

# Nelium – a Refrigerant with High Potential for the Temperature Range between 27 and 70 K

H. Quack, Ch. Haberstroh, I. Seemann, M. Klaus

Technische Universität Dresden, Dresden, Germany

## MOTIVATION

In the search for the optimum process for the liquefaction of Hydrogen, it was found that mixtures of Helium and Neon, called "Nelium," allow processes with very high efficiency compared with pure Helium or pure Neon. This is demonstrated in the design of a 500 kW refrigerator between 40 and 60 K, whereby the composition is varied between pure Helium and pure Neon.

## EFFICIENCY AND COST

In large cryogenic refrigerators an improved cycle efficiency leads also to a reduction of first cost. Using turbo compressors instead of screw compressors will lead to a plant efficiency of about 45% compared to 33% with present day large Helium refrigerators. The investment cost would be reduced by more than 20%.

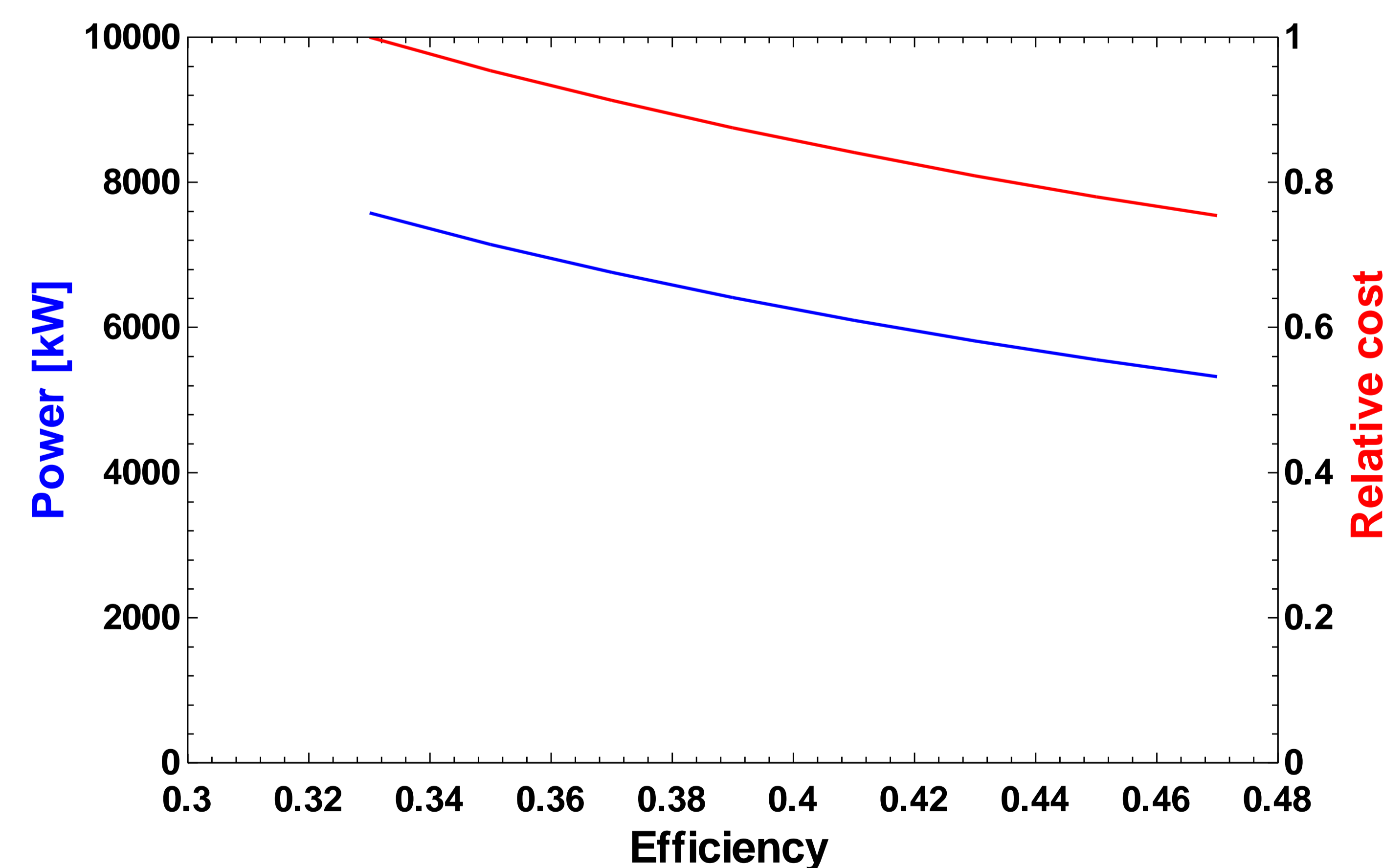


Fig. 1 Power consumption and relative cost of a 500 kW at 50 K refrigerator.

## FLOW DIAGRAM

The refrigerant is compressed in a three stage turbo compressor with inter- and after-coolers, followed by a booster compressor, which is driven by turbine T2. The coldbox contains two cryogenic heat exchangers HX1 and HX2. The turbine T1 is introduced to cover the losses of exchanger HX1, whereas turbine T2 produces the refrigeration.

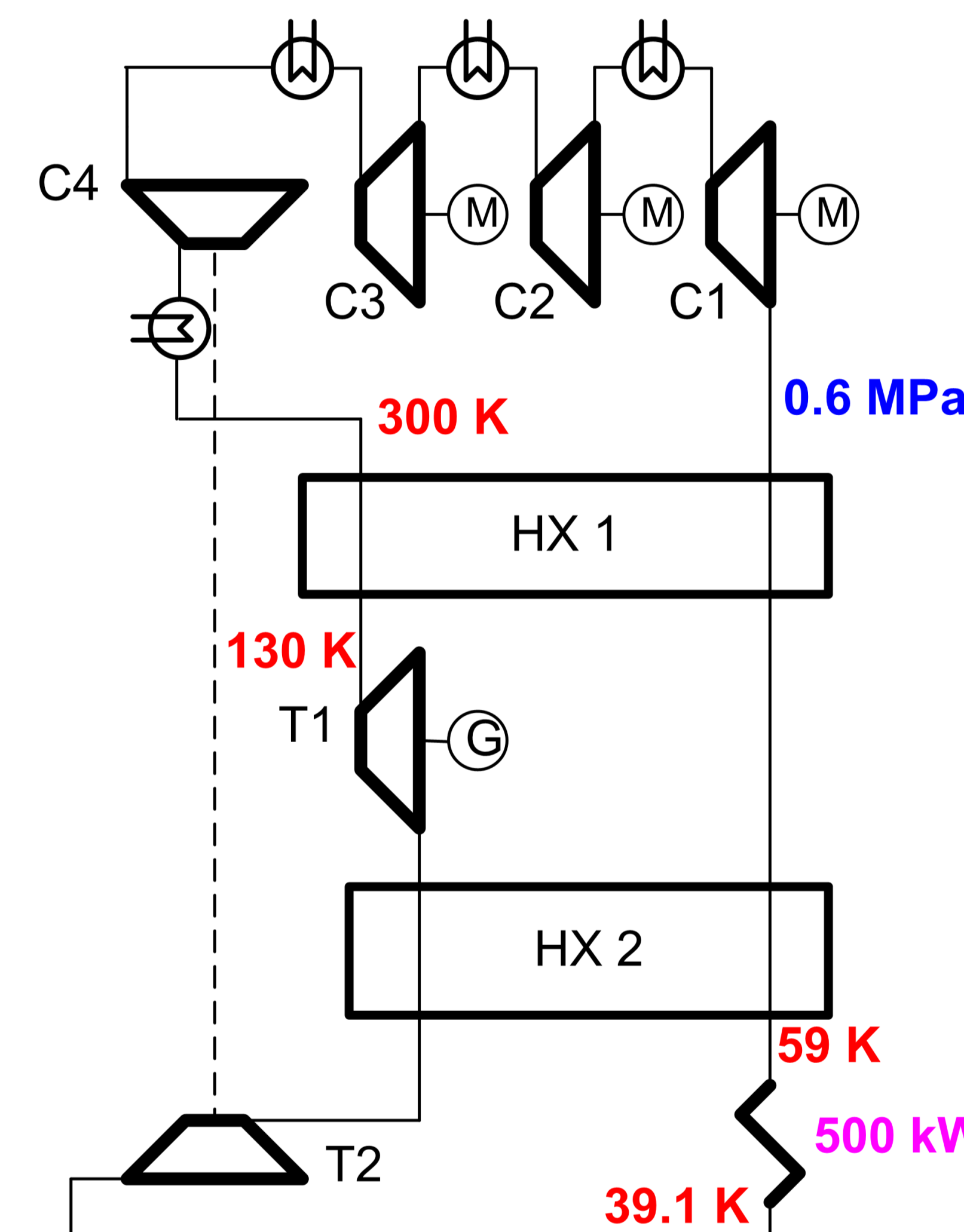


Fig. 2. Choice of cycle, boundary conditions and component efficiencies.

Table 1. Results of process calculations.

Refrigerant		Helium	Nelium 25	Nelium 50	Nelium 75	Neon
Mol. Weight	kg/kmol	4	8.1	12.1	16.1	20.2
Mass flow	kg/s	4.8	9.5	14	18	21.1
Molar flow	kmol/s	1.2	1.18	1.16	1.12	1.05
NTU <sub>HX</sub>		40	37.5	35	32.5	30
Δp <sub>HX</sub>	MPa	0.01	0.0125	0.015	0.0175	0.02
Compressor Power	kW	5678	5772	5834	5897	5984
Exergy	kW	2650	2662	2672	2684	2699
<b>Efficiency</b>		<b>0.467</b>	<b>0.461</b>	<b>0.458</b>	<b>0.455</b>	<b>0.451</b>

Refrigeration rate: 500 kW

Temperatures:

Outlet of all water coolers:	300 K
Inlet of turbine T1:	130 K
Outlet of turbine T2:	39.1 K
Outlet of load:	59 K

Pressure level:

Inlet to main compressor:	0.6 MPa
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Isentropic efficiencies:

All compressor stages:	80 %
Turbine T1:	80 %
Turbine T2:	85 %

Parameters dependent on gas composition:

Neon content: x [%]

Pressure drop in all heat exchangers:

$$\Delta p = 0.01 + 0.0001 \cdot x \text{ MPa}$$

NTU of both cryogenic heat exchangers:

$$NTU = 40 - 0.1 \cdot x$$

## HEAT EXCHANGER

The cross section of a stream channel in a heat exchanger is a function of the flow rate, the required NTU, the allowed pressure drop and in particular the molar weight of the refrigerant. The Neon-rich refrigerants therefore need a larger cross section than the Helium-rich refrigerants, even though the NTU are smaller and the pressure drop is larger.

$$A_i = m \cdot \sqrt{\frac{g^* \left(\frac{Pr}{0.7}\right)^{2/3} NTU_i}{2 \rho \Delta p_{all}}} = n \cdot \sqrt{\frac{g^* \left(\frac{Pr}{0.7}\right)^{2/3} NTU_i \cdot R^* T^* M}{2 \cdot p^* \eta_{Distr} \cdot \Delta p_{all}}}$$

Table 2. Cross section of the exchanger LP passage in HX1.

Refrigerant	Helium	Nelium 25	Nelium 50	Nelium 75	Neon	
Pr	0.67	0.57	0.59	0.63	0.67	
NTU <sub>LP</sub>	88.9	83.3	77.8	72.2	66.7	
Δp <sub>HX</sub>	MPa	0.01	0.0125	0.015	0.0175	0.02
<b>A</b>	<b>m<sup>2</sup></b>	<b>0.62</b>	<b>0.71</b>	<b>0.76</b>	<b>0.78</b>	<b>0.75</b>

## TURBINES AND COMPRESSORS

Table 3. Parameters of the turbines T2.

Refrigerant	Helium	Nelium 25	Nelium 50	Nelium 75	Neon	
Power	kW	561	541	520	497	469
Δh <sub>s</sub>	kJ/kg	138	67	44	32	26
V <sup>3</sup>	m <sup>3</sup> /s	0.626	0.595	0.560	0.521	0.461
<b>D</b>	<b>(m)</b>	<b>0.15</b>	<b>0.175</b>	<b>0.19</b>	<b>0.2</b>	<b>0.2</b>
<b>n</b>	<b>rpm</b>	<b>46808</b>	<b>27998</b>	<b>20842</b>	<b>17036</b>	<b>15279</b>

Table 4. Parameters of the first stage of compression.

Refrigerant	Helium	Nelium 25	Nelium 50	Nelium 75	Neon	
V <sub>0</sub>	m <sup>3</sup> /s	4.92	4.85	4.74	4.59	4.30
Pressure ratio		1.59	1.62	1.64	1.68	1.73
Δh <sub>s</sub>		315	163	111	88	75
P	kW	1886	1937	1943	1982	1987
Number of wheels		4	3	2	2	2
Δh <sub>s,wheel</sub>		78.7	54.4	55.7	44.0	37.6
u <sub>2,opt</sub>	m/s	397	330	334	297	274
<b>D<sub>2</sub></b>	<b>m</b>	<b>0.5</b>	<b>0.6</b>	<b>0.8</b>	<b>0.8</b>	<b>0.8</b>
<b>n</b>	<b>rpm</b>	<b>15165</b>	<b>10509</b>	<b>7969</b>	<b>7086</b>	<b>6550</b>