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Evaluation of a two-stage mixed refrigerant cascade for HTS cooling below 60 K

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Motivation

Cooling of high-temperature superconductors (HTS) in cables, transformers, fault current limiters, etc.

Requirements

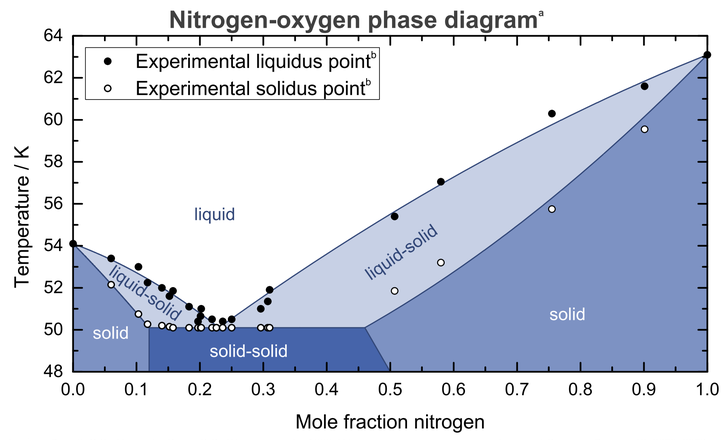
- Temperature: $T < 70$ K
- Cooling power: several 100 W to some kW
- Low investment and operating cost (high efficiency)
- Closed cycle system, low maintenance

Solution: Mixed refrigerant cycle (MRC)

- Established technology for $T > 90$ K
- Cascade setup extends temperature range

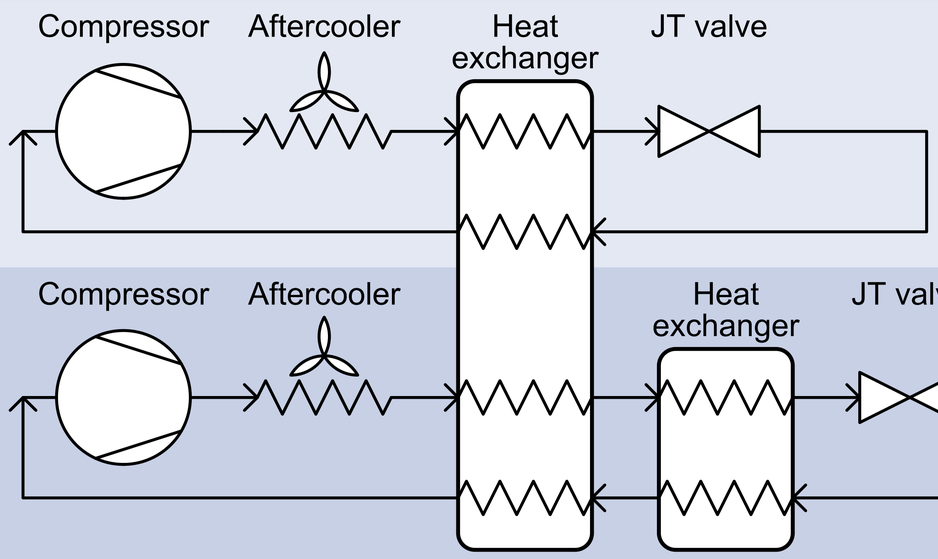
Low-temperature operation

- Oxygen lowers freezing temperature (pure nitrogen: 63.2 K)
- Operation temperatures down to 50 K possible
- Increase of current densities in HTS applications



a) adapted from Barrett, C.S., Meyer, L., Greer, S.C., Wasserman, J. , 1968. Nitrogen-oxygen phase diagram. Journal of Chemical Physics 48, 2670–2673.
b) Ruhemann, M., Lichter, A., Komarow, P., 1935. Zustandsdiagramme niedrig schmelzender Gemische: 2. Das Schmelzdiagramm Sauerstoff-Stickstoffund das Zustandsdiagramm Stickstoff-Kohlenoxyd. Physikalische Zeitschrift der Sowjetunion 8, 326–336.

Concept



- Pre-cooling to 120 K
- Nitrogen/hydrocarbon mixture
- Classical MRC setup
- Moderate pressures (20/5 bar)

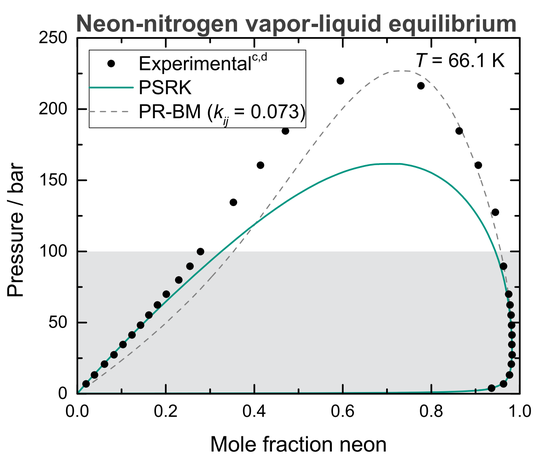
- Cooling to 55 K
- Neon/nitrogen/oxygen mixture
- High pressures (100/40 bar) increase efficiency

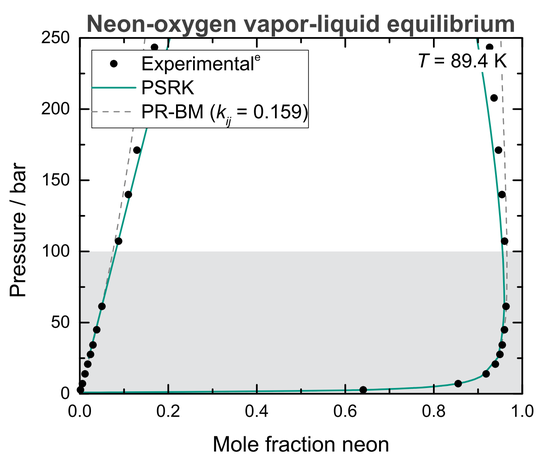
Process simulation with Aspen Plus®

Fluid model selection

Predictive Soave-Redlich-Kwong (PSRK) equation of state

- Performance satisfactory up to 100 bar
- No parameter fitting necessary





Simulation results

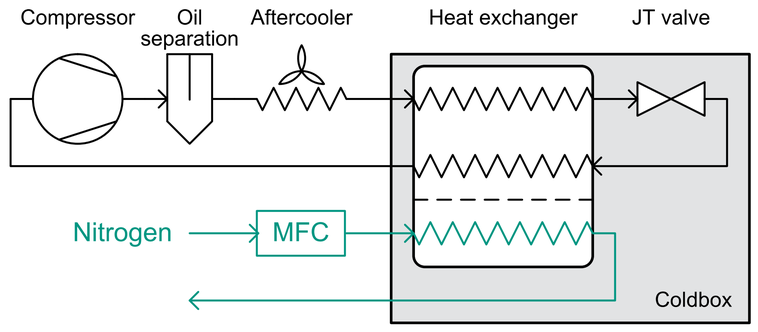
	First stage	Second stage
Refrigerant composition	15 % N_2 15 % CH_4 5 % C_2H_6 65 % C_3H_8	82 % Ne 12 % O_2 6 % N_2
Compressor power (for 300 W cooling power)	6 kW	10.5 kW
Combined COP	1.8 % (ca. 8 % of Carnot at 55 K)	

c) Streett, W.B., 1965. Liquid-vapor equilibrium in the system neon-nitrogen. Cryogenics 5, 27–33.
d) Streett, W.B., 1968. Density and phase equilibria in the system neon-nitrogen at high pressures. Cryogenics 8, 88–93.
e) Streett, W.B., Jones, C.H., 1966. Liquid-vapor equilibrium in the system neon-oxygen from 63 to 152 K and at pressures to 5000 psi. Advances in Cryogenic Engineering 11, 356–366.

Experimental validation of first stage

Approach

- Refrigerant composition optimized with Aspen Plus® model
- Pre-cooling heat load implemented by cooling down nitrogen flow



Results

- Prediction of ideal heat exchanger profile based on First Law and fluid properties