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Innovation and Creativity

# Meeting on LNG at Hydro Oil & Energy RC

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22th May 2006

# Outline

Simple cooling cycles

Ammonia cooling cycle

PRICO LNG process

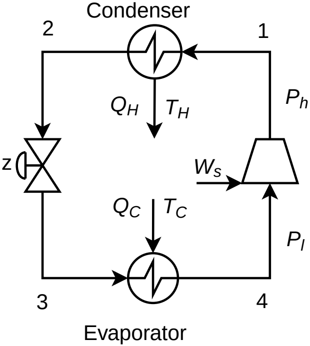
MFC LNG process

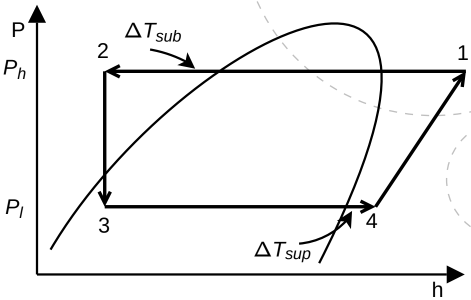
Concluding remarks

## Simple cooling cycles

- Introduction
- Specifications in design and operation
- Active charge and holdup tanks
- Degrees of freedom for operation
- Discussion of some designs
- Conclusion

# Introduction




## Coefficient of performance (COP)

$$COP_h = \frac{Q_h}{W_s} = \frac{\dot{n}(h_1 - h_2)}{\dot{n}(h_1 - h_4)} \qquad COP_c = \frac{Q_c}{W_s} = \frac{\dot{n}(h_4 - h_3)}{\dot{n}(h_1 - h_4)}$$

Theoretical limit: $COP_h = T_H / (T_H - T_C)$ $\qquad COP_c = T_C / (T_H - T_C)$

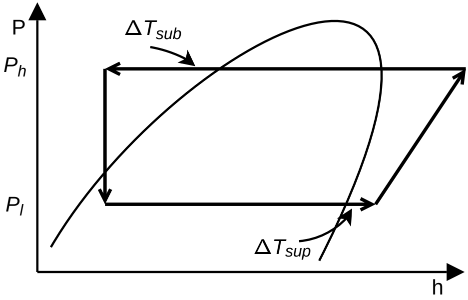
# Introduction

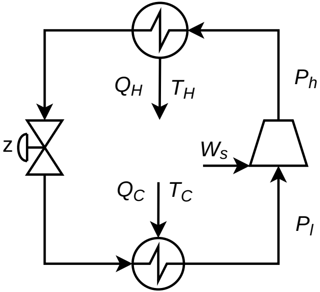
Stoecker, W. F., *Industrial refrigeration handbook*, McGraw-Hill, 1998:

> *The refrigerant leaving industrial refrigeration condensers may be slightly sub-cooled, but sub-cooling is not normally desired since it indicates that some of the heat transfer surface that should be be used for condensation is used for sub-cooling. At the outlet of the evaporator it is crucial for protection of the compressor that there be no liquid, so to be safe it is preferable for the vapor to be slightly super-heated.*

# Specifications in design and operation

| | Given | # |
|---|---|---|
| Design | Load (e.g. $Q_h$), $P_l$, $P_h$, $\Delta T_{sup}$ and $\Delta T_{sub}$ | 5 |
| Operation | $W_s$ (load), choke valve opening (z), $UA$ in two heat exchangers and ? | 5 |



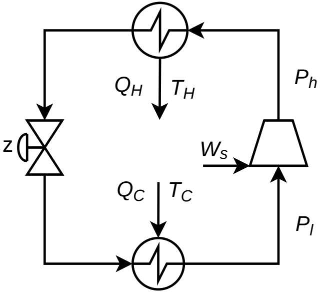



# Specifications in design and operation

| | Given | # |
|---|---|---|
| Design | Load (e.g. $Q_h$), $P_l$, $P_h$, $\Delta T_{sup}$ and $\Delta T_{sub}$ | 5 |
| Operation | $W_s$ (load), choke valve opening (z), $UA$ in two heat exchangers and active charge | 5 |

$$m_{tot} = \underbrace{m_{evap} + m_{con}}_{\text{Active charge}} + m_{tank}$$

Neglect holdup in compressor, valve and piping



# Active charge and holdup tanks

- The “pressure level” is indirectly given by the active charge
- A liquid receiver makes operation independent of total charge
- Liquid level in the receiver has an indirect steady state effect

**Rule 1**

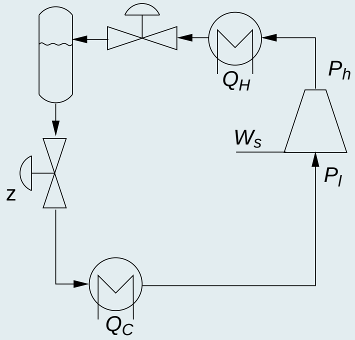
In each closed cycle, there is one degree of freedom related to active charge

**Rule 2**

In each closed cycle, there is one liquid level that does not need to be controlled, because the total mass is fixed.

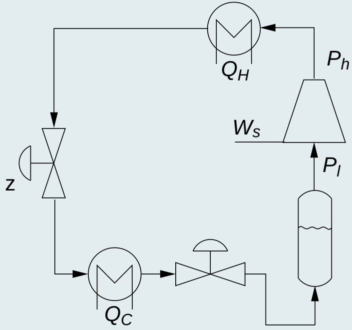
# Adjusting holdup with extra valve

## High pressure receiver




Pressure drop across the extra valve gives sub-cooling

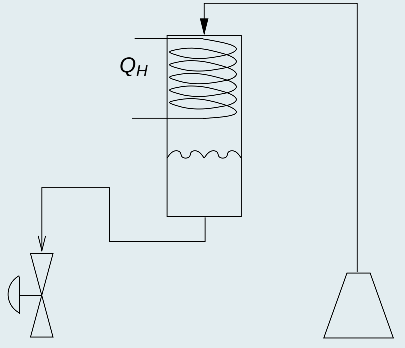
## Low pressure reciever




The extra valve gives sub-optimal operation!

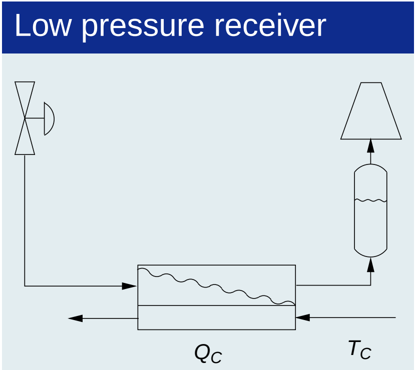
# Extra valves removed

High pressure receiver




- Tank and condenser may be merged together
- Condenser exit will be saturated liquid ($\Delta T_{sub} = 0\,^\circ$C)
- Disadvantage: Some sub-cooling often optimal
- Have used one degree of freedom (“no valve”) to set the degree of sub-cooling to a non-optimal value

# Extra valves removed




- Evaporator exit will be saturated vapour ($\Delta T_{sup} = 0\,^\circ$C)
- Advantage: No super-heating is optimal
- (Some super-heating might be necessary to avoid droplets in the compressor)
- Have used one degree of freedom (“no valve”) to set the degree of super-heating to an optimal value

# Degrees of freedom for operation

During operation the equipment is given. Nevertheless, we have some operational or control degrees of freedom.

1 The compression power $W_s$. We assume that it is used to set the “load” for the cycle

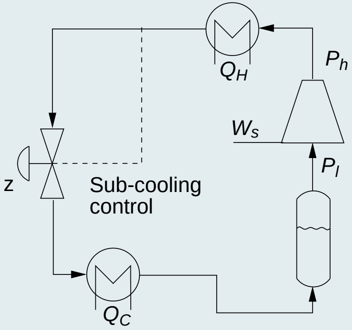
2, 3 Effective heat transfer area (UA). There are two degrees of freedom related to adjusting the heat transfer, which may thought of as adjusting (reducing) the effective UA value in each heat exchanger (i.e. bypasses). However, we generally find that it is optimal to maximize the effective UA.

4 Adjustable choke valve (z)

5 Adjustable active charge

# Optimal designs

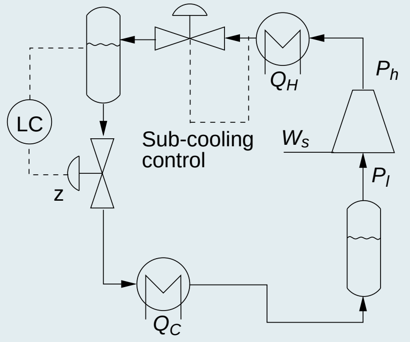
## Optimal 1




- Liquid receiver before compressor minimize super-heating
- Choke valve may be used to control sub-cooling (other control policies also possible)
- Potential problem: Vapour "blow out"

# Optimal designs

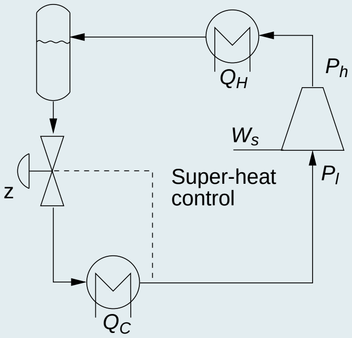
## Optimal 2




- Equivalent thermodynamically
- High pressure receiver prevents vapour “blow out”
- The new valve may control sub-cooling (other control policies also possible)
- Need to control one liquid level according to rule 2

# Non-optimal designs

## Non-optimal 1

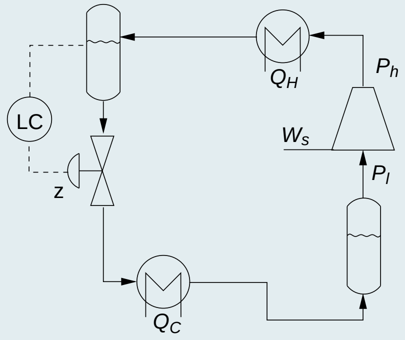



Two errors:

- Super-heating is not optimal. Can be controlled to a given value with a thermostatic expansion valve (TEV)
- There is no sub-cooling

# Non-optimal designs

## Non-optimal 2

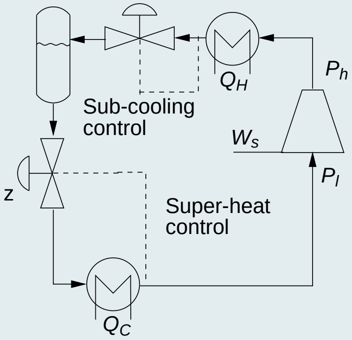



One error:

- There is no sub-cooling

# Non-optimal designs

## Non-optimal 3

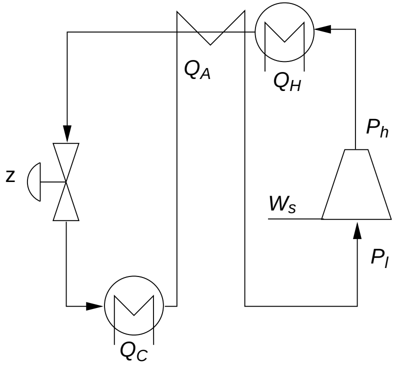



One error:

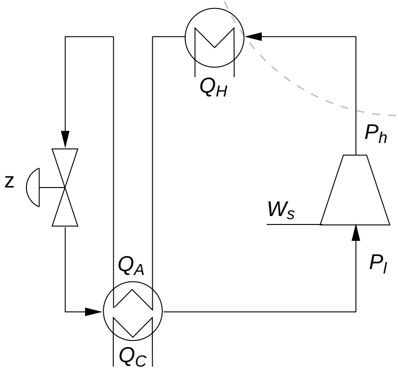
- Super-heating is not optimal

# Internal heat exchanger

**(tanks removed)**




Sometimes beneficial thermodynamically and gives useful super-heating




No effect for pure fluids, but often used for mixed refrigerant systems such as LNG processes

# Conclusion

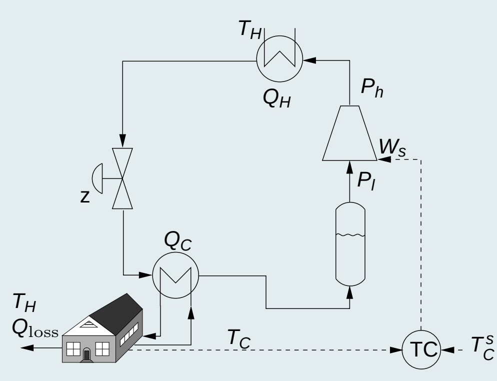
- Variable active charge makes operation independent of total charge of the system
- Variable active charge gives one extra degree of freedom that depending on the design might be available for control
- Optimally; $\Delta T_{sup} = 0\,^\circ$C, but $\Delta T_{sub} \neq 0\,^\circ$C
- There are two degrees of freedom in a simple cooling cycle (given load and max effective UA in the heat exchangers)
- One should be used to minimize the super-heating
- The second should be used for self-optimizing control
- A receiver with no extra valve consumes one dof
  - Optimal before compressor
  - Sub-optimal before choke valve

## Ammonia cooling cycle

- Process description
- Modelling
- Design vs. operation
- Selection of CV's
- Conclusion

# Process description

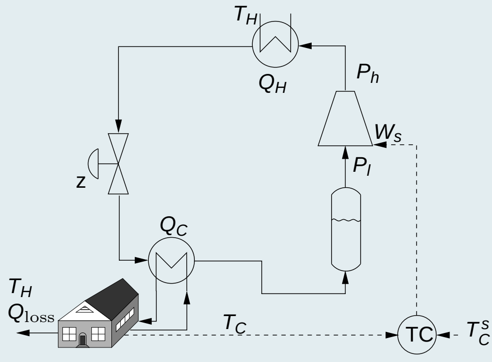
## Ammonia case study




- Four constrained inputs:
  - $W_s$ controls the load (with a temperature controller)
  - Maximum UA: We do not manipulate flow of hot and cold fluid, and have no bypass of heat exchangers
  - Fixed super-heating; $\Delta T_{sup} = 0\,^\circ\mathrm{C}$
- One degree of freedom
  - Choke valve opening z

# Process description

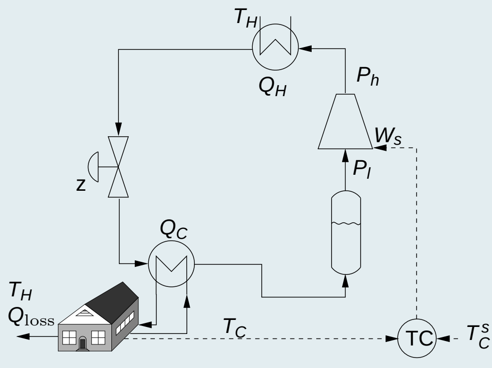
## Ammonia case study




- $T_C = T_{\text{room}}$
- $T_H = T_{\text{amb}}$
- $Q_{\text{loss}} = UA_{\text{loss}} \cdot (T_H - T_C)$
- Temperature control gives $Q_C = Q_{\text{loss}}$

# Modelling

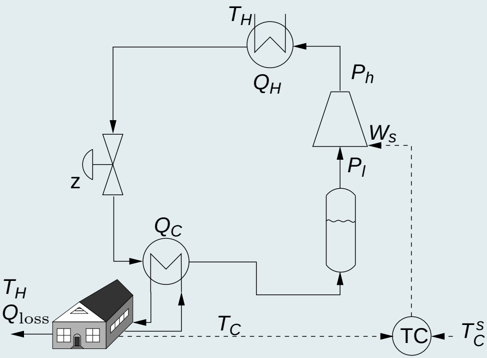
## Ammonia case study




- SRK equation of state
- Cross flow heat exchangers with constant air temperature
- Constant isentropic efficiency (95 %) in compressor
- Molar flow through valve: $\dot{n} = z \cdot C_v \cdot \sqrt{\Delta P \cdot \rho}$

# Design vs. operation

## Ammonia case study




## Design: $\Delta T_{min} = 5\,^{\circ}\mathrm{C}$

$$\min\,(W_s)$$
$$\text{subject to} \quad \Delta T - \Delta T_{min} \geq 0$$

## Operation: $A_{\max} = A_{\text{design}}$

$$\min\,(W_s)$$
$$\text{subject to} \quad A - A_{max} \leq 0$$

# Alternative design method

## Rigorous design

$$\min \left(J_{\text{operation}} + \sum_{i \in \text{Units}} C_{\text{fixed,i}} + \sum_{i \in \text{Units}} C_{\text{variable,i}} \cdot S_i^{n_i}\right)$$

- Consider only size dependent cost ($C_{\text{fixed,i}} = 0$)
- Consider only heat exchanger costs ($C_{\text{variable,i}} = 0$ for $i \notin \text{HX}$)
- Assume $C_{\text{variable,i}} = C_0$ and $n_i = n$
- Fix n (i.e. to 0.65) and use $C_0$ as tuning parameter to achieve rules of thumb (may be given in $\Delta T_{min}$)

## Simplified TAC method

$$\min \left(J_{\text{operation}} + C_0 \cdot \sum_i A_i^n\right)$$

## Ammonia case study

$$\min \left(W_s + C_0 \cdot (A_{con}^{0.65} + A_{vap}^{0.65})\right)$$

| | $\Delta T_{min}$ | | Simplified TAC | | |
|---|---|---|---|---|---|
| | Des. | Oper. | $C_0 = 264$ | 273 | 2650 |
| $\Delta T_{min}^{vap}$ [°C] | **5.00** | 5.00 | 3.79 | 3.86 | 12.89 |
| $\Delta T_{min}^{con}$ [°C] | **5.00** | 0.49 | 0.67 | 0.70 | *5.00* |
| $A_{con}$ [m$^2$] | 8.70 | **8.70** | 7.42 | 7.28 | 2.25 |
| $A_{vap}$ [m$^2$] | 4.00 | **4.00** | 5.28 | 5.18 | 1.55 |
| $A_{tot}$ [m$^2$] | 12.70 | 12.70 | *12.70* | 12.46 | 3.80 |
| Cost [-] | 1.00 | 1.00 | 1.01 | *1.00* | 0.46 |
| $P_l$ [bar] | 2.17 | 2.17 | 2.28 | 2.28 | 1.53 |
| $P_h$ [bar] | 11.63 | 11.68 | 12.00 | 12.05 | 18.93 |
| $\Delta T_{sub}$ [°C] | 0.00 | 4.66 | 5.40 | 5.50 | 17.39 |
| Flow [mol s-1] | 1.039 | 1.017 | 1.016 | 1.017 | 1.052 |
| $W_s$ [kW] | 4648 | 4567 | 4496 | 4518 | 7623 |
| COP [-] | 4.30 | 4.38 | 4.45 | 4.43 | 2.62 |

# Design vs. operation

- The $\Delta T_{min}$ method fail to indicate that sub-cooling is optimal
- Need to re-optimize with given equipment to achieve optimal operation
- The simplified TAC method gives optimal operation directly and correctly gives sub-cooling

# Selection of controlled variables (CV's)

- We have one unconstrained degree of freedom that should be used to optimize operation for all disturbances and operating points
- We could envisage an on-line optimization scheme where one continuously optimizes the operation by adjusting the valve
- Such schemes are quite complex and sensitive to uncertainty, so in practice one uses simpler schemes, where the valve is used to control some other variable
- What should be controlled?
- The objective is to achieve "self-optimizing" control where a constant setpoint for the selected variable indirectly leads to near-optimal operation
- First use a simple screening process where we use a linear model

# Linear method

1. With fixed active constraints, obtain a linear model (G) from the unconstrained inputs (u) to outputs:

$$y = Gu$$

2. Scale the linear model in the inputs such that the effect of all inputs on the objective function is equal.
3. Scale the linear model in the outputs so their expected variety is equal:

$$G' = G/span\ y \qquad \text{where} \qquad span\ y = \Delta y_{opt} + n$$

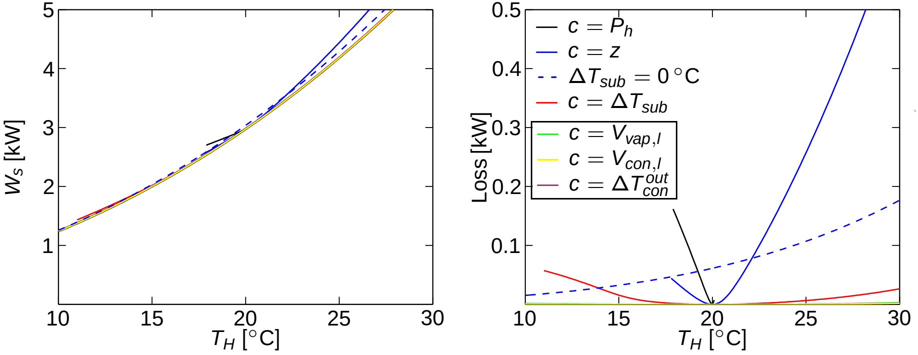
4. We are looking for controlled variables that maximize the minimum singular value of the scaled linear gain matrix.

# Linear method

| | | | | Should be large |
|---|---|---|---|---|
| Variable | $G$ | $\Delta y_{opt}$ | n | $\lvert G' \rvert$ |
| $P_l$ [bar] | 0.00 | 0.623 | 0.300 | 0.00 |
| $T_{com}^{out}$ [°C] | -143.74 | 42.211 | 1 | 3.33 |
| $P_h$ [bar] | -17.39 | 4.166 | 1.00 | 3.37 |
| $z$ [-] | 1 | 0.092236 | 0.05 | 7.03 |
| $T_{con}^{out}$ [°C] | 287.95 | 10.406 | 1 | 25.25 |
| $V_{l,vap}$ [m$^3$] | 5.1455 | 0.014263 | 0.05 | 80.07 |
| $\Delta T_{\rm sub}$ [°C] | -340.78 | 2.6173 | 1.5 | 82.77 |
| $V_{l,con}$ [m$^3$] | -5.7 | 0.0064312 | 0.05 | 101.01 |
| $\Delta T_{con}^{out}$ [°C] | -287.95 | 0.53062 | 1.5 | 141.80 |

# Non-linear analysis of CV's

## Disturbance rejection



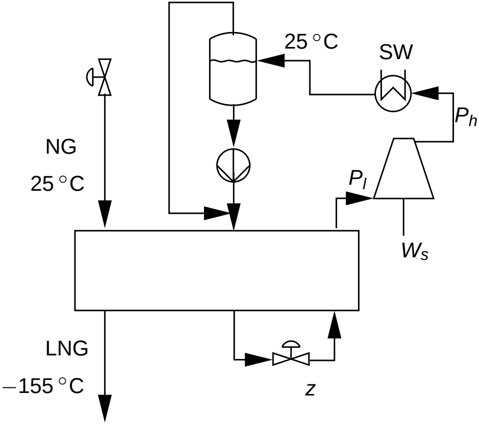
# Conclusion ammonia case example

- The $\Delta T_{min}$ method does not give the true optimum (might lead to the conclusion that sub-cooling is not optimal)
- Optimal operation is with some sub-cooling in the condenser
- Sub-cooling gives a small decoupling between pressure and temperature out of the condenser, which gives one extra degree of freedom related to active charge
- For the ammonia case study we found that no sub-cooling gives a loss in the order of 2 %
- The process has one unconstrained degree of freedom
- Controlling $\Delta T_{con}^{out}$ gives self-optimizing control

PRICO LNG process

- Process description
- Degree of freedom analysis
- Design vs. operation
- Selection of CV's
- Conclusion

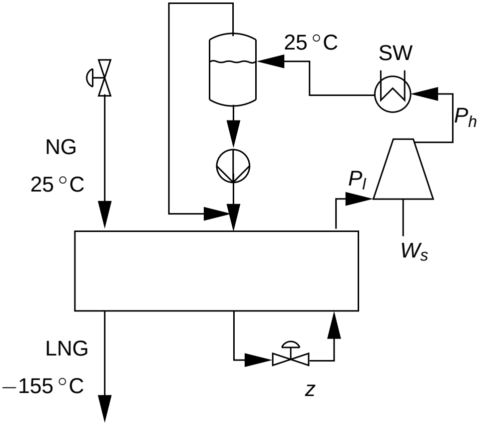
# Process description




## PRICO LNG process

- $P_{NG} = 55\,\mathrm{bar}$
- $\dot{n}_{NG} = 1\,\mathrm{kmol\,s^{-1}}$
- Composition of NG:
  - 89.7 % methane
  - 5.5 % ethane
  - 1.8 % propane
  - 0.1 % n-butane
  - 2.8 % nitrogen
- Refrigerant is a mix of $C_1$, $C_2$, $C_3$, $n - C_4$ and $N_2$

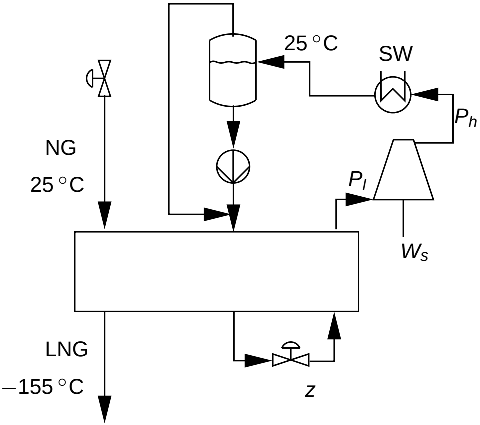
# Process description




## Steady state model

- SRK equation of state
- Compressor $\eta = 0.80$
- Constant heat transfer coefficient
- Main heat exchanger distributed in 100 points
- Constant pressure drops
  - 5 bar in NG stream
  - 0.1 bar in SW cooler
  - 4 bar for hot ref.
  - 1 bar for cold ref.

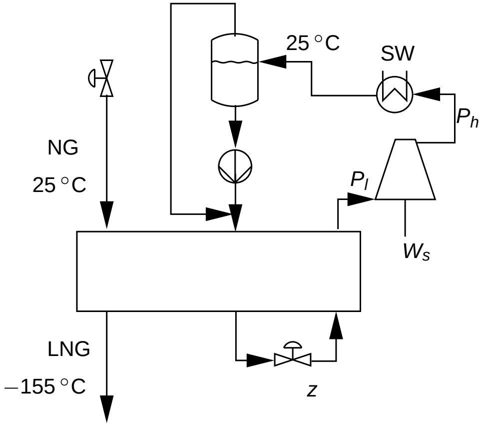
# Operation: Degree of freedom analysis




## 9 manipulated inputs

- Compressor power $W_s$
- Choke valve opening $z$
- Active charge (liquid pump)
- Flow of sea water (SW)
- Flow of natural gas
- Four refrigerant compositions (5-1)

# Degree of freedom analysis



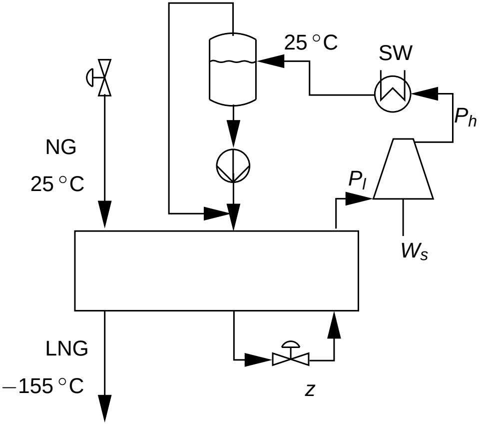

## 2 active constraints

- $\Delta T_{sup} = 10\,^\circ\mathrm{C}$
- $T_{LNG} = -155\,^\circ\mathrm{C}$

## 2 given variables

- Flow of natural gas
- Maximum cooling, assume $T = 25\,^\circ\mathrm{C}$ after SW cooler

# Degree of freedom analysis




## 5 degrees of freedom

- Four refrigerant compositions
- For example $P_h$

## Assume constant compositions

- 1 dof during operation

# Design vs. operation

## Design with given $\Delta T_{min}$

$$\min(W_s)$$
$$\text{subject to} \quad \Delta T - \Delta T_{\min} \geq 0$$

## Operation (given equipment)

$$\min(W_s)$$
$$\text{subject to} \quad A_{\max} - A \geq 0$$

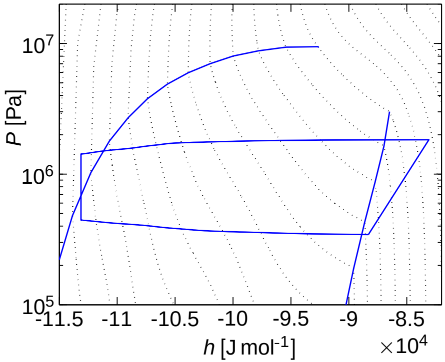
## Simplified TAC design

$$\min(W_s + C_0 \cdot \sum_i (A_i^n))$$

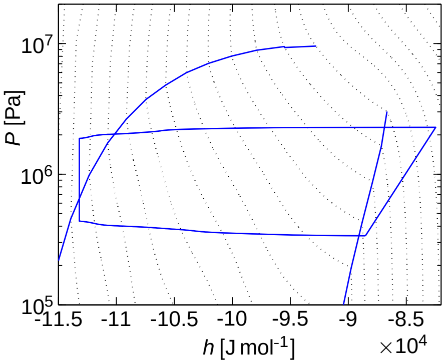
| | $\Delta T_{min}$ | | Simplified TAC | | |
|---|---|---|---|---|---|
| | Des. | Oper. | $C_0 = 21052$ | 20650 | 62500 |
| $\Delta T_{min}^{HOT}$ [°C] | **1.20** | 0.46 | 0.62 | 0.45 | *1.20* |
| $\Delta T_{min}^{NG}$ [°C] | **1.20** | 0.55 | 0.46 | 0.61 | 1.44 |
| $A_{HOT}$ [m$^2$] | 1683 | **1683** | 1722 | 1743 | 765 |
| $A_{NG}$ [m$^2$] | 428 | **428** | 389 | 394 | 220 |
| $A_{Tot}$ [m$^2$] | 2111 | 2111 | *2111* | 2137 | 985 |
| Cost [-] | 1.00 | 1.00 | 0.99 | *1.00* | 0.61 |
| $P_h$ [bar] | 18.32 | 22.86 | 22.62 | 22.54 | 29.77 |
| $P_l$ [bar] | 3.44 | 3.37 | 3.34 | 3.35 | 2.60 |
| $\dot{n}$ [kmol s$^{-1}$] | 3.31 | 2.76 | 2.77 | 2.77 | 2.44 |
| $\mathbf{W_s}$ [MW] | 17.31 | 16.74 | 16.76 | 16.73 | 19.18 |

# Design vs. operation

## Design

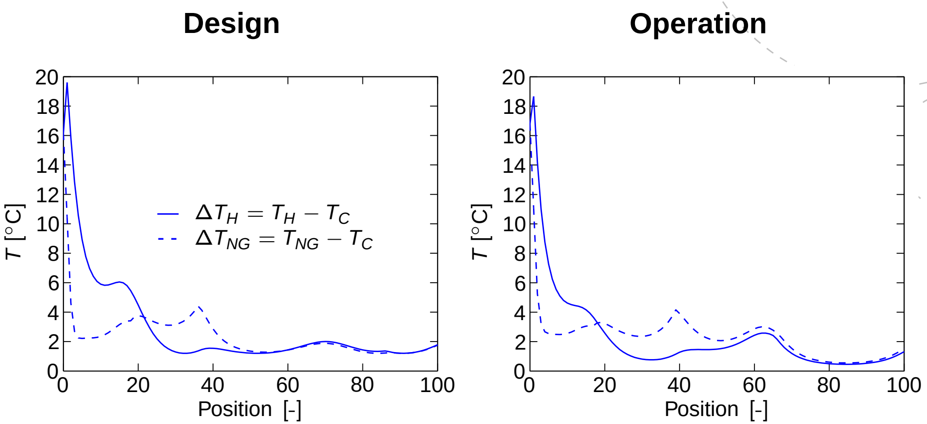



## Operation




Note: Different composition

# Design vs. operation



# Selection of CV's: Linear analysis

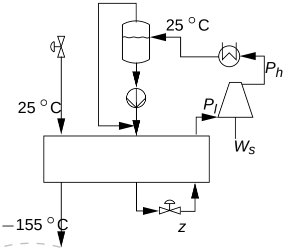
| CV | G | n | $\Delta y_{opt}$ | $\lvert G' \rvert \cdot 1e7$ |
|---|---|---|---|---|
| $\Delta T_{sub}$ [°C] | -2.30e-5 | 1.5 | 41.3 | 5.44 |
| $T_H(13)$ [°C] | -2.11e-5 | 1 | 55.0 | 3.76 |
| $T_C(11)$ [°C] | -1.78e-5 | 1 | 48.3 | 3.62 |
| $T_{NG}(12)$ [°C] | -1.75e-5 | 1 | 48.7 | 3.53 |
| $\Delta T_H(40)$ [°C] | 8.24e-6 | 1.5 | 24.6 | 3.16 |
| $\Delta T_H(22)$ [°C] | -3.38e-6 | 1.5 | 10.3 | 2.87 |
| $T_{com}^{out}$ [°C] | 2.88e-5 | 1 | 104.2 | 2.74 |
| $P_h$ [Pa] | 1 | 1e5 | 37.69e5 | 2.58 |
| $P_l$ [Pa] | -0.04 | 0.5e5 | 5.57e5 | 0.66 |

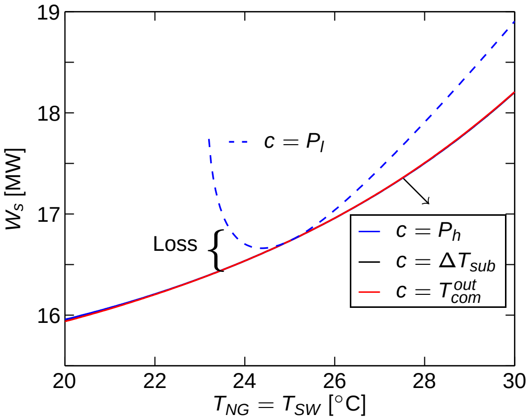
Loss $\propto (1/G')^2$

# Selection of CV's: Non-linear analysis

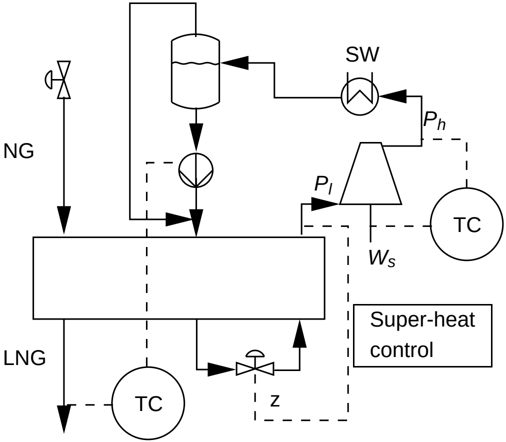
## Max. losses

- $P_h$: 2.98 %
- $T_{com}^{out}$: 1.14 %
- $\Delta T_{sub}$: 0.78 %



# Selection of CV's: Structure




## Control AC

- $\Delta T_{sup} = 10\,°C$
- $T_{LNG} = -155\,°C$

## Control

- $T^{out}_{com} = 114\,°C$

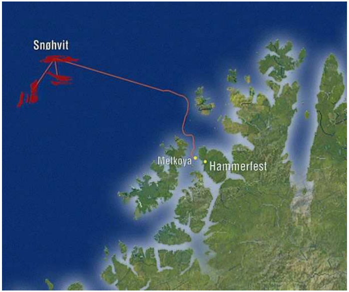
# Conclusion

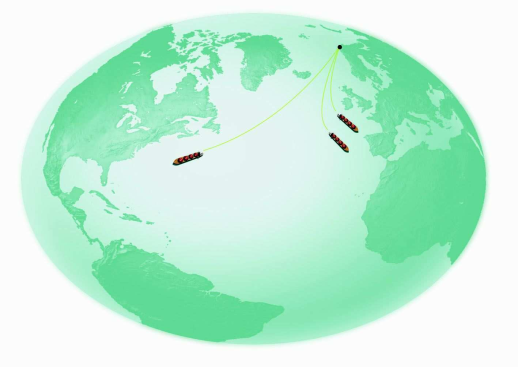
- We have found an operating point that is better than what has been reported previously
- The method of specifying $\Delta T_{min}$ in design does not give the true optimum
- We found that there are one unconstrained degree of freedom (in addition to composition)
- Controlling either the degree of sub-cooling ($\Delta T_{sub}$) or the compressor outlet temperature ($T_{com}^{out}$) gives good steady state performance

## MFC LNG process

- Snøhvit
- Process description
- Degree of freedom analysis
- Optimization results
- Control structure
- Conclusion

# Snøhvit

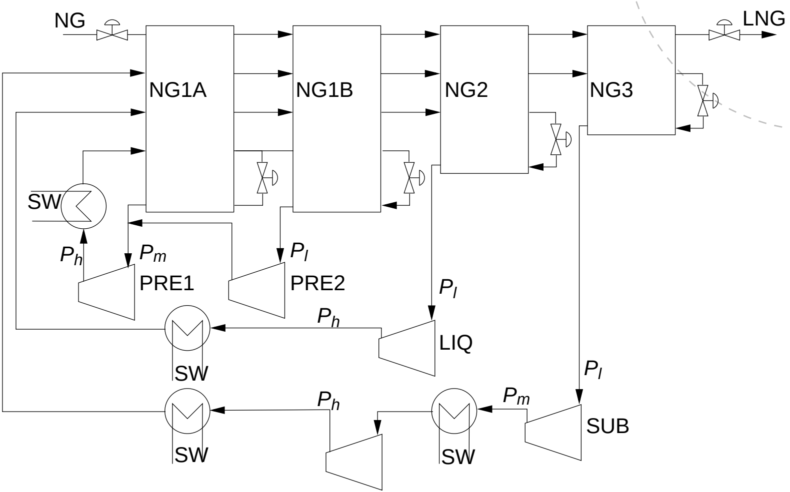


Figures from Statoil*

* www.statoil.com/snohvit

# MFC process: Flowsheet



# Nominal conditions:

- Feed: NG enters with P=61.5 bar and T=11$^\circ C$ after pretreatment. The composition is: 88.8% methane, 5.7% ethane, 2.75% propane and 2.75% nitrogen. Nominal flow rate is 1 kmol/s
- Product: LNG is at P=55.1 bar and T=-155$^\circ C$
- The refrigerants are a mix of nitrogen ($N_2$), methane ($C_1$), ethane ($C_2$) and propane ($C_3$) and the compositions are used in optimization.
- The refrigerant vapour to the compressors are super-heated 10$^\circ C$
- The refrigerants are cooled to 11$^\circ C$ in all sea water (SW) coolers (assumed maximum cooling)

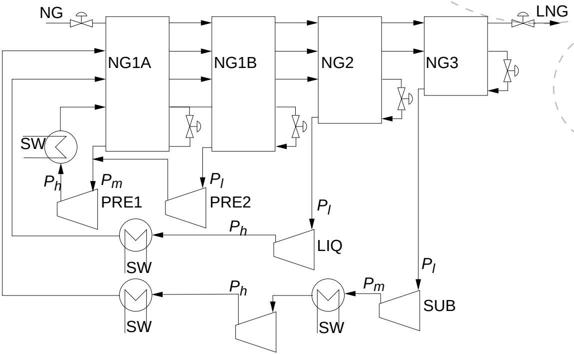
# Nominal conditions:

- Pressure drops are 0.5 bar in SW coolers, 0.5 bar for hot flows in main heat exchangers and 0.2 bar for cold refrigerant in main heat exchangers
- The SRK equation of state is used both for NG and the refrigerants
- The heat exchangers are distributed models with constant heat transfer coefficients
- The compressors are isentropic with 90% constant efficiencies

# Degree of freedom analysis

In total 26 manipulated variables (degrees of freedom):

- 5 Compressor powers $W_{s,i}$
- 4 Choke valve openings $z_i$
- 4 SW flows in coolers
- 1 NG flow
- 9 Composition
- 3 active charges



# Constraints during operation

There are some constraints that must be satisfied during operation:

- Super-heating: The vapour entering the compressors must be $\geq 10^{\circ}C$ super-heated
- $T_{LNG}^{out}$: NG Temperature out of NG3 must be $\leq$-155$^{\circ}C$ or colder
- Pressure: 2 bar$\geq$ P $\leq$60 bar
- NG temperature after NG1A and NG1B (not considered in this paper)
- Compressor outlet temperature (not considered in this paper)

# Active constraints

We are able to identify some constraints that will be active at optimum. In total there are 12 active constraints:

- 4 Super-heatings to be minimized, that is $\Delta T_{sup,i}$=10$^\circ C$ at 4 locations
- Excess cooling is costly so $T_{LNG}^{out}$=-155$^\circ C$
- Optimal with low pressure in cycles so $P_l$=2 bar (for all 3 cycles)
- Maximum cooling: Assume T=11$^\circ C$ at 4 locations

# Unconstrained degrees of freedom

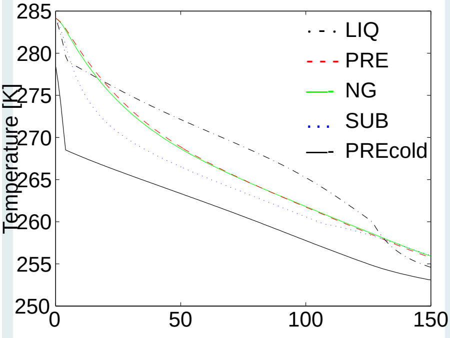
After using 12 of the 26 manipulated inputs to satisfy active constraints, we are left with 14 MV's. We consider NG flow given, so we have 13 unconstrained degrees of freedom:

- 3 NG temperatures (after NG1A, NG1B and NG2)
- $P_m$ in SUB
- 9 Refrigerant compositions

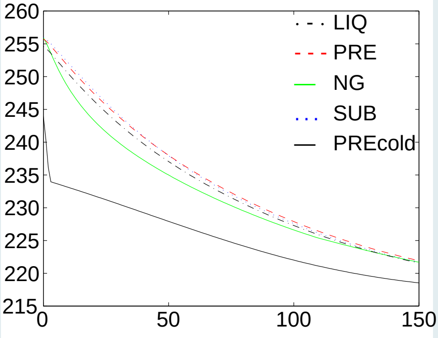
We will not consider manipulating refrigerant composition in operation (only in the optimization), so of the 13 unconstrained degrees of freedom we are left with 4 during operation.

# Optimization results

## NG1A

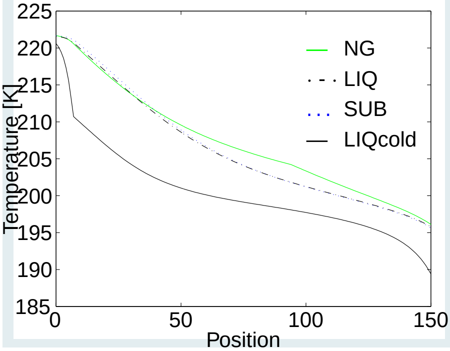



## NG1B

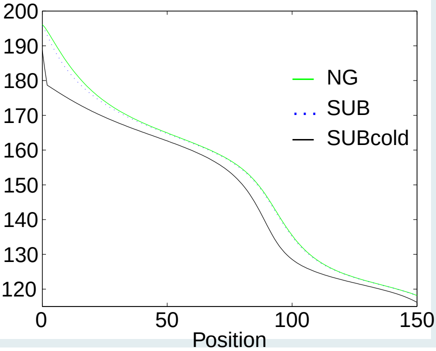


# Optimization results

## NG2




## NG3



# Optimization results

| | | PRE1 | PRE2 | LIQ | SUB |
|---|---|---|---|---|---|
| $P_l$ | [Pa] | 6.45 | 2.00 | 2.00 | 2.00 |
| $P_m$ | [Pa] | | 6.45 | - | 28.38 |
| $P_h$ | [Pa] | 15.03 | 15.03 | 20.58 | 56.99 |
| $C_1$ | [%] | 0.00 | 0.00 | 4.02 | 52.99 |
| $C_2$ | [%] | 37.70 | 37.70 | 82.96 | 42.45 |
| $C_3$ | [%] | 62.30 | 62.30 | 13.02 | 0.00 |
| $N_2$ | [%] | 0.00 | 0.00 | 0.00 | 4.55 |
| Flow | [mol/s] | 464 | 685 | 390 | 627 |
| $W_s$ | [MW] | 1.2565 + 2.644 | | 2.128 | 3.780+1.086 |

# Optimization results

- The total shaft work is 10.896 MW
- The optimal NG temperature out of NG1A, NG1B and NG2 is 255.9 K, 221.7 K and 196.1 K, respectively
- In the true design there will separators at the high pressure side of the cycles, which has not been considered here
- In SUB cycle the pressure ratios over the two compressor stages are far from equal. This is because the inlet temperature to the first stage (approximately -80$^\circ C$) is much lower than inlet temperature to the second stage (11$^\circ C$)
- Nitrogen is present in SUB only to satisfy the minimum pressure of 2 bar

# Implemented optimum in practice

First we need to control the active constraints:

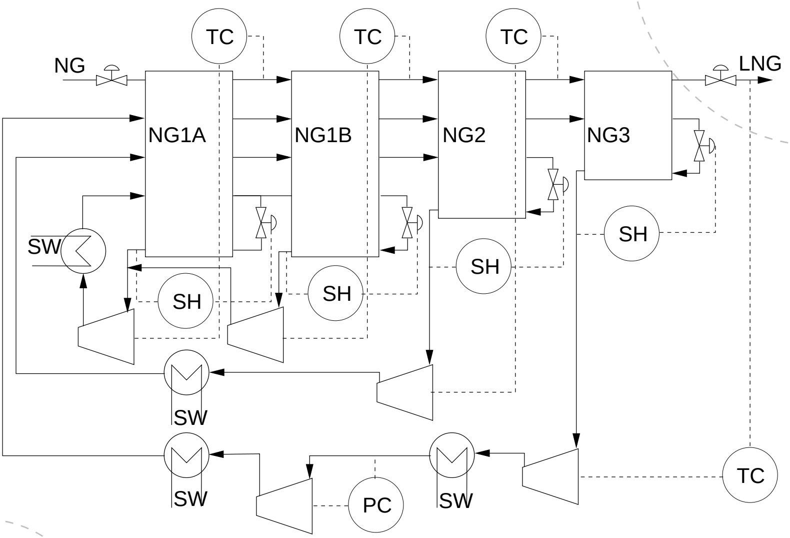
- Degree of super-heating (4 locations): For this we may use the corresponding choke valve opening
- $P_l$ is for each of the 3 cycles: For this we may use “active charge” (see discussion above)
- Maximum cooling in 4 SW coolers: SW flow at maximum
- LNG outlet temperature at -155$^\circ C$: May use first compressor stage in SUB

# Implemented optimum in practice

Now the unconstrained degrees of freedom:

- $T^{out}_{NG1A}$: May use first compressor stage in PRE
- $T^{out}_{NG1B}$: May use second compressor stage in PRE
- $T^{out}_{NG2}$: May use compressor in LIQ
- $P_m$ in SUB: May use second compressor stage in SUB

# Control structure



# Conclucion

- The MFC LNG process has at most four unconstrained degrees of freedom (without composition control)
- We have a working model of the MFC process

Concluding remarks

- Conclusion
- Further work
- References

# Conclusion

- We started with very simple cooling processes to understand the basics and found some interesting results
  - Sub-cooling is often optimal
  - The $\Delta T_{min}$ method is unreliable
  - Active charge might be used for control
- Have worked our way to the PRICO LNG process
  - Have optimized the process
  - Have studied control by using self-optimizing control
- Are now looking at more complex processes (MFC etc.)

# Further work

- Publish the work on the simple cooling cycles
- Finnish and publish the work on the PRICO LNG process
- Study control of the MFC LNG process
- Study other LNG processes?
- Work with Linde on the MFC process?
- Compare different LNG processes with the same conditions (how large differences are there?)
- Write the thesis!

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