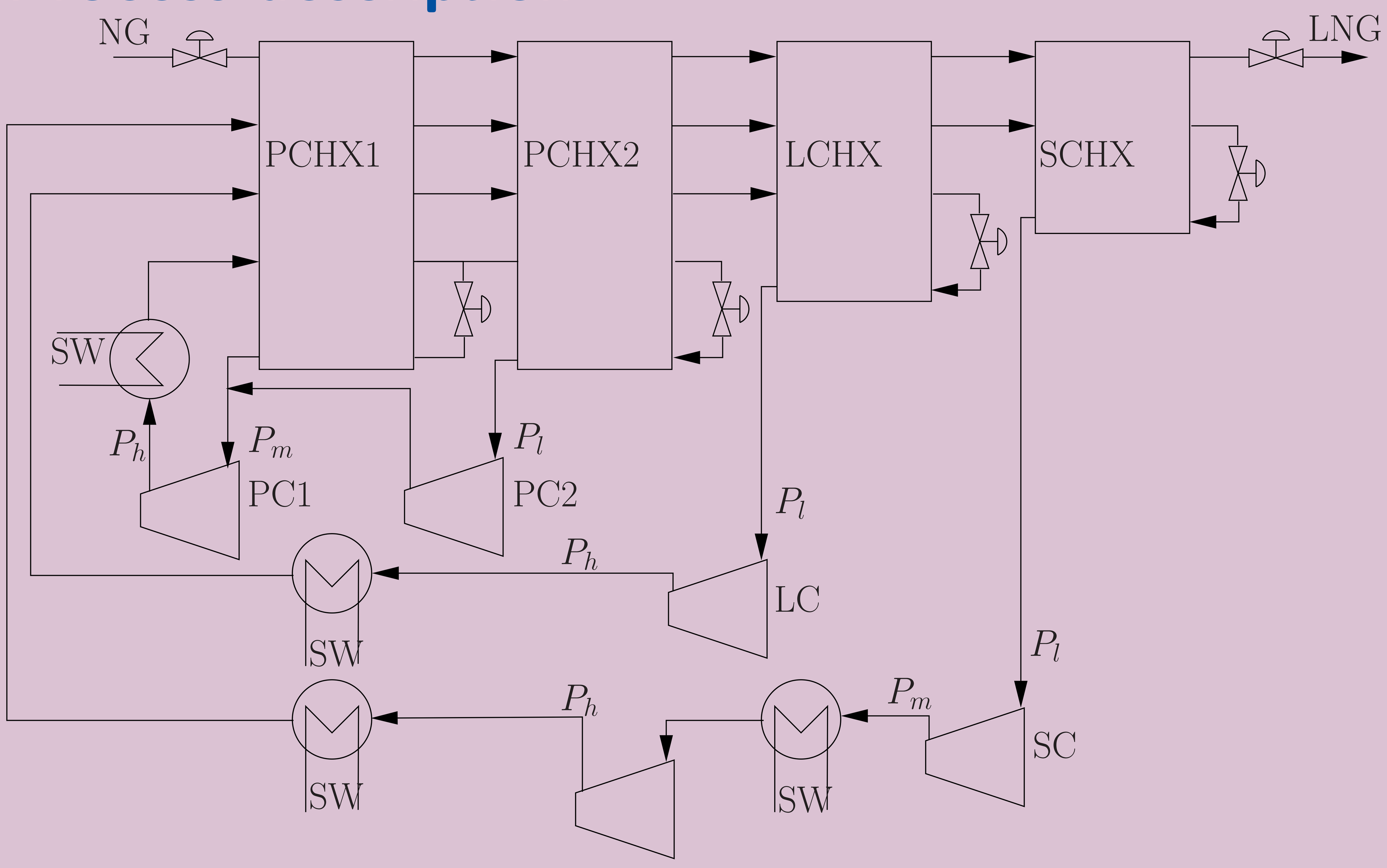
Optimal operation of a mixed fluid cascade LNG process

Jørgen Bauck Jensen & Sigurd Skogestad*
Deparment of Chemical Engineering, NTNU Trondheim Norway

Introduction

Large amounts of natural gas (NG) are found at locations that makes it infeasible or not economical to transport it in gaseous state (in pipelines or as compressed NG) to the customers. The most economic way of transporting NG over long distances is to first produce liquefied natural gas (LNG) and then transport the LNG by ships. At atmospheric pressure LNG has approximately 600 times the density of gaseous NG and a temperature of approximately $-162\,°C$. The process of cooling and condensing the NG requires large amounts of energy.

Process description



NG feed stream

$\dot{n} = 1.0\,\text{kmol s}^{-1}$

$T_{in} = 11\,°C$	Methane: 88.8 %	Ethane: 5.7 %
$P_{in} = 61.5$ bar	Propane: 2.75 %	Nitrogen: 2.75 %

26 Manipulated variables

- 5 Compressor powers $W_{s,i}$
- 4 Choke valve openings z_i
- 4 SW flows in coolers
- 1 NG flow (can also be considered a disturbance)
- 9 Composition of three refrigerants
- 3 active charges (one for each cycle)

12 Active constraints

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

14 Unconstrained degrees of freedom

- 3 NG temperatures (after PCHX1, PCHX2 and LCHX)
- P_m in SC
- 9 Refrigerant compositions
- Feedrate (assume given)

Optimization results for the four cycles

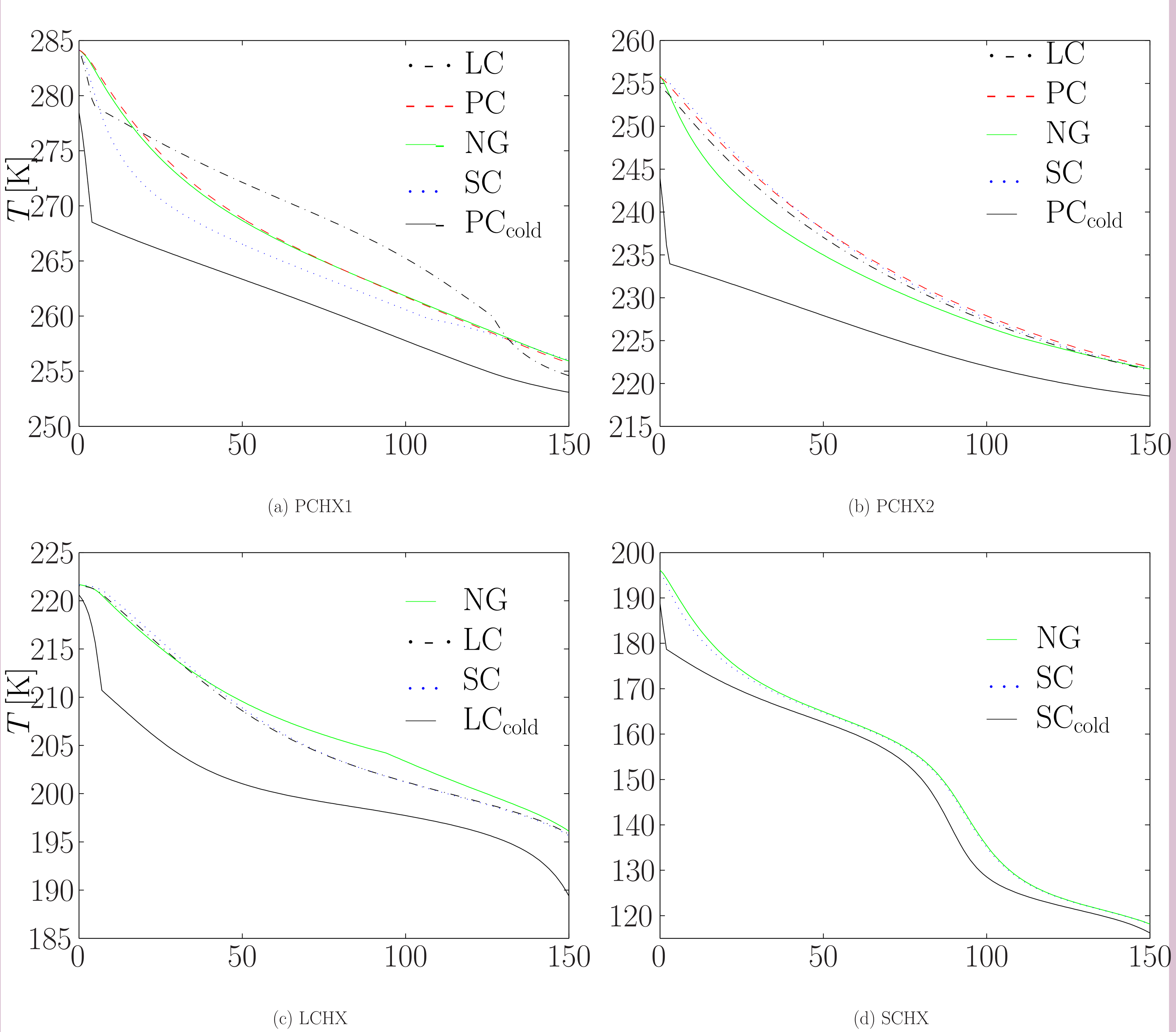
Cycles

	PC1	PC2	LC	SC
P_l [bar]	6.45	2.00	2.00	2.00
P_m [bar]		6.45	-	28.38
P_h [bar]	15.03	15.03	20.58	56.99
$\dot{n}$ [mol s^{-1}]	464	685	390	627
W_s [MW]	1.2565	2.644	2.128	3.780+1.086
Optimal composition of refrigerant				
Methane [%]	0.00	0.00	4.02	52.99
Ethane [%]	37.70	37.70	82.96	42.45
Propane [%]	62.30	62.30	13.02	0.00
Nitrogen [%]	0.00	0.00	0.00	4.55

- The total shaft work is 10.9 MW
- Optimally the temperatures at heat exchanger outlets are:

PCHX1: $-17.3\,°C$
PCHX2: $-51.5\,°C$
LCHX: $-77.1\,°C$

Temperature profiles



(a) PCHX1 (b) PCHX2 (c) LCHX (d) SCHX

Implementation

1. Feed and composition of refrigerants assumed given
2. Control 12 active constraints:
   - Super-heating before 4 compressors
   - LNG outlet temperature
   - Low pressure in all cycles
   - Maximum cooling with sea water
3. Control 4 "self-optimizing" variables:
   - Future work will focus on this

Acknowledgements

This work has been done as part of the The Gas Technology Center, NTNU-SINTEF. Funding from the Norwegian Research Council is gratefully acknowledged.

*skoge@chemeng.ntnu.no