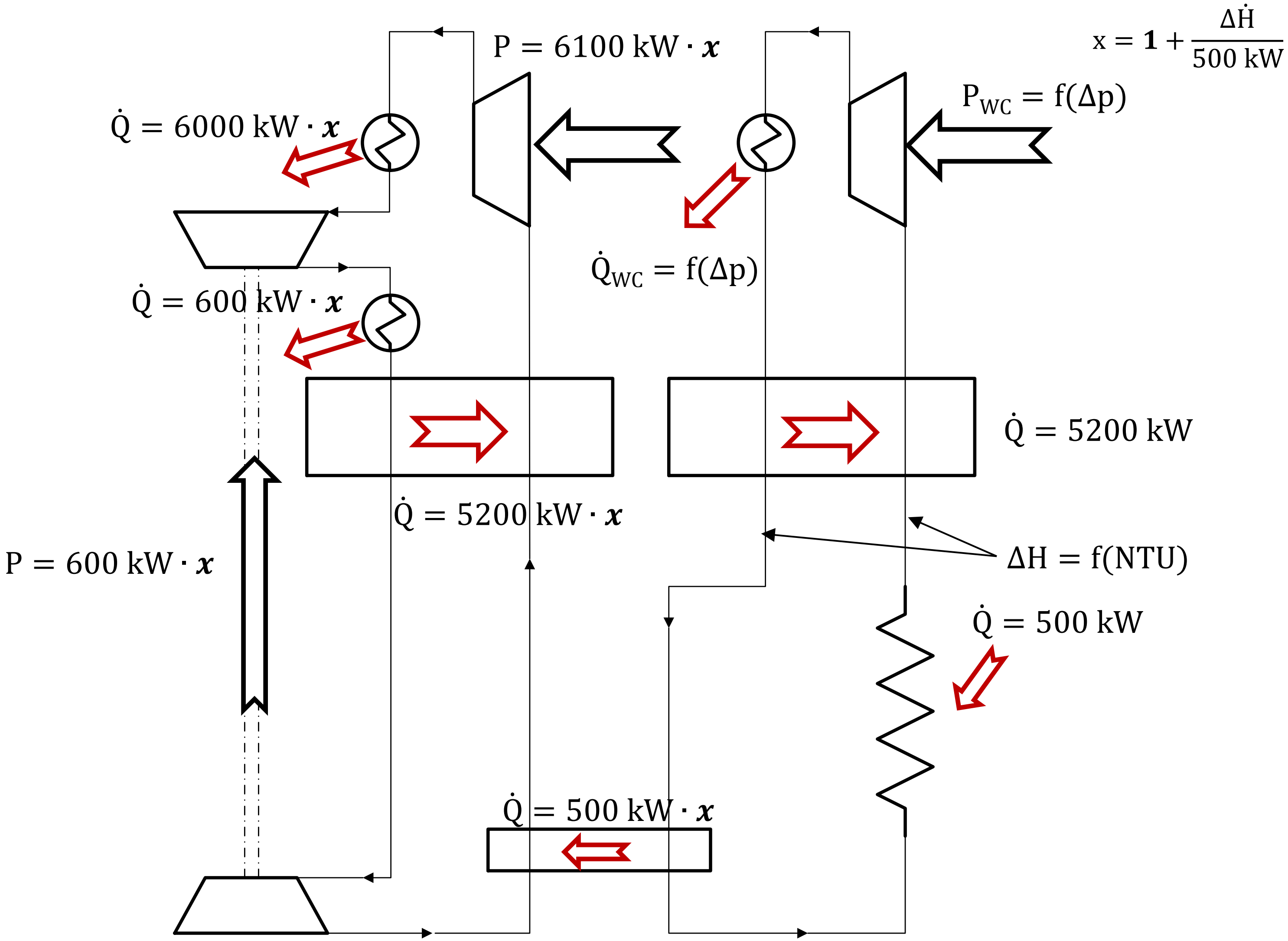
- ➔ Instead of cooling the beam screen directly use a second loop



Secondary Loop: Cold Compressor

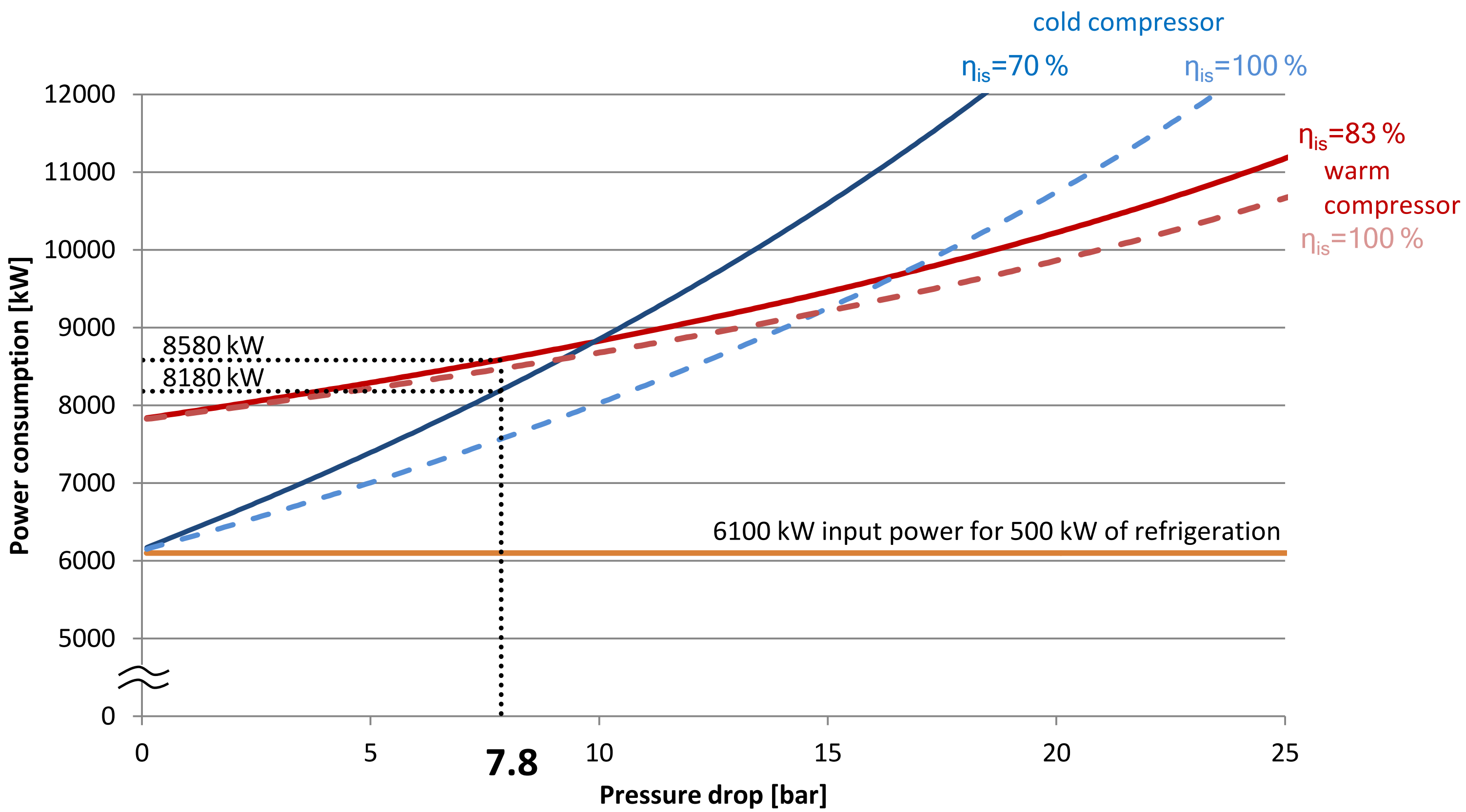


Secondary Loop: Warm Compressor



Secondary Loop: Results

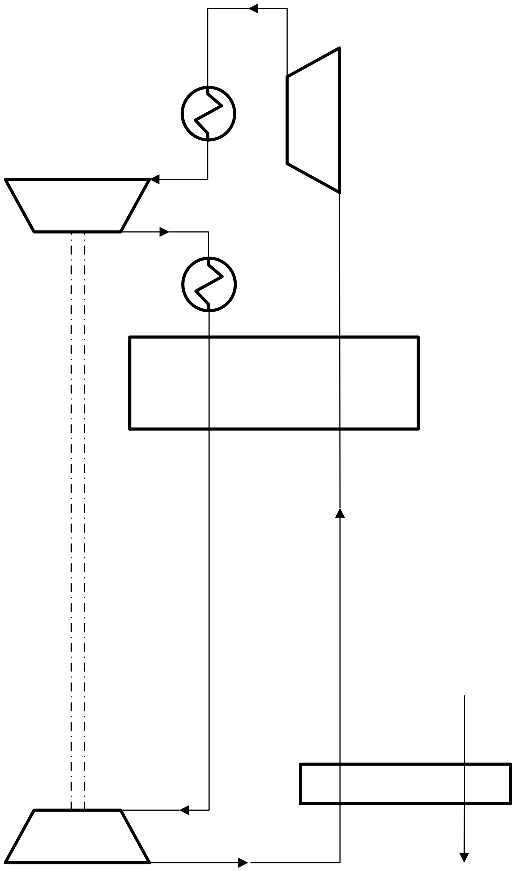
Assuming a circulation compressor outlet pressure of 50 bar and a NTU of the HX of 40:



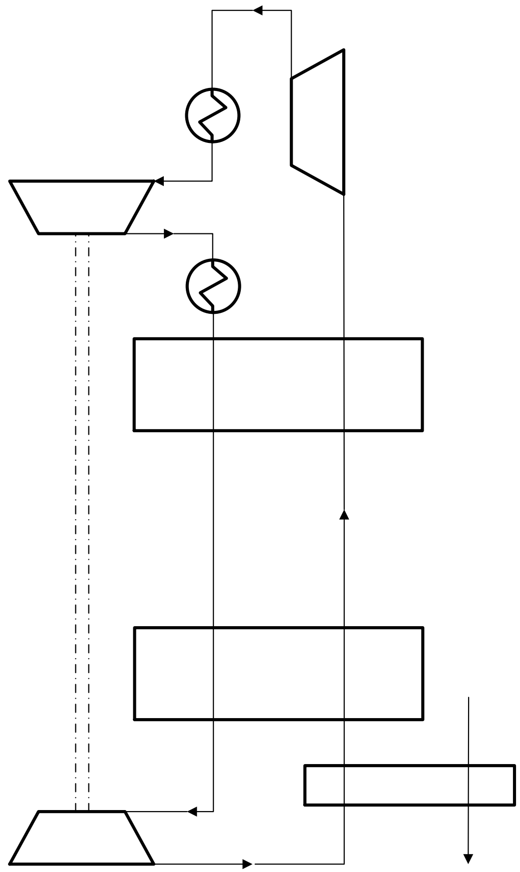
- A cold compressor is the better choice for this configuration
- One quarter of the overall power consumption is required for the circulation

Primary Cycle Variations

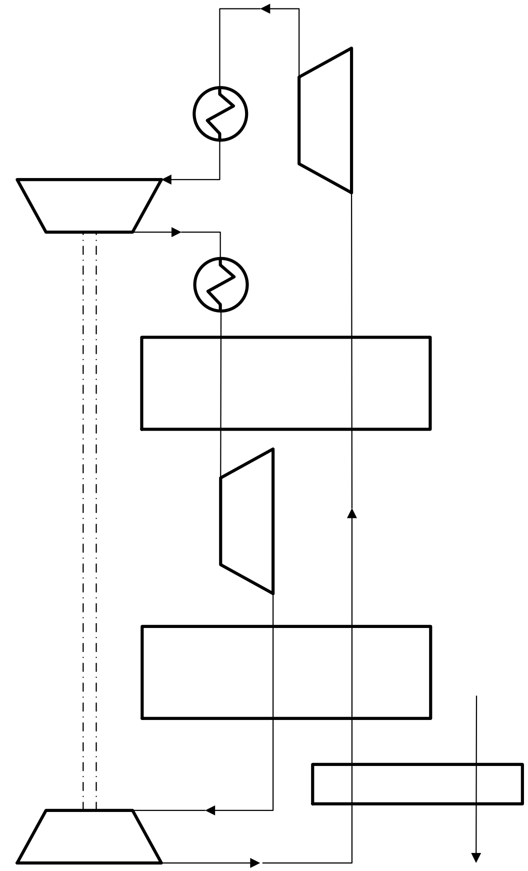
Variant A: as shown before



Variant B: with a double inner HX

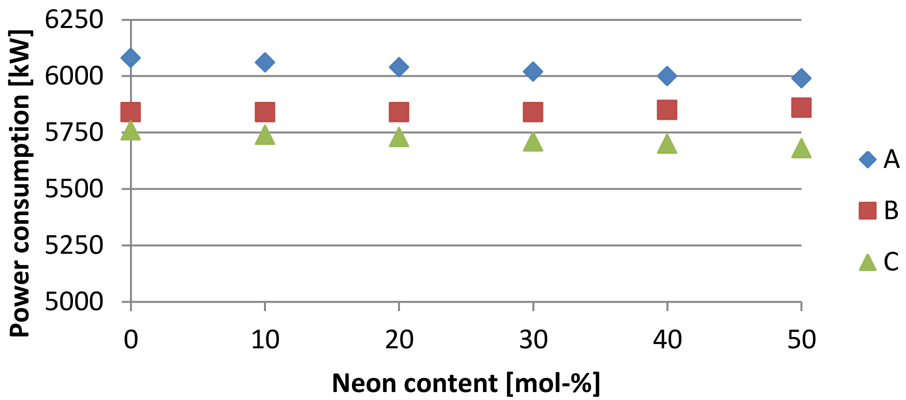


Variant C: with a precooling turbine between the HX



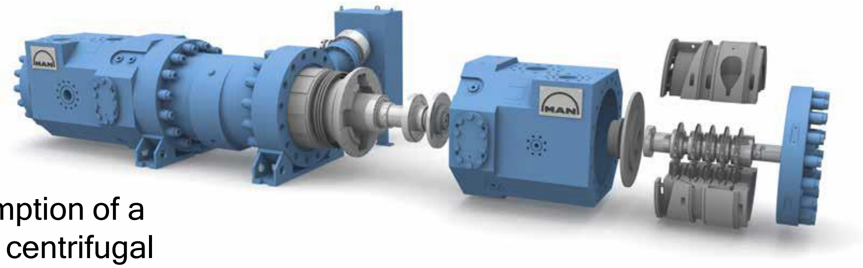
Primary Cycle Variations: Results

Results of the first order cycle calculation (constant NTUs, efficiencies etc.)



➔Neon content has only a small impact on the cycle efficiency (neglecting influence on HX etc.)
➔Small improvements are possible through better HX and/or precooling turbine
➔The largest influence on the power consumption has the main compressor

Power consumption of a system with a screw compressor: **7400 kW**



Power consumption of a system with a centrifugal compressor: **5760 kW**

Summary

A highly efficient beam screen cooling can be realized with a Brayton cycle using a mixture of helium and neon instead of pure helium

A concept was worked out, which allows to compress this mixture in a centrifugal compressor with a reasonable number of stages

For comparison, three different cycles are investigated

A current lead cooling concept will be added, including a new design of the current leads

Next step:

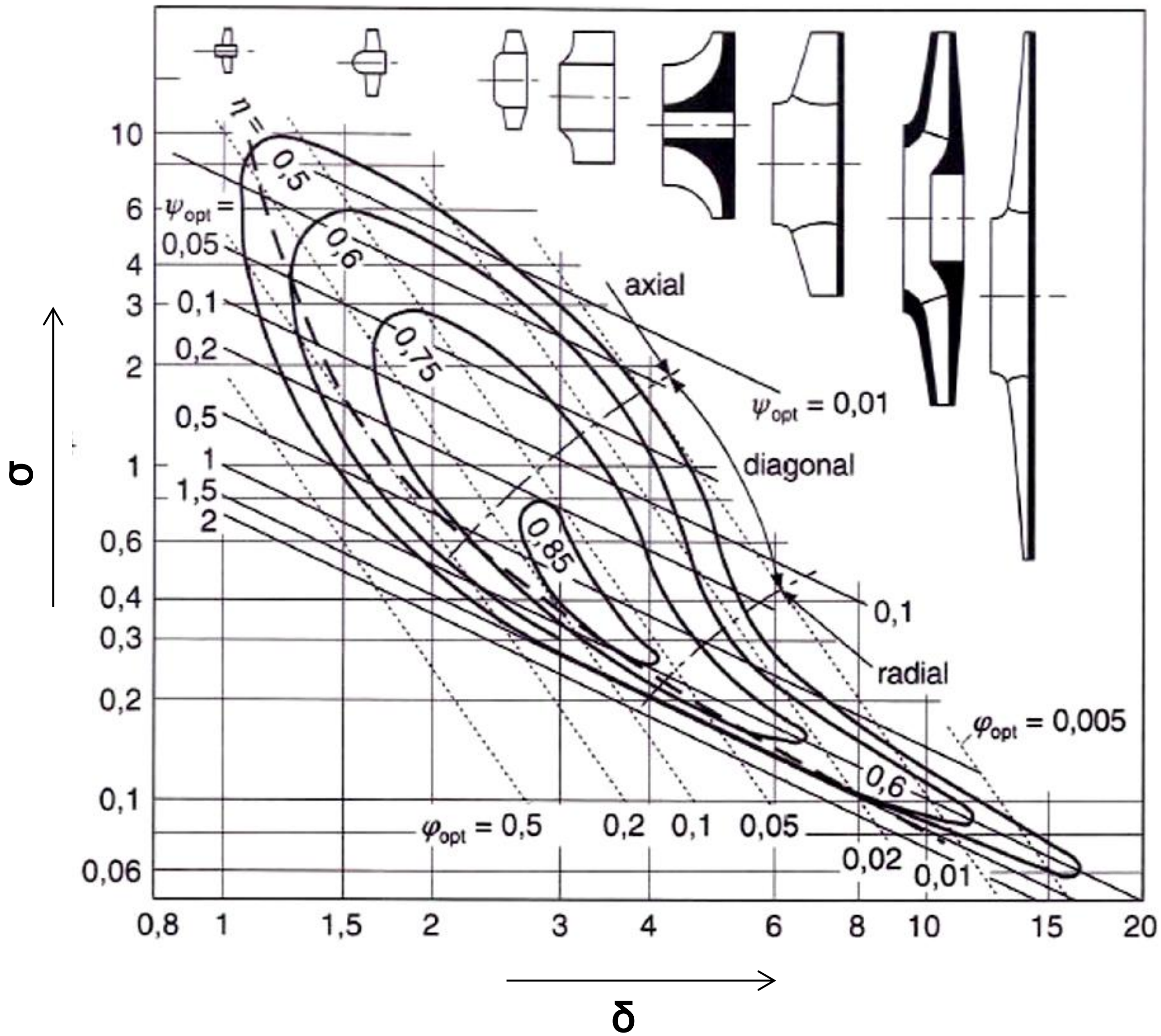
Preliminary configuration of the main compressor:

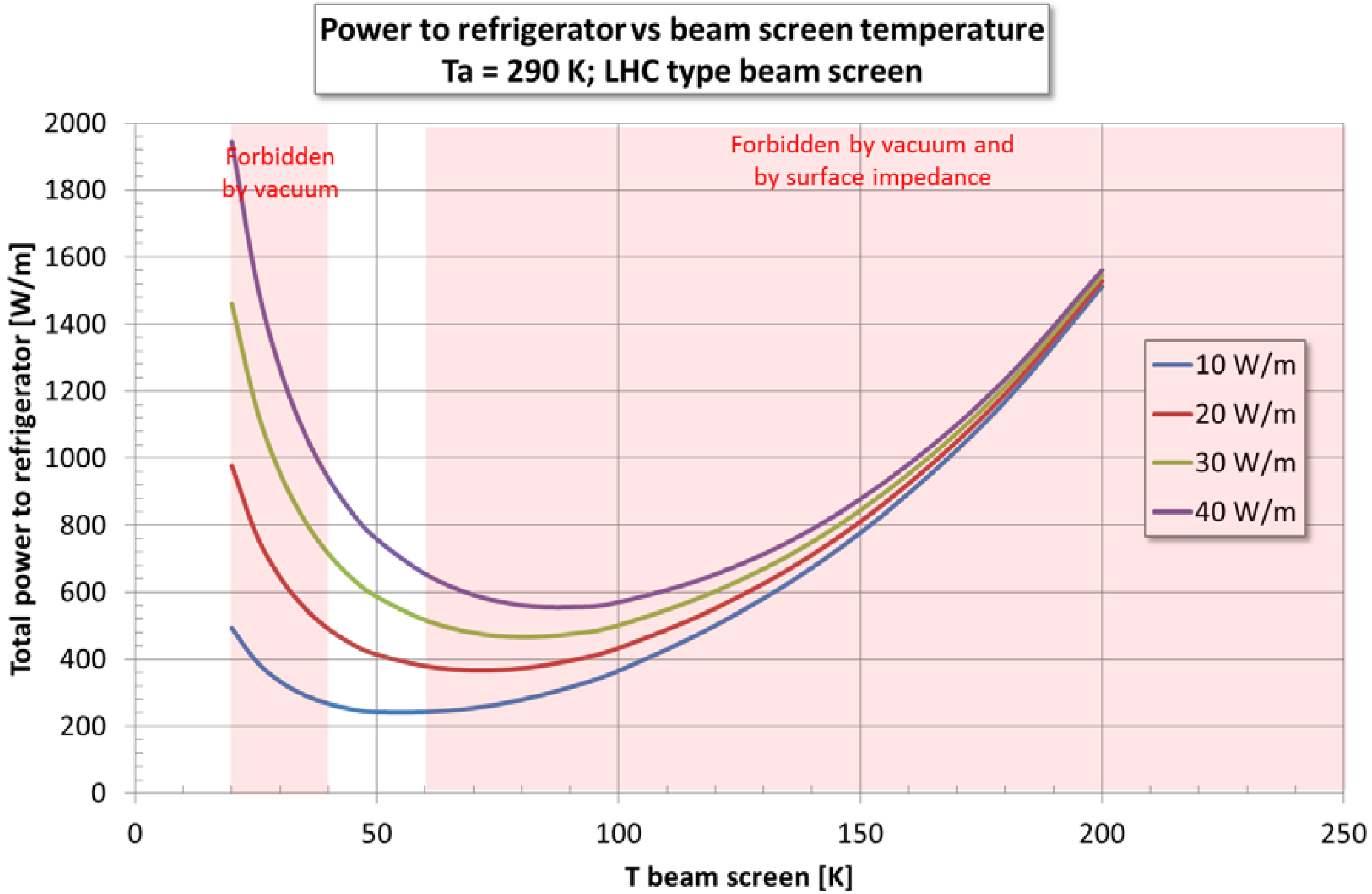
- Number of stages, stage groups, machines

Thank you for your attention!

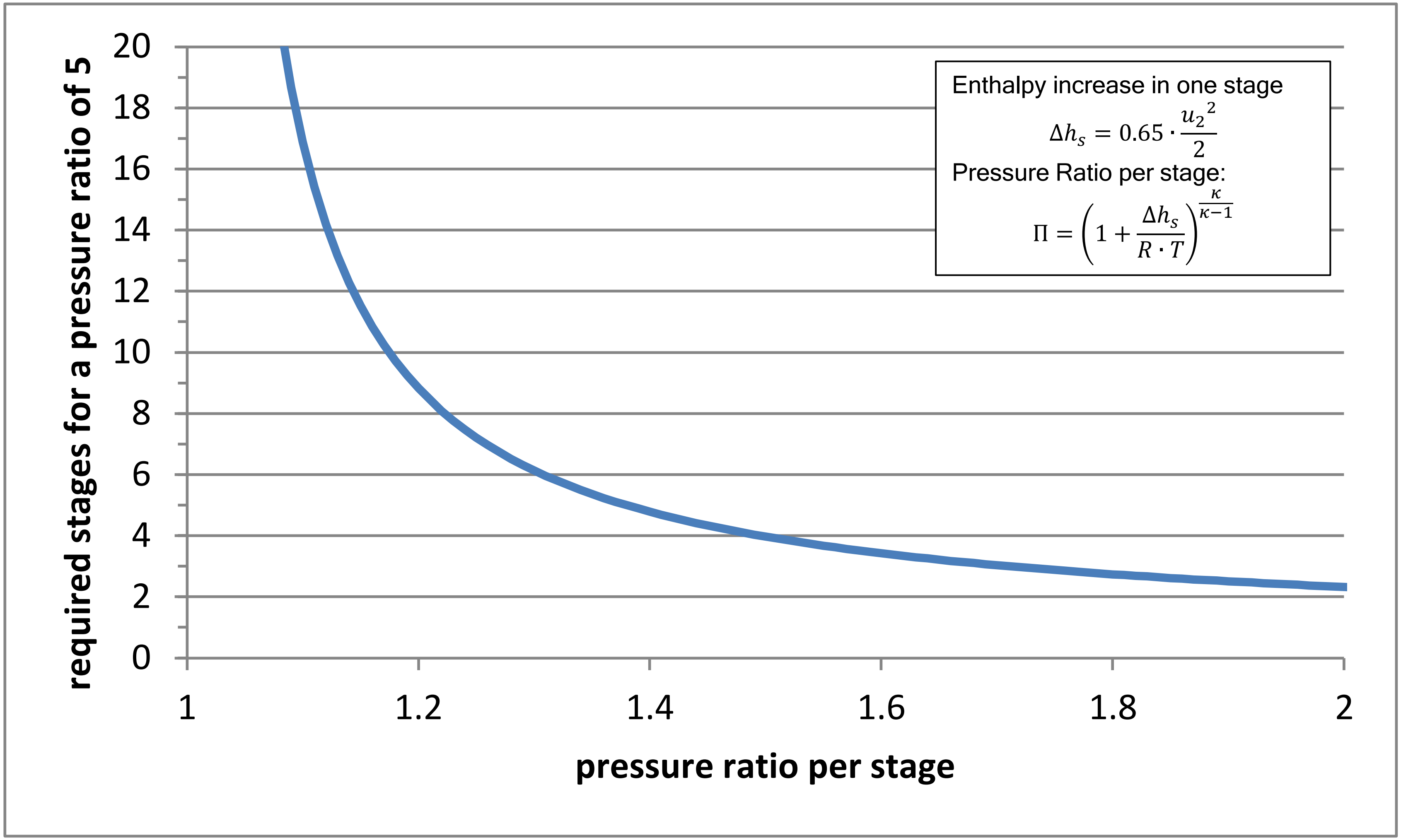
Back-up

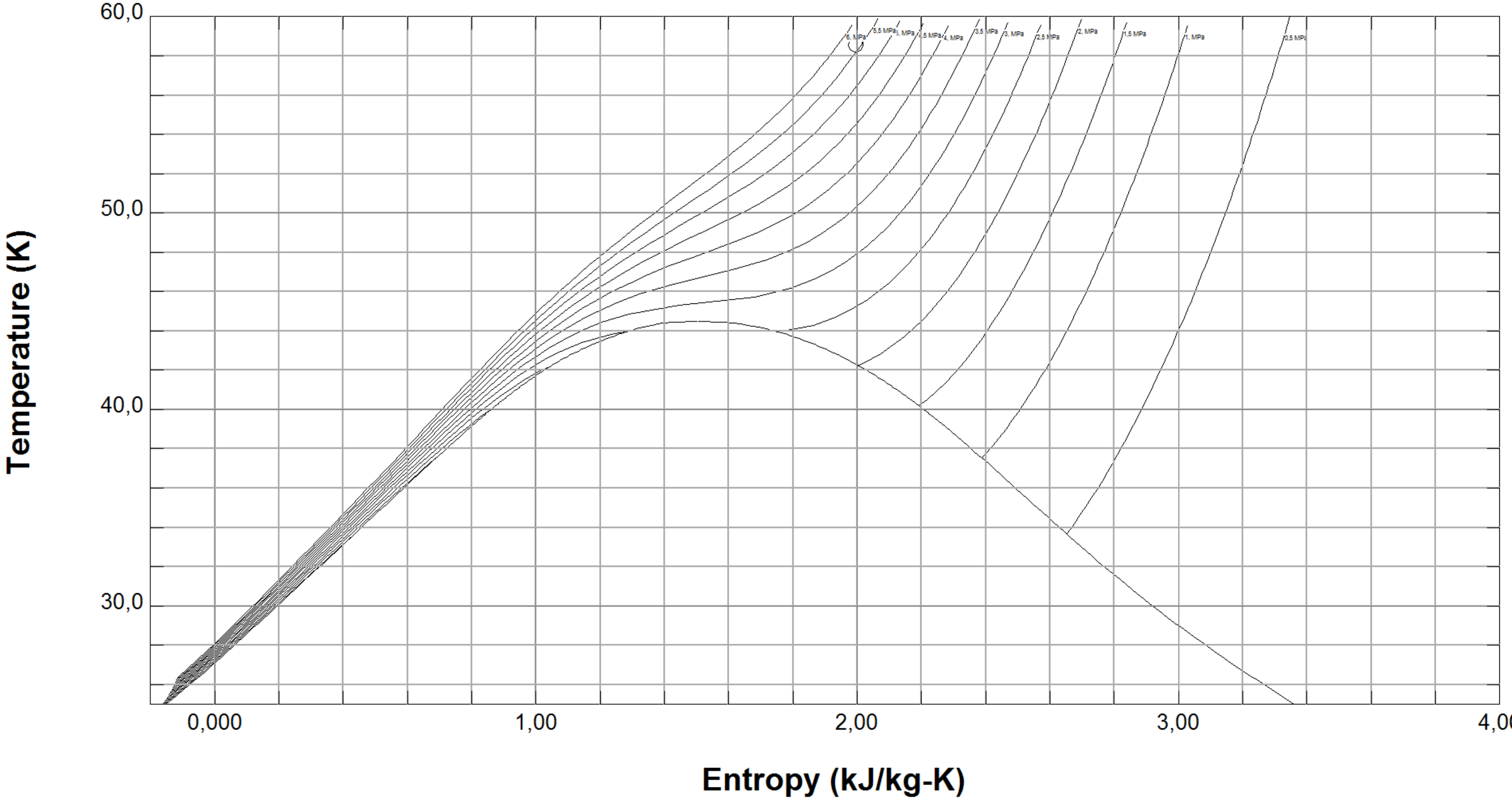
Cordier Diagram




Power to refrigerator vs beam screen temperature
Ta = 290 K; LHC type beam screen
Forbidden
by vacuum
Forbidden by vacuum and
by surface impedance
Total power to refrigerator [W/m]
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
50
100
150
200
250
T beam screen [K]
10 W/m
20 W/m
30 W/m
40 W/m

Stages needed




60,0
50,0
40,0
30,0
Temperature (K)
0,000
1,00
2,00
3,00
4,00
Entropy (kJ/kg-K)
6, MPa
5,5 MPa
MPa
4,5 MPa
4, MPa
3,5 MPa
3, MPa
2,5 MPa
2, MPa
1,5 MPa
1, MPa
0,5 MP