Modelling of multistream heat exchanger for natural gas liquefaction

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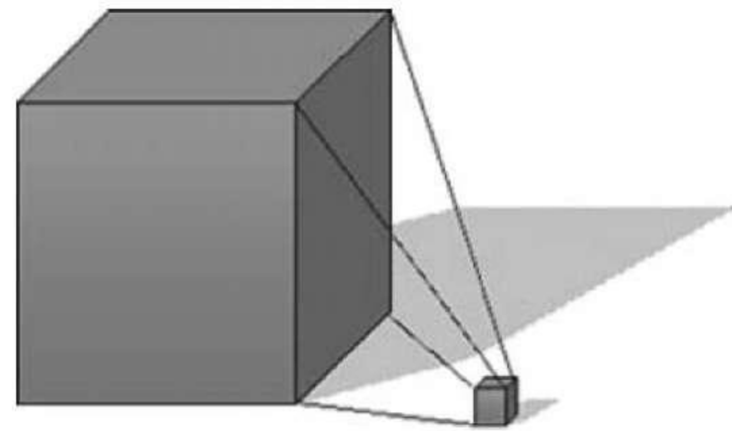
Introduction

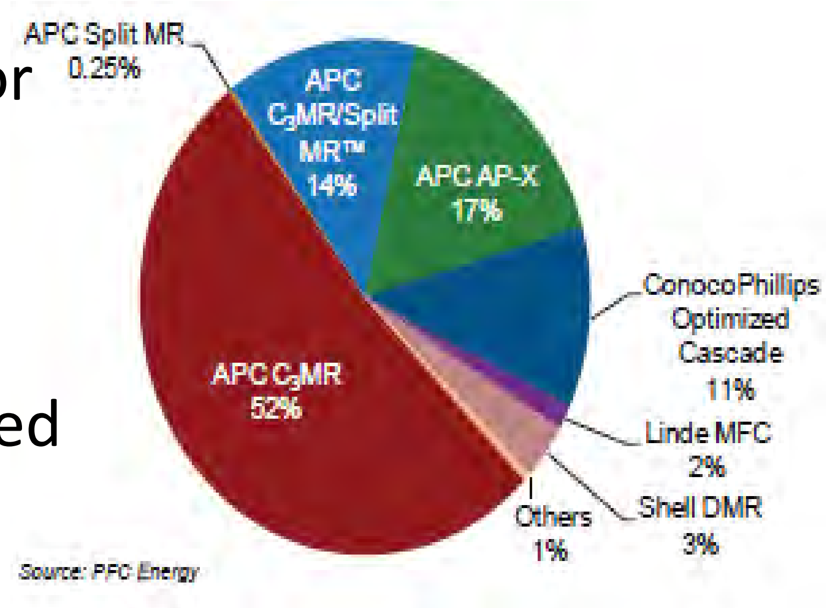
- "green" energy source, with market in expansion.
- Necessity to reduce transported volumes.
- LNG cost distribution.



NG Production	NG Purification/ Liquefaction → LNG	LNG Transportation	LNG Regasification
15-20%	30-45%	10-30%	15-25%

Why modelling LNG HX

- HX is the core equipment in the major LNG processes.



- Intellectual property are highly guarded and not freely accessible.

- Need of the LNG producer to become more **independent** from equipment supplier.

Why modelling LNG HX

- Traditional sizing tecnique are not applicable:
  - Complex geometry
  - Extreme operative conditionsT→ -160 : 30 °C

    P → 1 : 70 bar
  - High efficiency of LNG heat exchanger ($\varepsilon = \dfrac{c_{p,in}\left(T_{C,out} - T_{C,in}\right)}{c_{p,\min}\left(T_{H,in} - T_{C,in}\right)}$ > 90%)

Thesis objectives

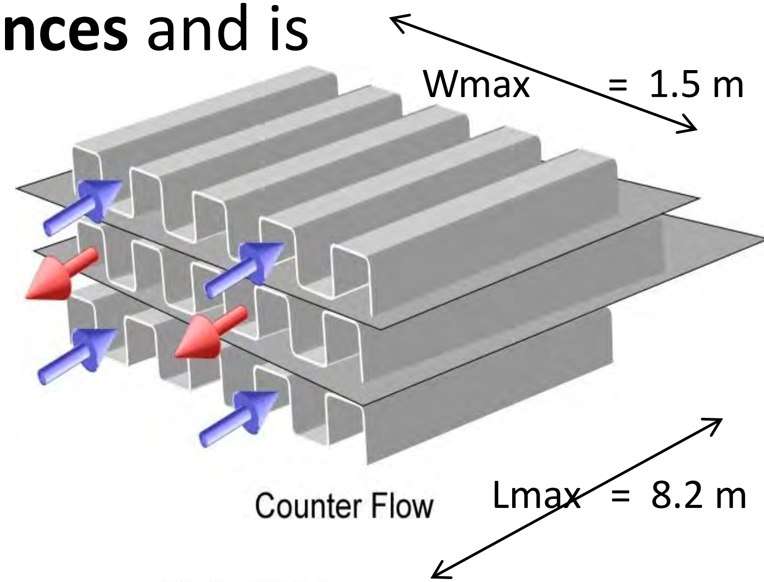
- Development of a model for NG liquefaction HX:
  - Plate and Fin Heat Exchanger (PFHX);
  - Coil Wound Heat Exchanger (CWHX);

MAX: 1.5m·3.0m·8.2m

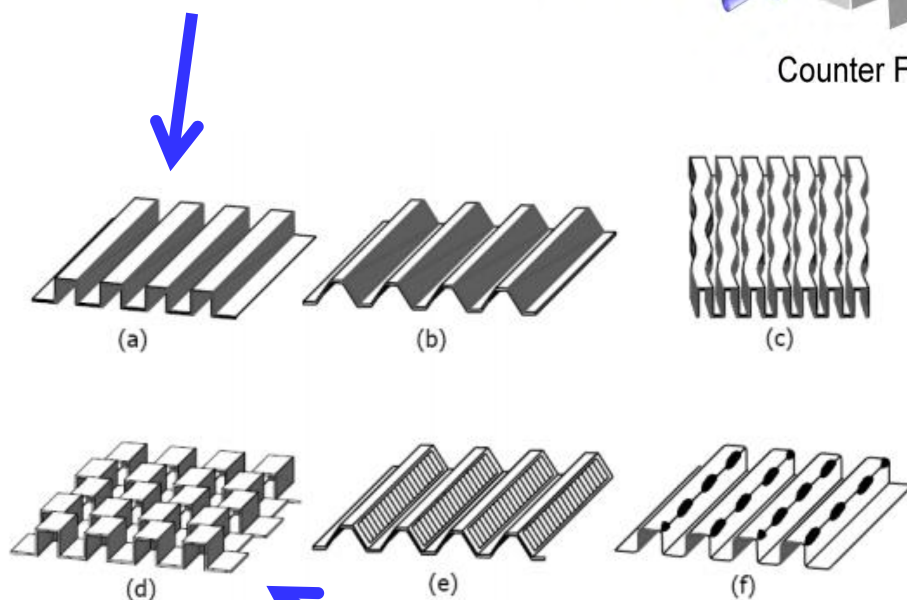
Diameter ~5m
Length ~40m

Plate and Fin Heat Exchanger (PFHX)

- Main features: achieves **high performances** and is extremely **compact**
- Flow configurations:
  - Co-current
  - **Counter-current**
  - Cross-flow



- Fin types:
  - Plain fins (a)
  - Louvered fins(e)
  - Wavy fins (c)
  - Offset/Strip fins (d)



Types of plate fin surfaces: (a) plain rectangular (b) plain trapezoidal (c) wavy (d) serrated or offset strip fin (e) louvered (f) perforated

Model structure

Model structure objectives

- Development of a general and flexible architecture able to simulate a wide range of operative conditions and designs.

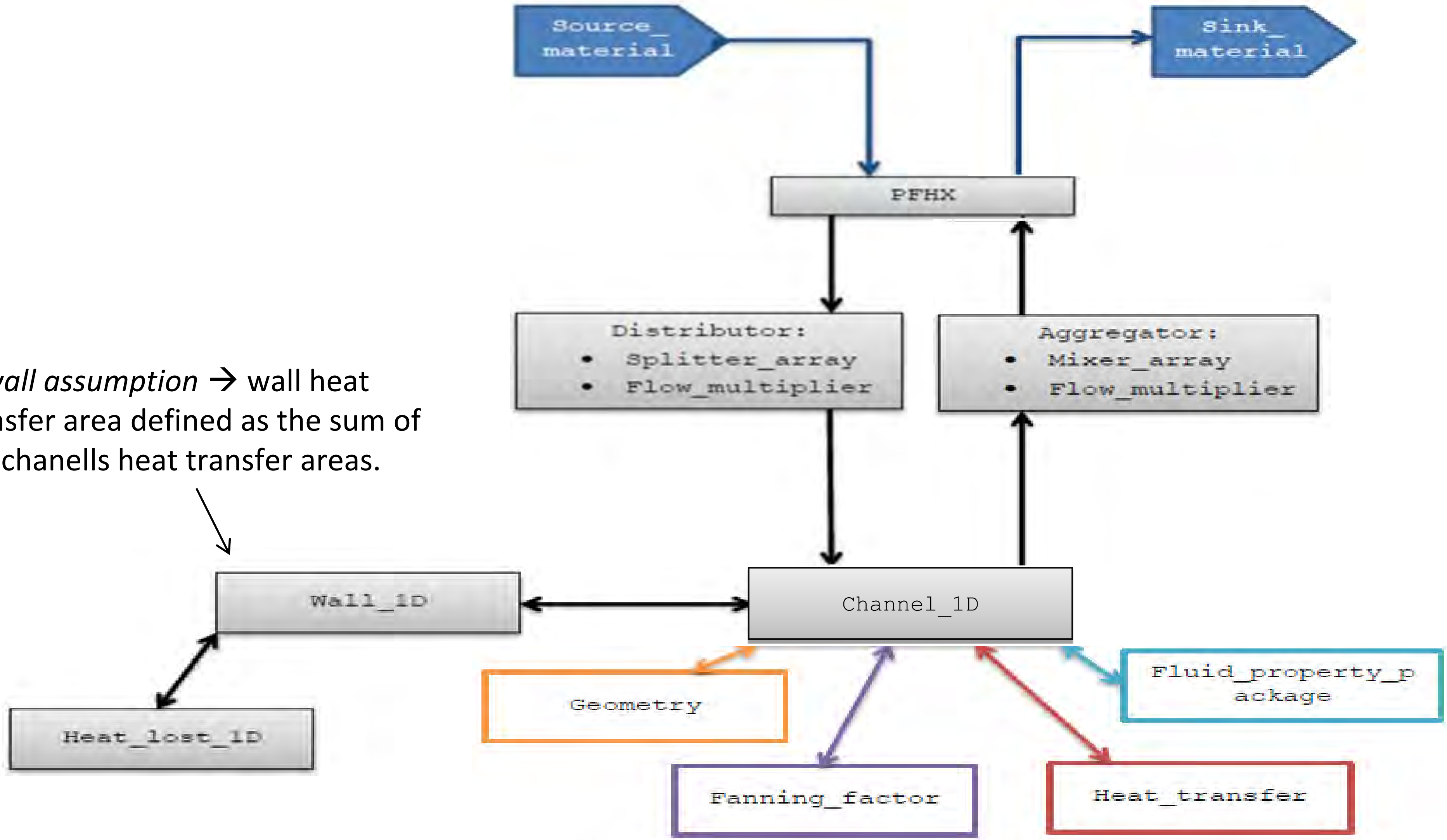
↓

- Development of a model usable by the costumer for the simulation of his LNG HX.

- The model should consider:
  - Specific geometry of the fins,
  - Changes in fluid properties,
  - Variable htc and Fanning factor.

Model structure

Single wall assumption → wall heat transfer area defined as the sum of the chanells heat transfer areas.



PFHX sub-models: offset fins

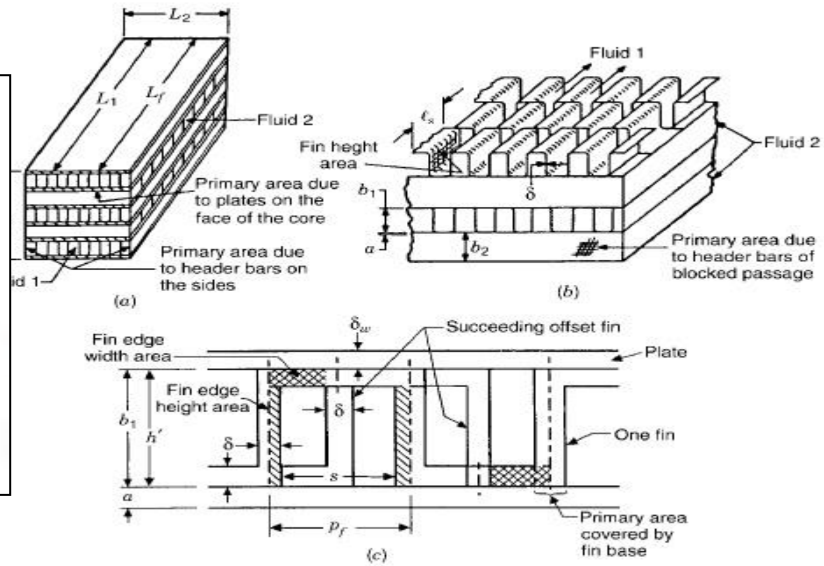
Shah and Sekulic, Fundamentals of Heat Exchanger Design, 2003

- **Geometry model**

$$A_{frontal} = L_1 \cdot L_2$$

$$A_{cross.ch} = h \cdot L_2 - (h-t) \cdot t$$

$$A_{surface,ch} = 2 \cdot L_2 L_1 - 2 \cdot t \cdot L_1 + 2 \cdot h \cdot L_2 + 2(h+2t) \cdot L_2 + 2(h-t) \cdot L_1 + 2(h-2t) \cdot t \cdot n_{offsetstrips} + (s+t)t \cdot (n_{offsetstrips} - 1) + 2(s+t)t$$



- **HTC model**

$$j(z) = 0.6522 \, \mathrm{Re}(z)^{-0.5403} \left(\frac{s}{h}\right)^{-0.1541} \left(\frac{t}{l_f}\right)^{0.1499} \left(\frac{t}{s}\right)^{-0.366} \cdot \left[1 + 5.269 \cdot 10^{-5} \, \mathrm{Re}(z)^{1.34} \left(\frac{s}{h}\right)^{0.504} \left(\frac{t}{l_f}\right)^{0.456} \left(\frac{t}{s}\right)^{-1.055}\right]^{0.1}$$

- **Fanning factor model**

$$f(z) = 9.6243 \, \mathrm{Re}(z)^{-0.7433} \left(\frac{s}{h-t}\right)^{-0.1856} \left(\frac{t}{l_f}\right)^{0.3053} \left(\frac{t}{s}\right)^{-0.2659} \left[1 + 7.66 \cdot 10^{-8} \, \mathrm{Re}(z)^{4.429} \left(\frac{s}{h-t}\right)^{0.92} \left(\frac{t}{l_f}\right)^{3.767} \left(\frac{t}{s}\right)^{0.236}\right]^{0.1}$$

PFHX offset fins: CASE STUDY

- Operative conditions.

	NG	MR vapour	MR liquid
Flowrate [kg/s]	118	200	400
Temperature [K]	305	305	167
Pressure [bar]	66.5	38.6	9.8

PFHX offset fins: CASE STUDY II

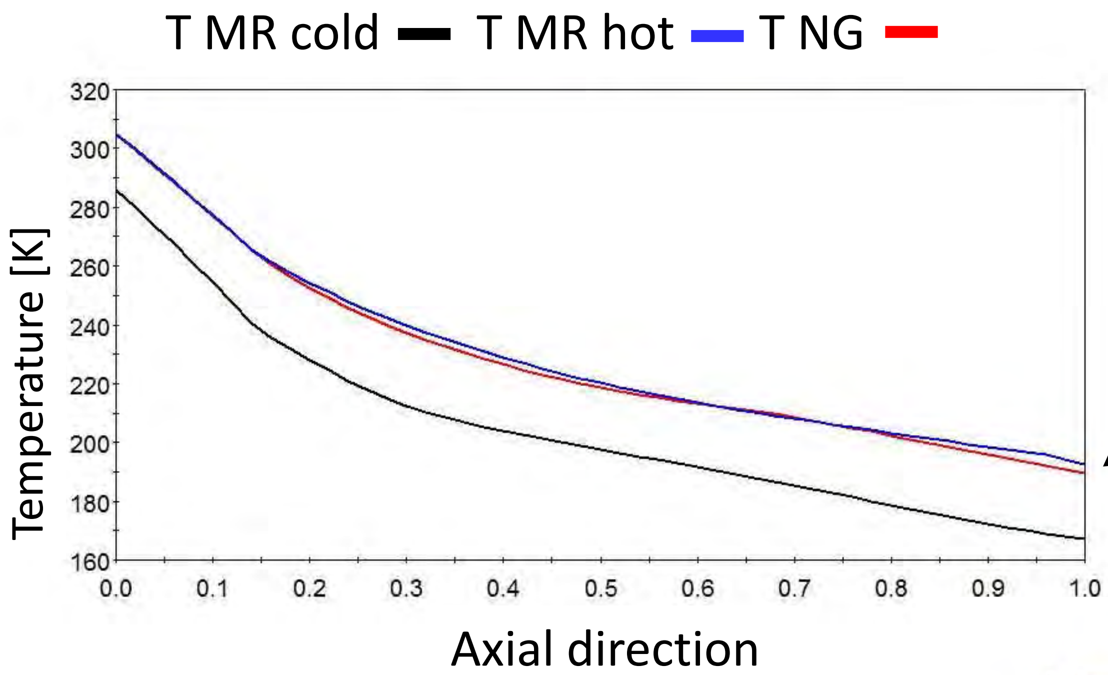
- Design

Tab: Design Hot streams

Number of channels per stream	150 NG 700 MR	
Operation mode	Co-current	

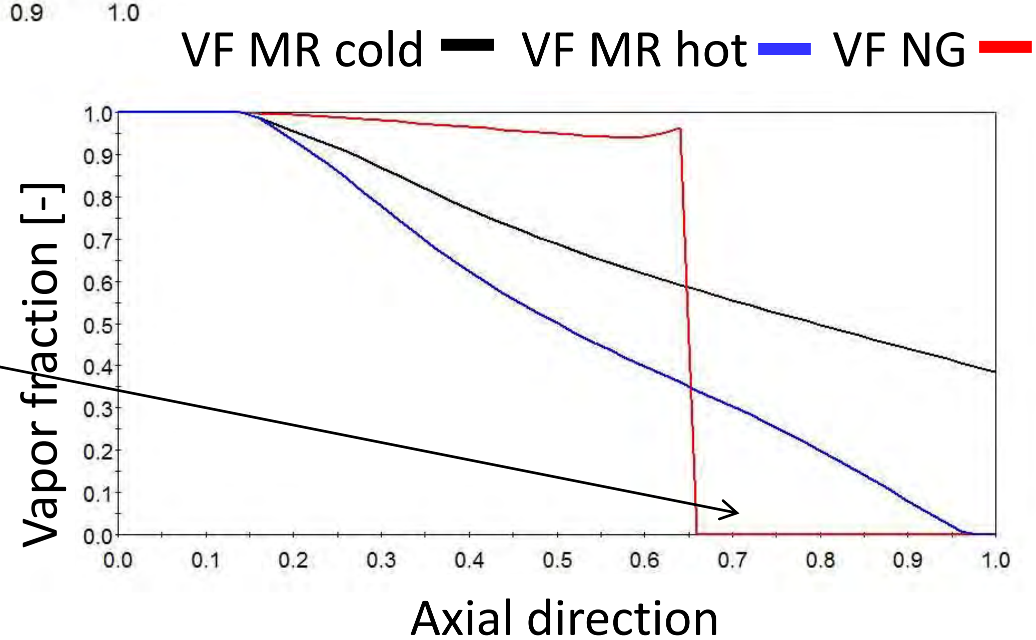
Plate flow length	5	[m]
Plate width	1.5	[m]
Spacing between plates	0.665	[mm]
Spacing between fins	5	[mm]
Hydraulic radius	0.143	[mm]
Fin thickness	0.0254	[mm]

PFHX offset fins: results T, VF

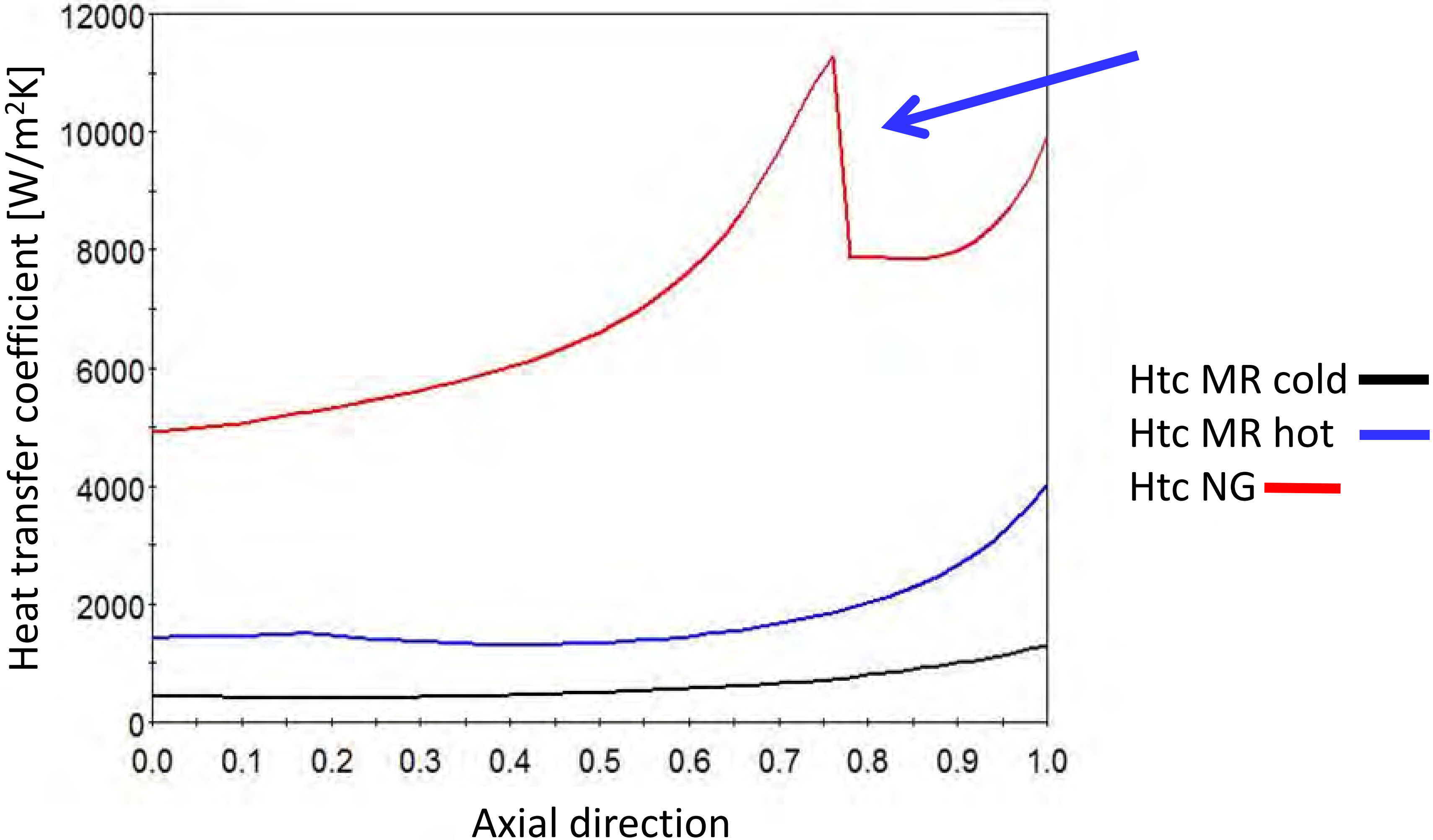


T NG out ~ 200 K

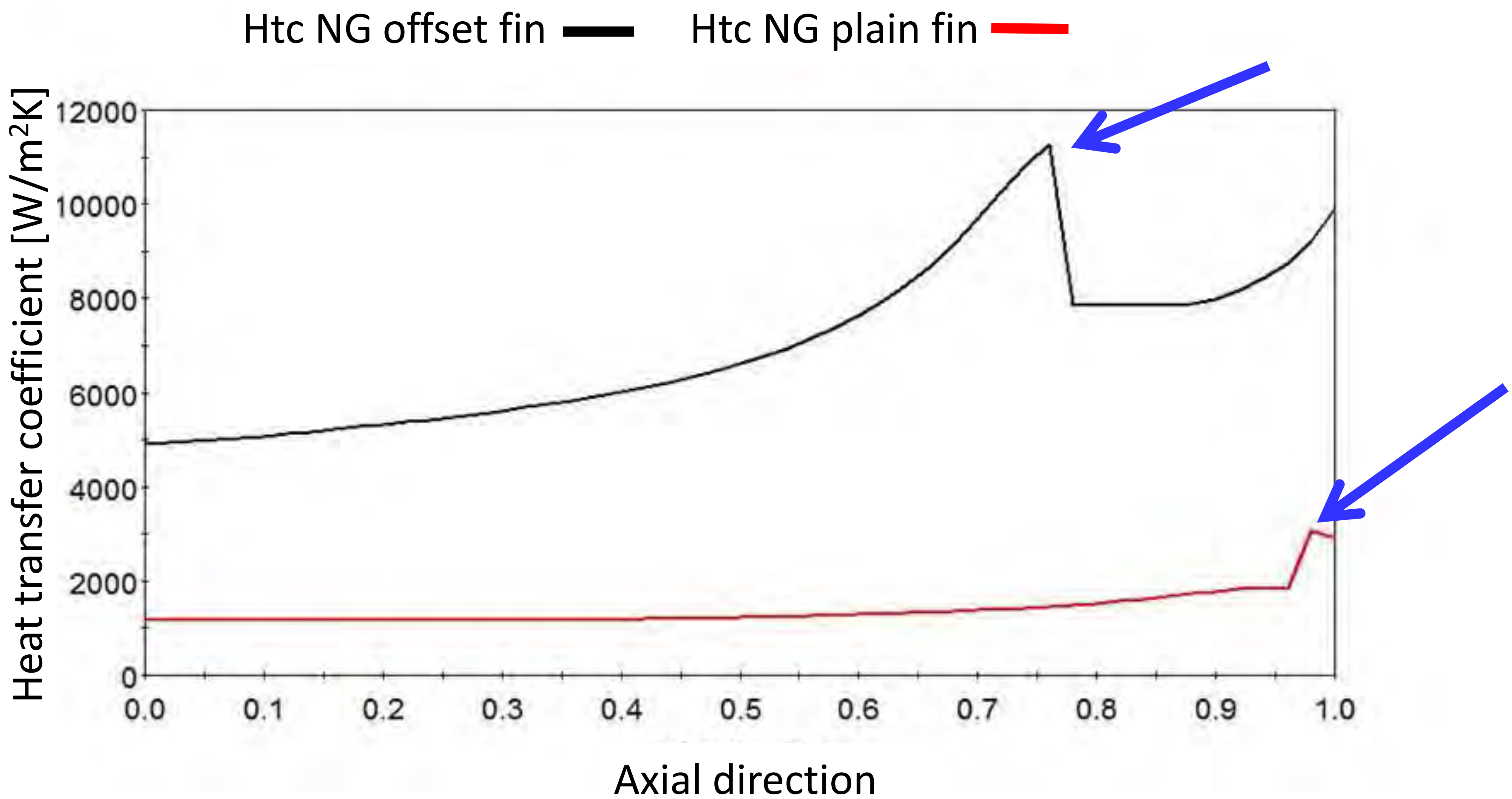
liquefaction achieved within length of HX



PFHX offset fins: results HTC



Comparison HTC



Conclusions

- The final model accounts for:
  - fluid properties variation in the axial direction,
  - specific geometry of the HX,
  - fluid to wall variable convective heat transfer in the axial direction,
  - variable friction factor in the axial direction,
  - single phase correlations for htc(z) and f(z).

- The model structure and the correlations used for the channel simulation have been usefully implemented in the PSE model libraries.

Future Works

- Evaluation of the model with experimental data.

- Development of a 2-D model (especially for the CWHX).

Thanks for your attention!

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- Programme
- gPROMS Model builder 4.1.0.20140520 (x64) dev

Streams composition

Table A.1. *NG stream composition used for the simulations.*

Nitrogen	0.0144	kg/kg
Methane	0.8622	kg/kg
Ethane	0.0534	kg/kg
Propane	0.0328	kg/kg
2-Methylpropane	0.0033	kg/kg
Butane	0.0020	kg/kg
2-Methylbutane	0.0033	kg/kg
Pentane	0.0020	kg/kg
Hexane	0.0049	kg/kg
Heptane	0.0034	kg/kg

Table A.2. *MR stream composition used for the simulations.*

Nitrogen	0.03822	kg/kg
Methane	0.4793	kg/kg
Ethane	0.4132	kg/kg
Propane	0.0024	kg/kg
2-Methylpropane	0.02728	kg/kg
Butane	0.03952	kg/kg