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# Design and Optimisation of Compact Heat Exchangers and Processes used for Liquefaction of Natural Gas

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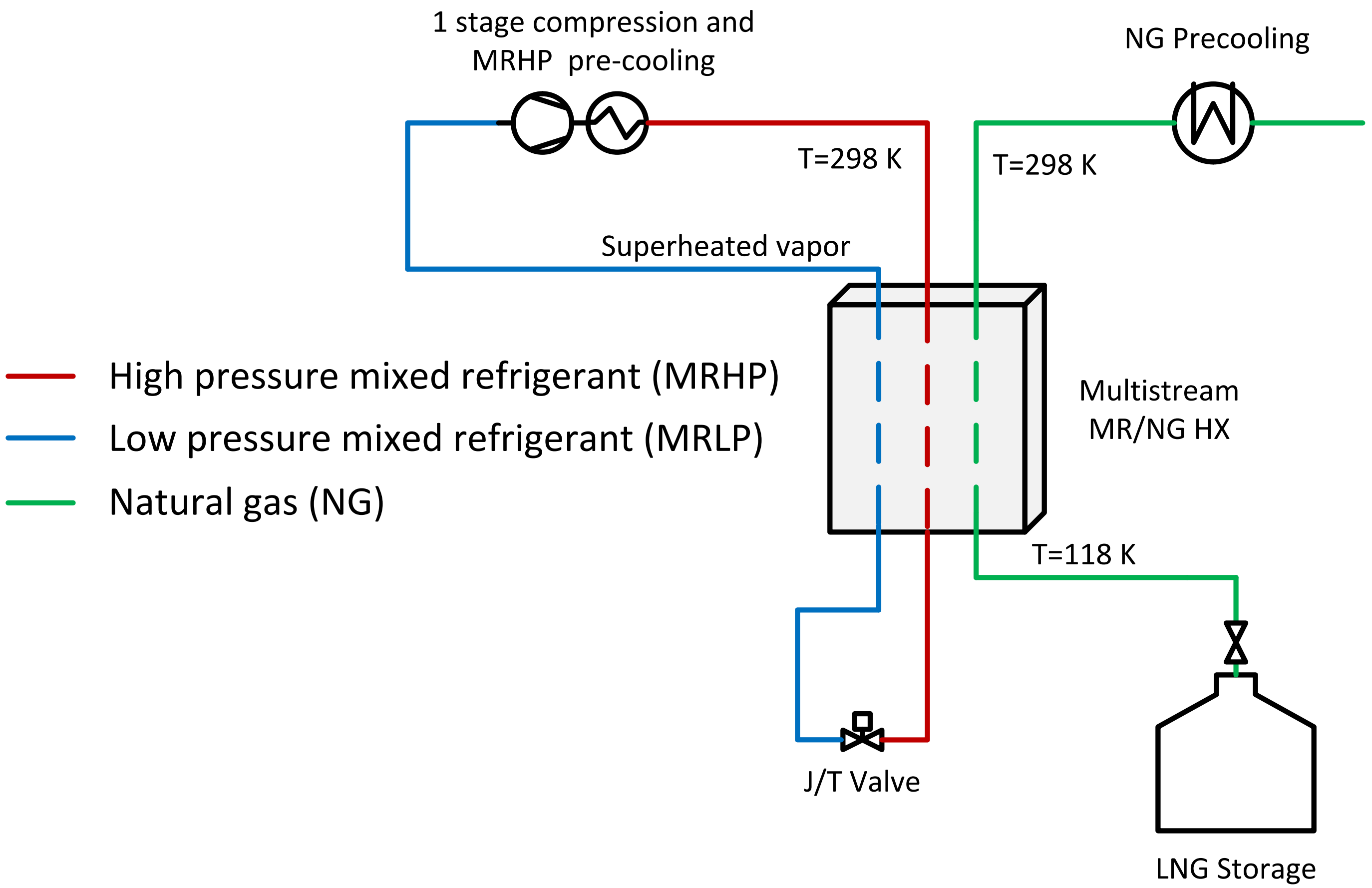
# Motivation and overview

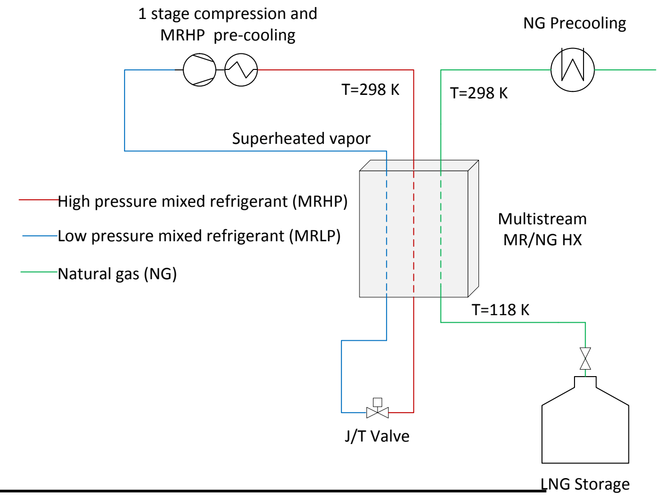
- Optimization of a simple LNG process using a detailed heat exchanger model for the main cryogenic heat exchanger
  - Heat exchanger size and weight as additional constraints
  - Results are compared to a pure thermodynamic optimization

- Content
  - Description of the process
  - Description of the heat exchanger model
  - The optimisation problem
  - Results and conclusions

# Example of SMR process layout



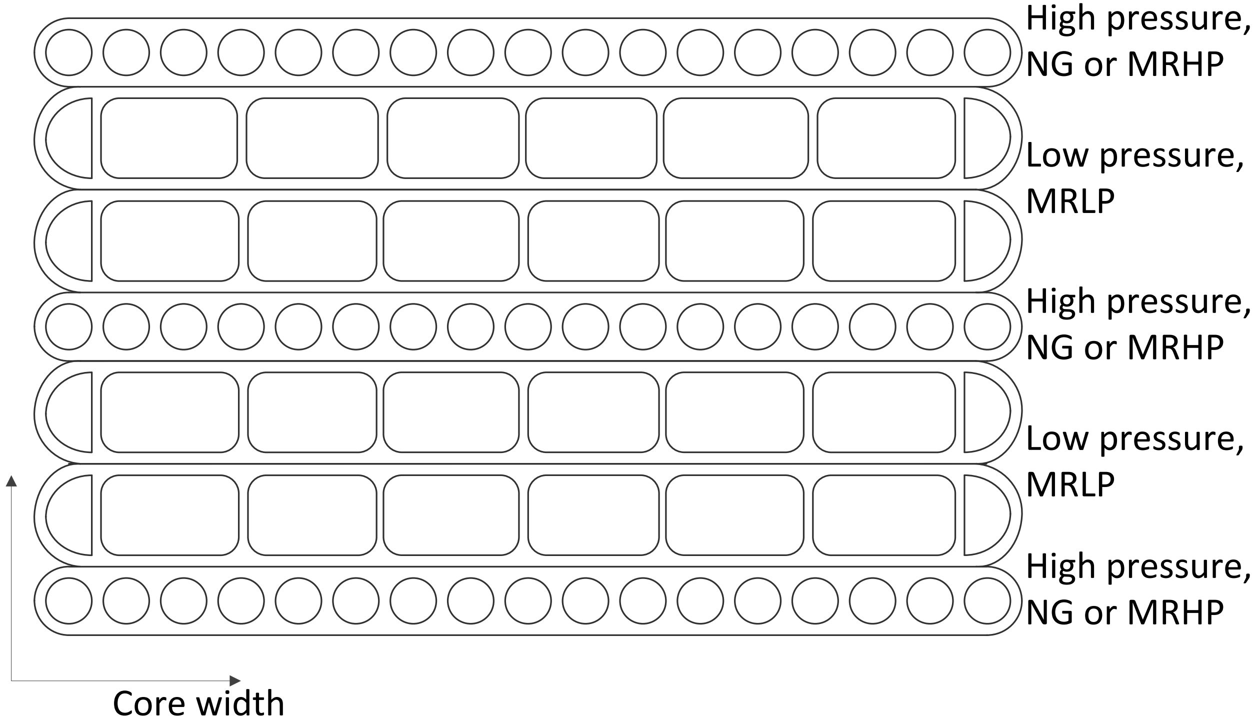
# Operating conditions and constraints



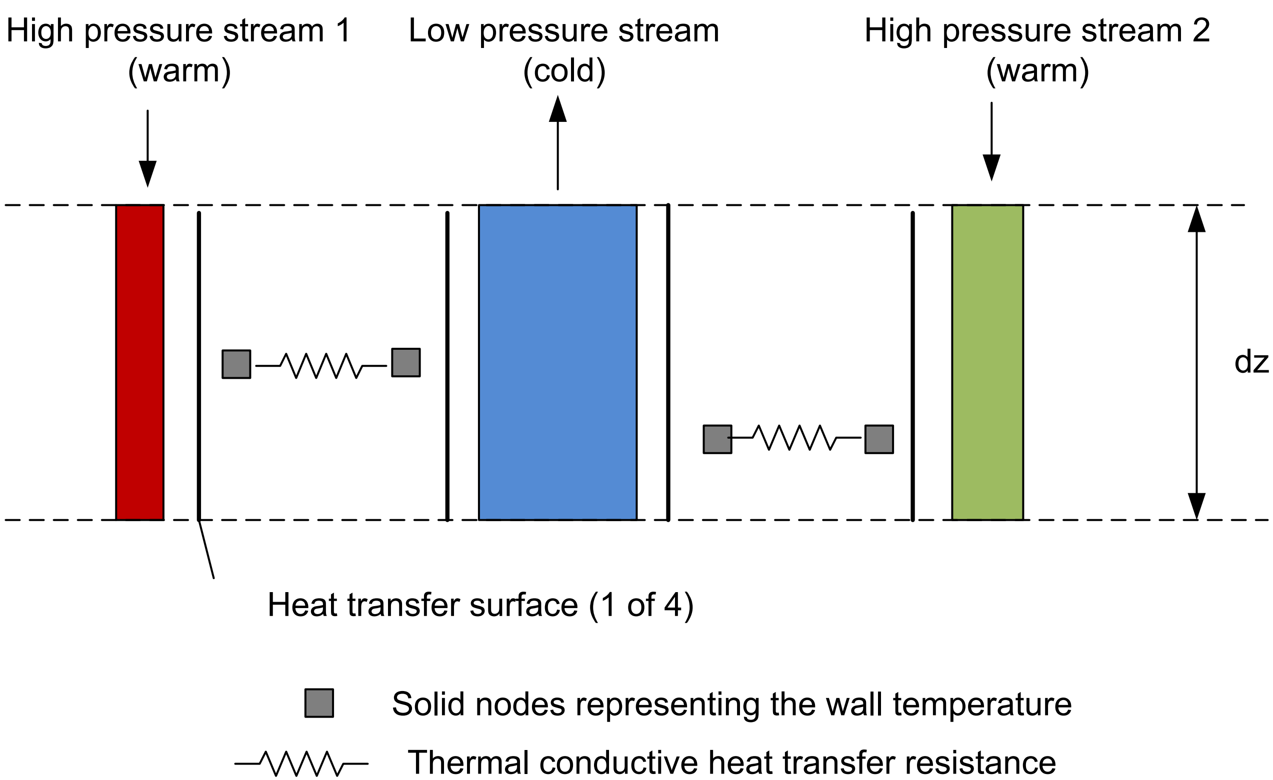

| | |
|---|---|
| NG flow-rate: | 0.265 kg/s (8.4 kTonnes/year) |
| NG pressure: | 70 bar |
| NG composition (mole %): | C1/89.8, C2/5.5, C3/1.8, NC4/0.1, N2/2.8 |
| MR composition (mole %): | C1/29.13, C2/38.87, NC4/22.71, N2/9.29 |
| MRHP and NG inlet temperature: | 298.15 K |
| Required outlet NG temperature: | < 118 K |

# The heat exchanger model

Stacked layers of multiport extruded aluminium tubes



# Heat exchanger modelling principle



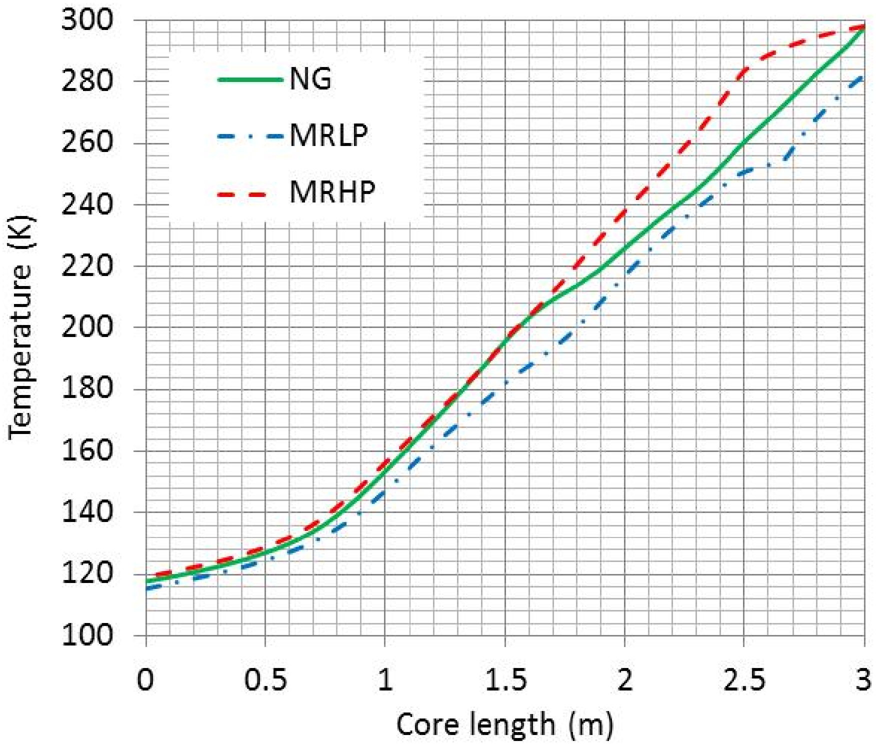

- Fluid nodes and solid nodes are "connected" through surfaces and thermal resistors.
- Sequence of fluid nodes defines a pass. The performance is integrated as a system of differential equations
- A system of non-linear equations is solved to update the wall temperatures

# Thermophysical properties- and numerical models

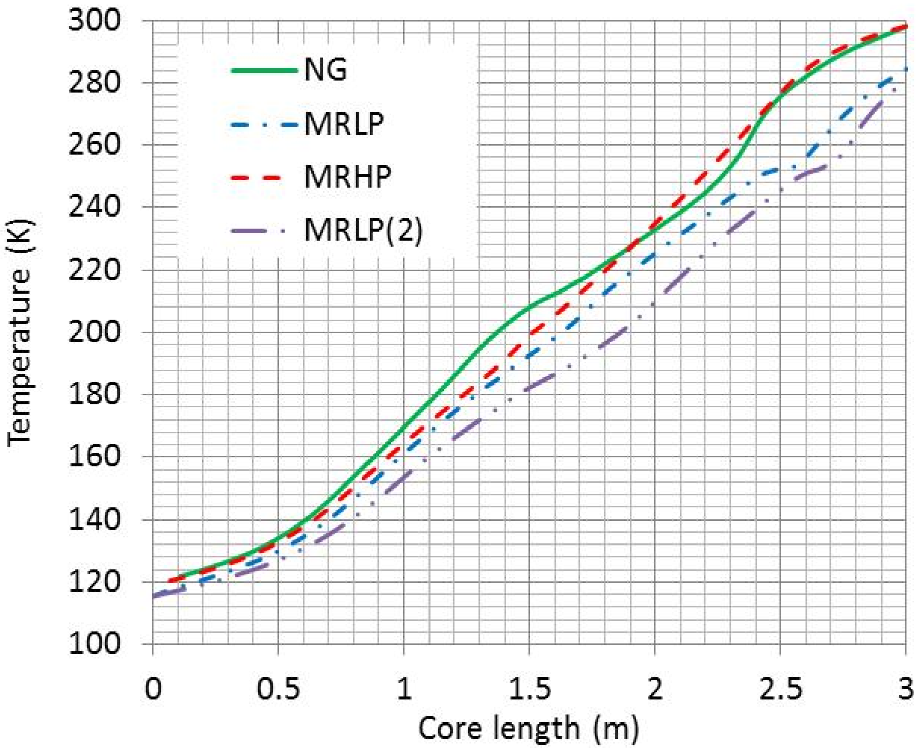
- Phase equilibrium and calorimetric properties: Peng-Robinson cubic equation of state
- Density and transport properties: TRAPP corresponding state method
- Heat transfer coefficients and friction factors : Local empirical correlations as a function of flow-rate, fluid phase, fluid and wall temperature, heat flux and local thermo-physical properties. Temperature glide effects with the Silver-Bell-Ghaly method
- Numerical methods
  - Runge-Kutta-Fehlberg from the SLATEC library for integration of performance for each fluid pass in the main heat exchanger
  - DNSQE from the SLATEC library for solving the wall-temperature linked equations in the main heat exchanger
  - NLPQL by Prof Schittkowski – for the system optimisation problem

# 3 or 4 stream heat exchanger model

## - Calculated stream temperature profiles

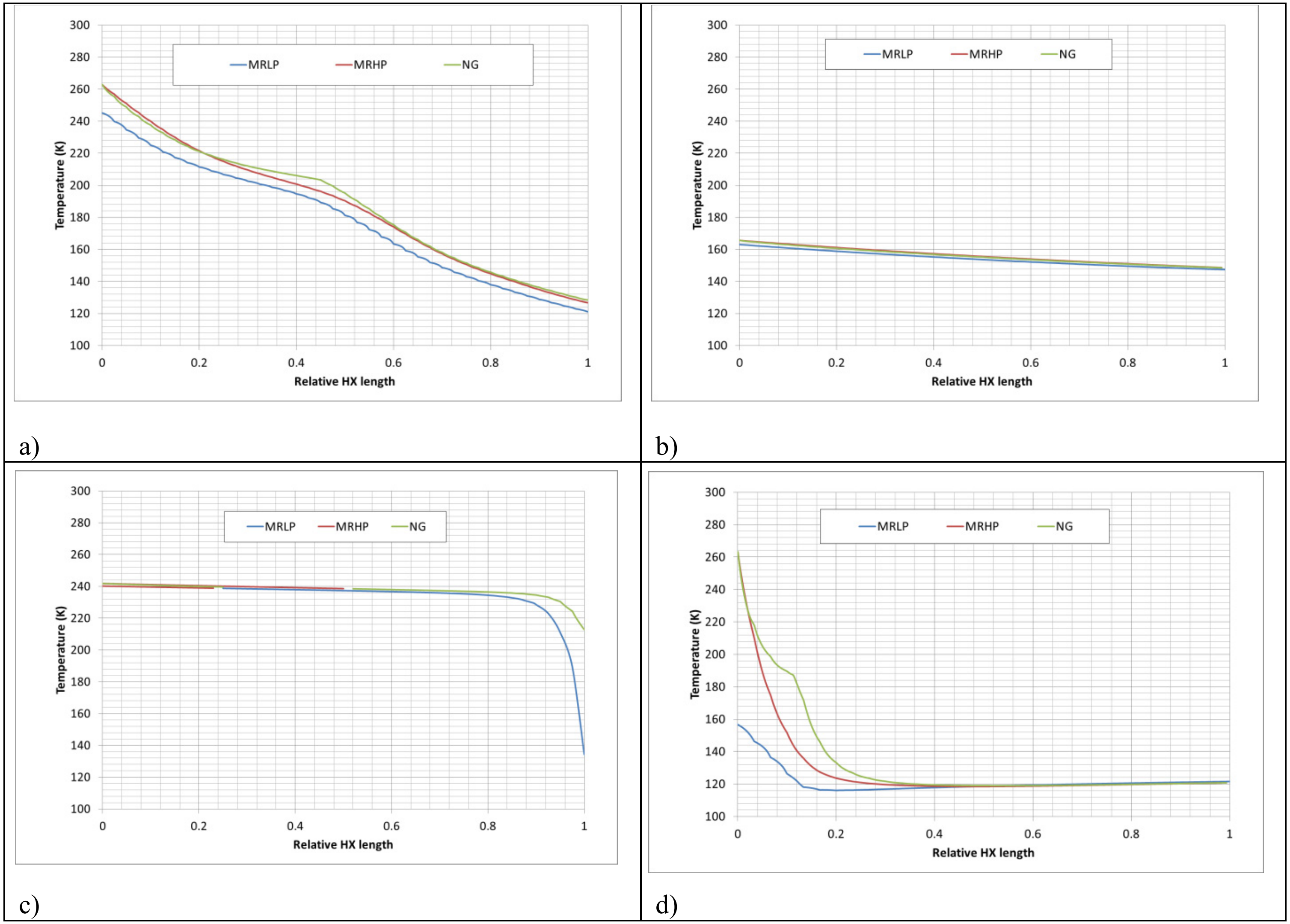



Common cold stream




Individual cold streams

# Effect of varying input conditions on the temperature profile



# Reduction of geometry variables (from 3)

Length :

Given as a parameter (2,3,4 and 6 m)

Width :

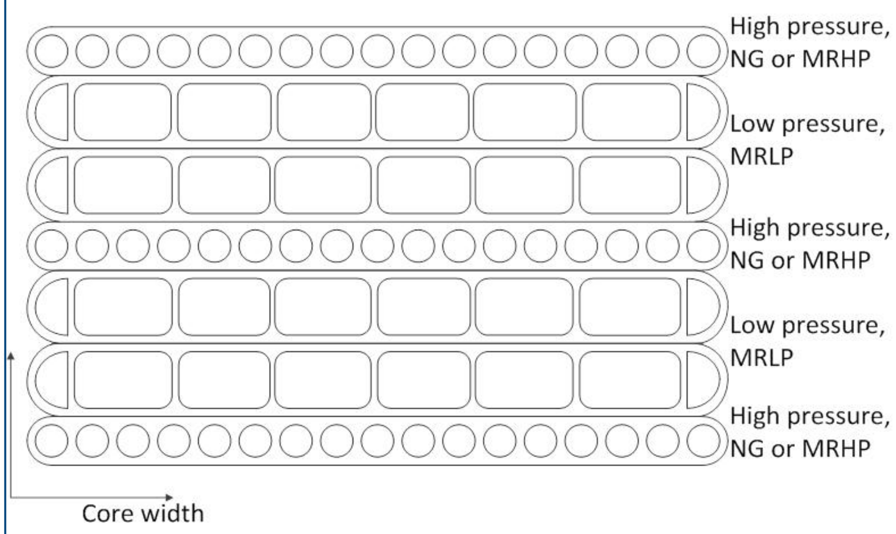
Function of number of channels and channel diameter

- 0.8 mm circular for high pressure 4x3 mm rectangular for low pressure.
- Equal width for each layer

Depth:

Layer configuration

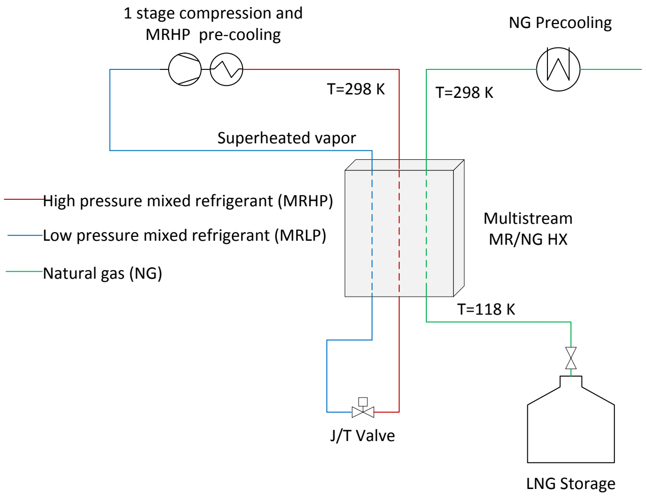
- Always "double banked"
- Ratio of MR tubes / NG tubes held fixed at 40/30

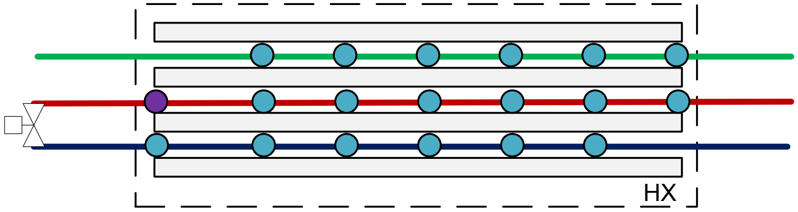



1 free geometry variable pr. studied length: Number of NG layer channels

# System optimisation model

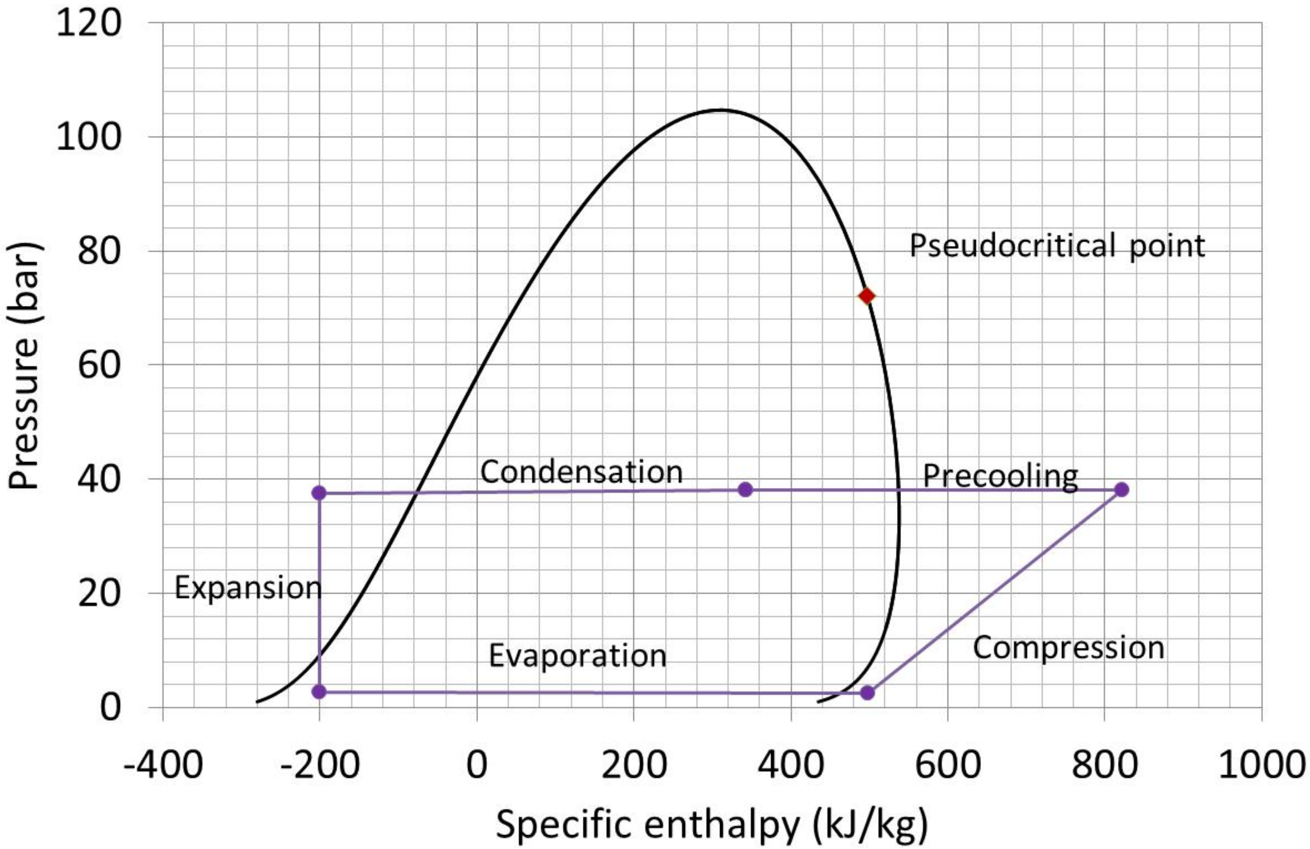
- Object function
  - Compressor power consumption
- Equality constraints
  - Heat balances on the HX-level
- Inequality constraints
  - Calculated outlet NG temperature
  - Calculated refrigerant superheat
  - Calculated weight
- Free variables
  - Compressor suction pressure
  - Compressor discharge pressure
  - Refrigerant flow rate
  - Number of NG channels
- Parameters
  - HX length



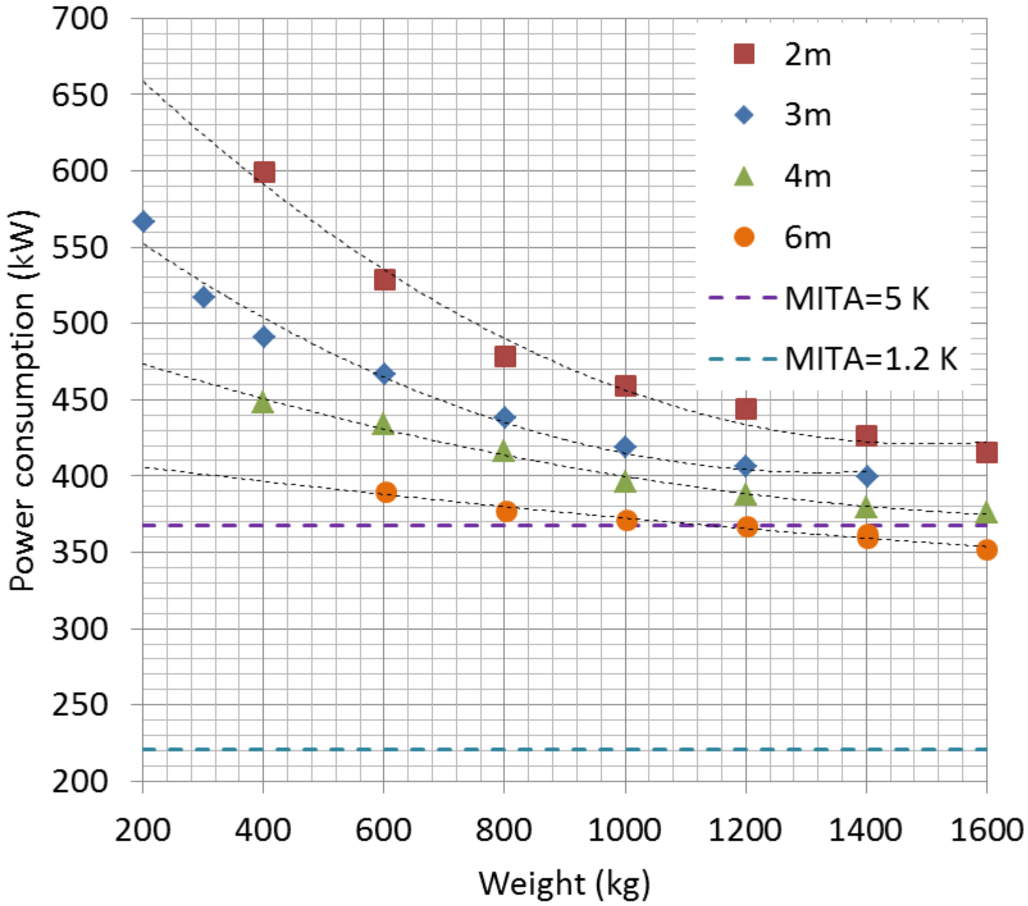




Refrigerant calculated as one pass with an internal valve element

# The pressure-enthalpy diagram for the refrigerant cycle



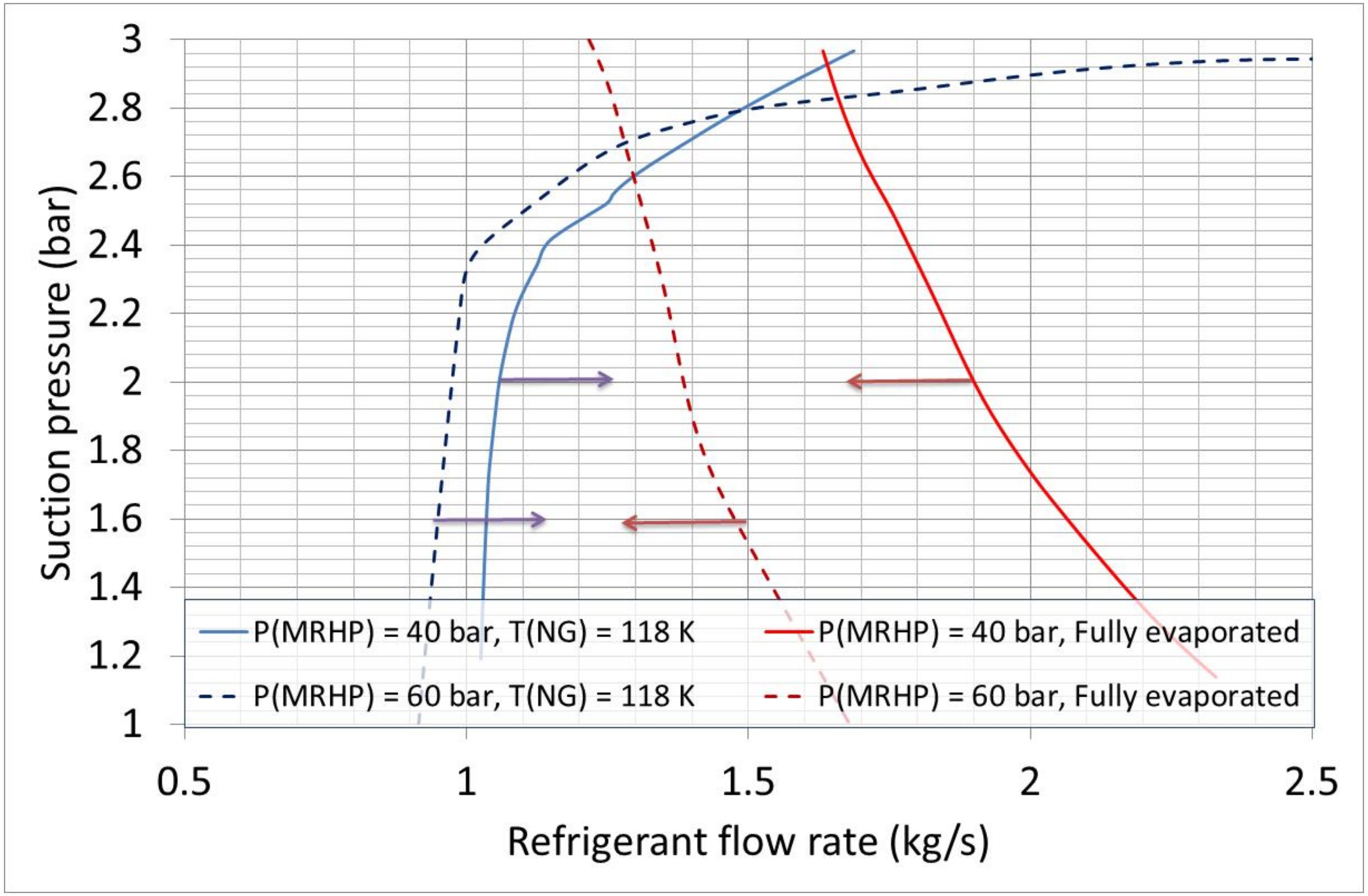
# Main results from the optimisation




MITA = Minimum Internal Temperature Approach

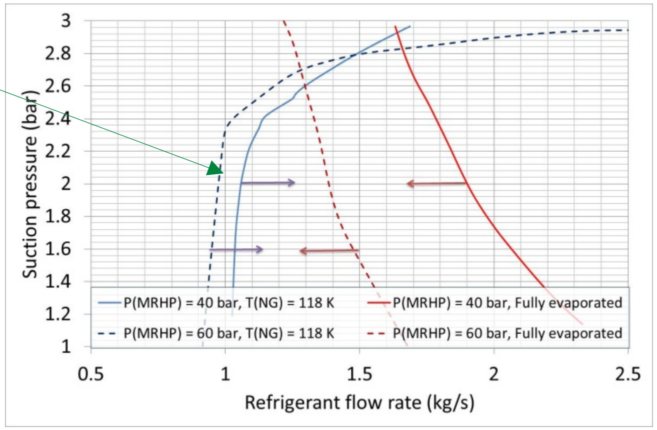
From thermodynamic optimisation with no actual HX geometry

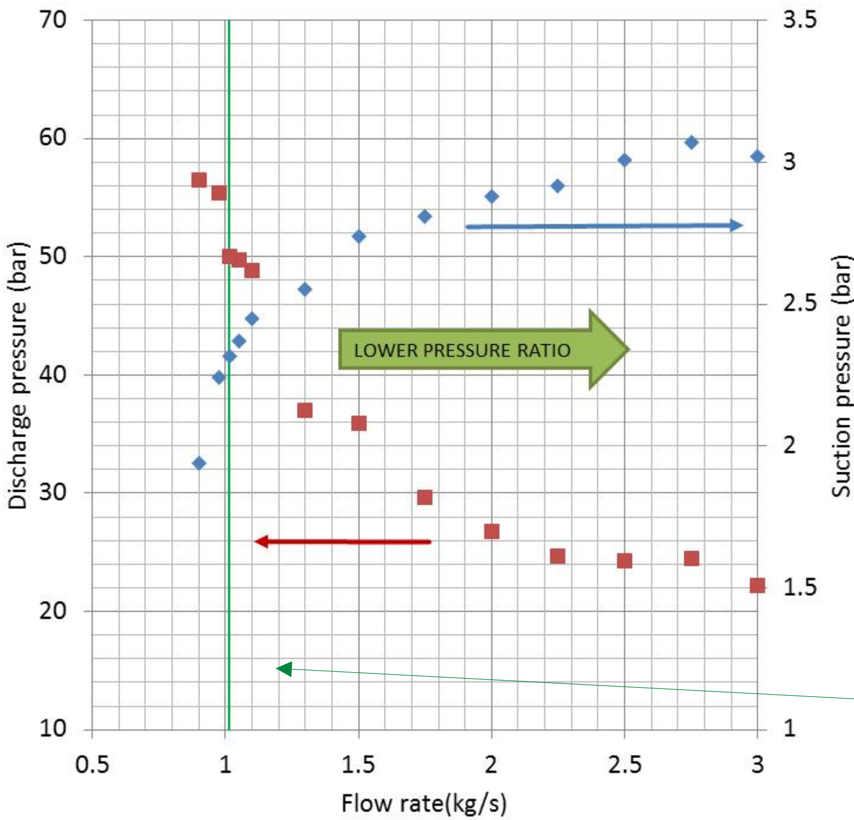
# Feasible operating range: One geometry and two condenser pressures - Simulation



# Optimisation of pressures for L=4 m and W=1000 kg

Solutions with minimum power consumption and all process constraints fulfilled



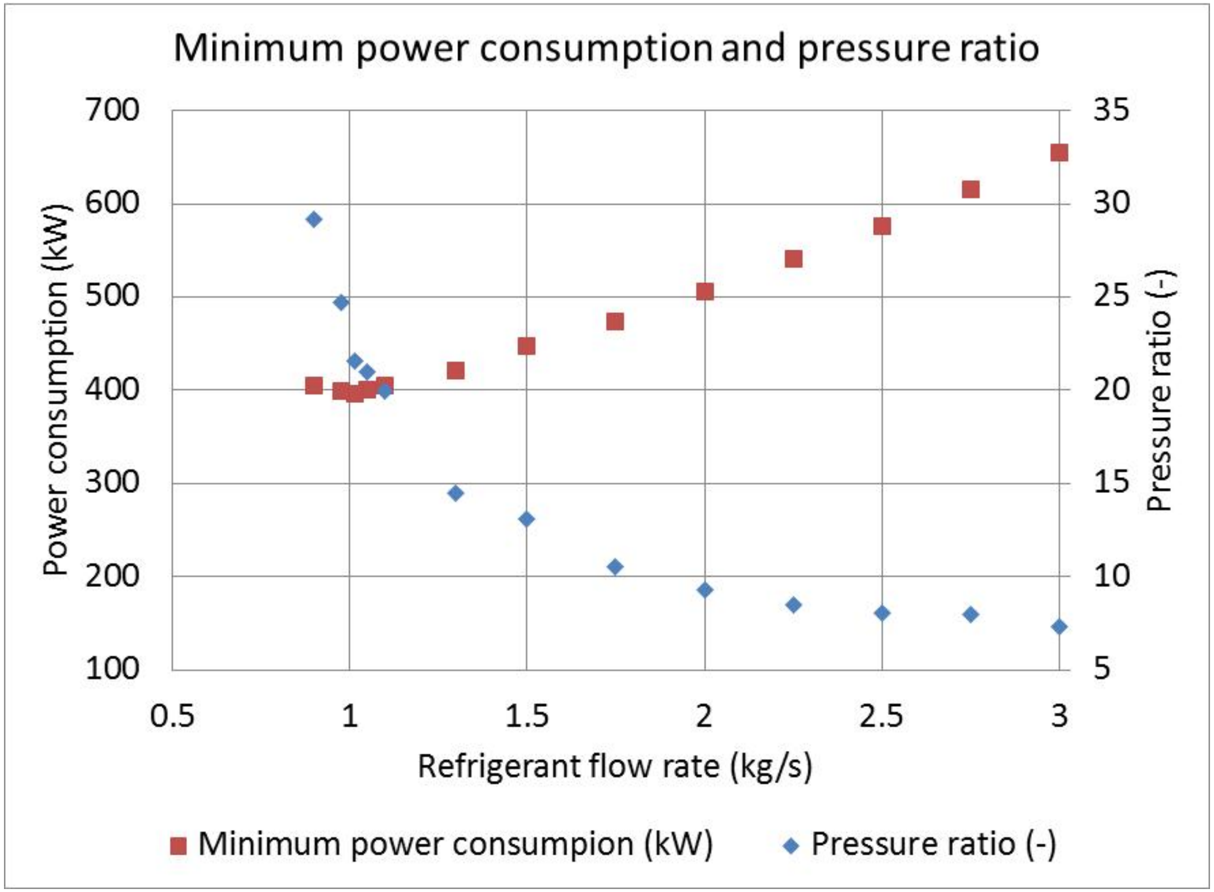



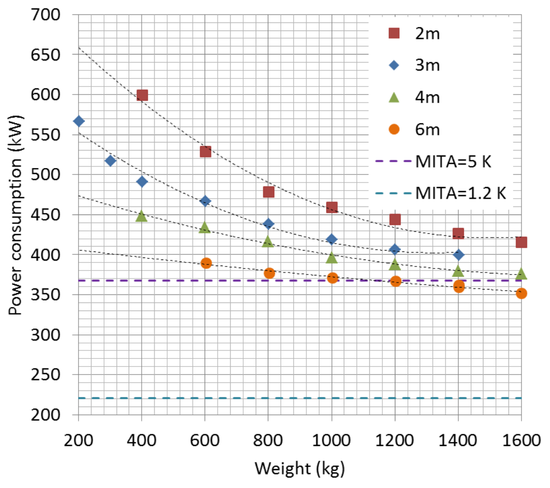

"Higher suction pressure => lower pressure ratio"

Optimum flow rate from the optimisation for 4 m and 1000 kg

Suction pressure: Variable, Discharge pressure: Variable, Flow rate: Fixed, Geometry: Fixed

# Minimum power consumption for L=4 m and W=1000 kg




Solution from the optimisation for 4 m and 1000 kg

Suction pressure: Var, Discharge pressure: Var, Flow rate: Fixed, Geometry: Fixed

# Conclusions

- We have searched for optimal design and operating conditions for a single mixed refrigerant process
- An optimisation of the SMR process including the main heat exchanger with full geometry and accurate thermo-physical models has been performed. The returned solution has been compared with a thermodynamic optimization without information about geometry.
- The optimisation result has been verified for a case with 4 m heat exchanger of 1000 kg with a parametric study.
- The main conclusion from this was that the power consumption decreases asymptotically with the heat exchanger size to values in the range almost twice the values obtained from thermodynamic optimization based on low MITA values found in the literature.
- This strongly motivates the use of detailed heat exchanger models in optimisation of LNG processes where weight and size is of significance

# Acknowlegements

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# Further work

- With improved solution algorithms and calculation speed up (will be presented by Morten Hammer), more geometry specifications can be included as free variables in the optimisation
- Evaluate the possibility and need for more detailed heat exchanger model (layer-by-layer).

SP2

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SP3

- More heat exchangers should be included in the optimisation - look at total hx weight
- Comparison of this methodology with implementation in HYSYS flowsheet.
- What are the correct constraints and their values (UA, LMTD, MITA)