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Modelling of bunkering of LH2
Results from H2Maritime project

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H2Maritime - Hydrogen and Fuel Cells for Maritime Applications
Knowledge-building Project for Industry - MAROFF

- Hydrogen produced with zero emissions can be an alternative solution for several maritime applications
- Partners : IFE, NTNU, USN, Equinor, ABB, Havyard, Umoe Adv. Comp., Lloyds, Norwegian Maritime Authority
- Research areas
  1. Hydrogen bunkering and storage
  2. Hydrogen safety
  3. Fuel cells systems

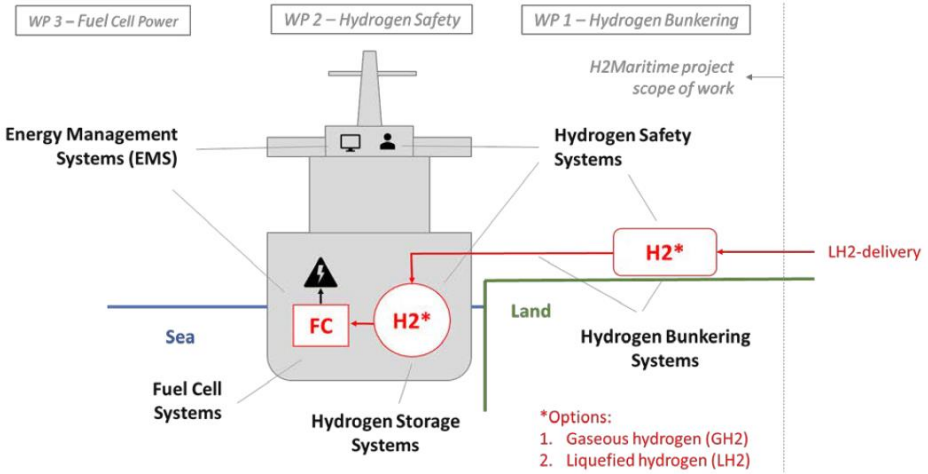


Figure 1: Illustration of H2Maritime project scope of work.

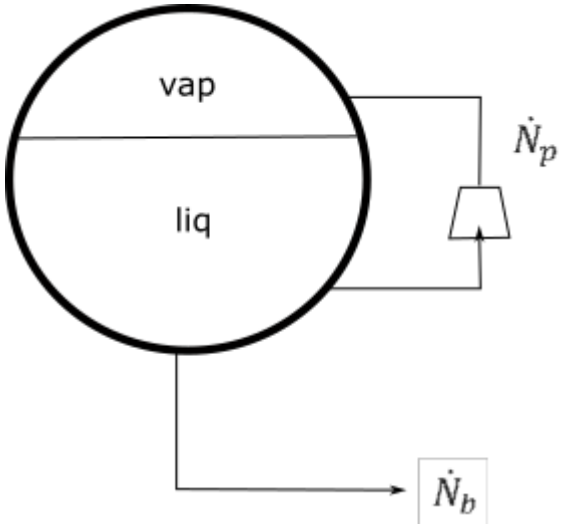
Tank model

$$\frac{dN_{liq}}{dt} = -\dot{N}_b - \dot{N}_p$$

$$\frac{dN_{gas}}{dt} = \dot{N}_p$$

$$\frac{dU_{gas}}{dt} = \dot{N}_p h_p - \dot{Q}$$

$$\frac{dU_{liq}}{dt} = -(\dot{N}_b + \dot{N}_p)h_{liq} + \dot{Q}$$



Pressure (and all other state variables) are calculated from a Helmholtz free energy based EOS*

$$p = p\left(N_{gas}, U_{gas}, N_{liq}, U_{liq}\right)$$

Heat transfer between phases:

$$\dot{Q} = -HTC \cdot A_{sur}\left(T_{gas} - T_{liq}\right)$$

Pressure loss in tanker, hose, etc.:

$$\Delta p_{t-t} = \left(f\frac{L}{D} + \sum K_{minor}\right)\frac{1}{2}\rho\left(\frac{\dot{m}}{\rho A}\right)^2$$

*(Leachman, J.W. & al. “Fundamental Equations of State for Parahydrogen, Normal Hydrogen, and Orthohydrogen.” Journal of Physical and Chemical Reference Data A, 2009: 721-784.)

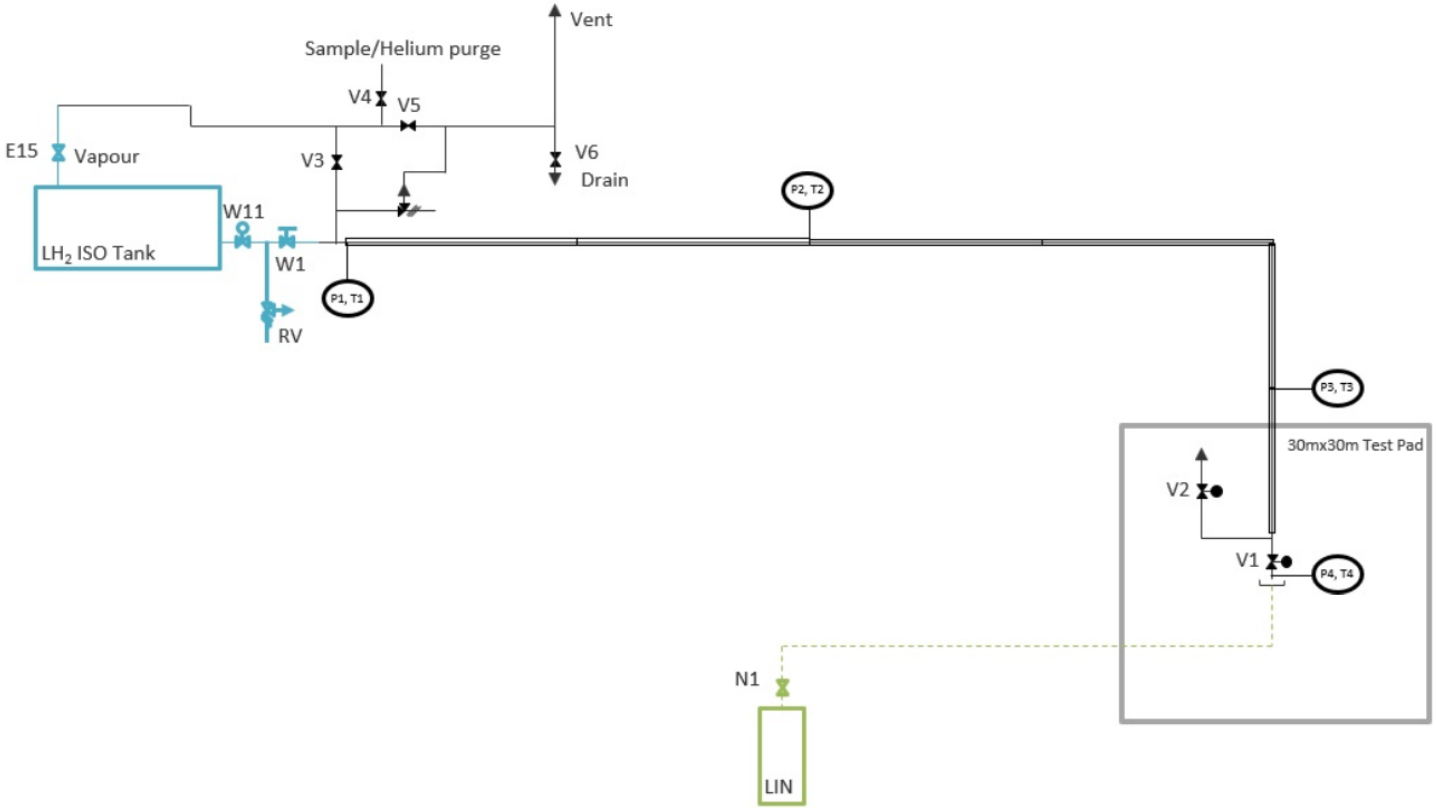
DNV·GL

LIQUID HYDROGEN SAFETY

Data Report: Closed room and ventilation mast studies

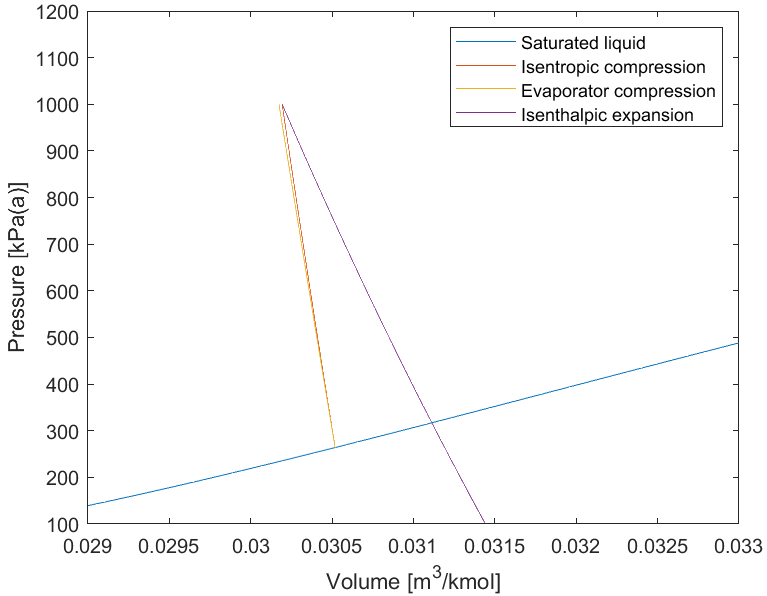
Forsvarets forskningsinstitutt (FFI) Norwegian Defence Research Establishment

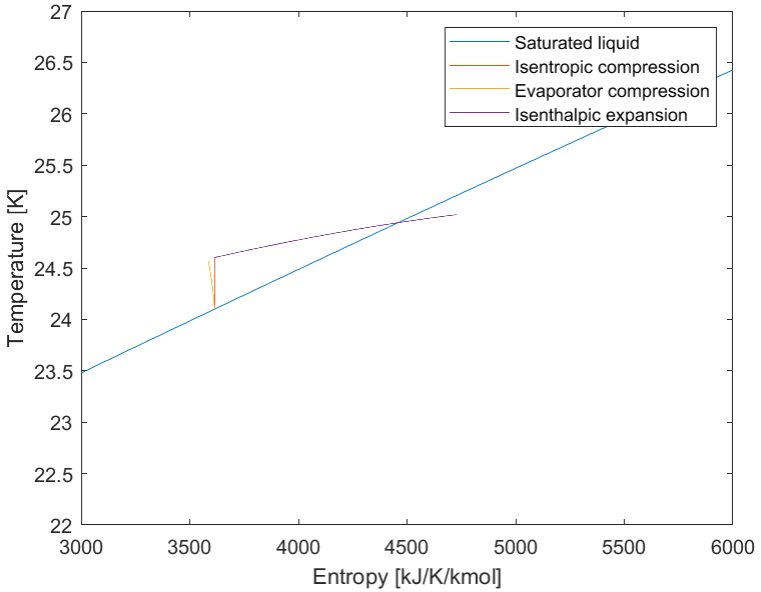
Report No.: 902696, Rev. 2
Document No.:
Date: 2020-05-04



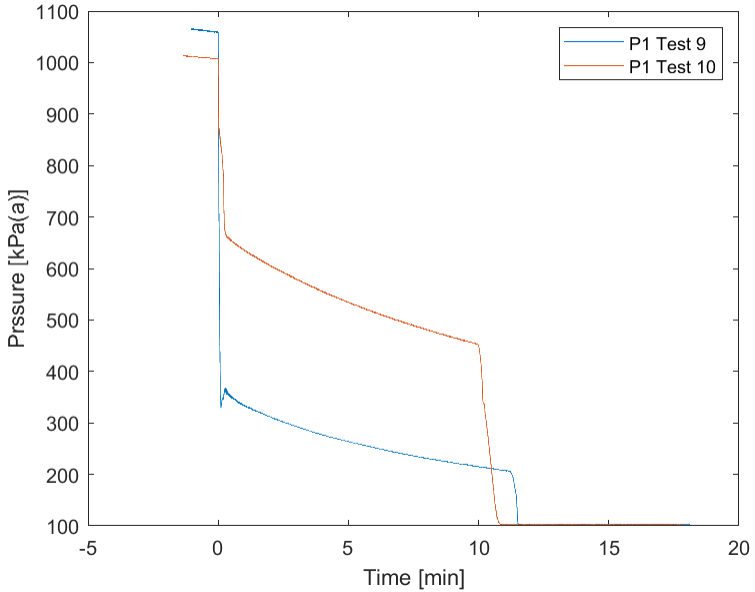
Experimental set-up of LH2-release tests at Spadeadam
(copied from Clara Huescar Medina and Dan Allason (2020), LIQUID HYDROGEN SAFETY Data Report: Closed room and ventilation mast studies https://liquidhydrogentests.z6.web.core.windows.net/.)

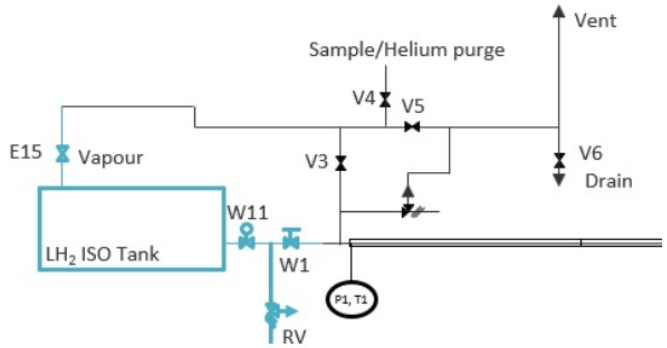
Test #	Nozzle	P0	Pdrop	Mf_init	P4_start	Dt	M0	Me
8	1”	No inc. 1.64 barg	0.35 **	0.22	-	11	21.9282	21.8275
9	1”	9.6 barg	2.6 barg *	0.64	2.47	10	21.7909	21.4246
10	0.5”	9.0 barg	5.65 barg	0.54	5.45	9	21.3331	21.0218
11	0.5”	9.7 barg	6.5 barg	0.56	6.55	5	21.0218	20.7471
12	0.5”	9.9 barg	6.1 barg	0.59	6.06	3	20.7196	20.5274
14	0.5”	9.9 barg	7.4 barg	-	-	2	20.3259	20.2893





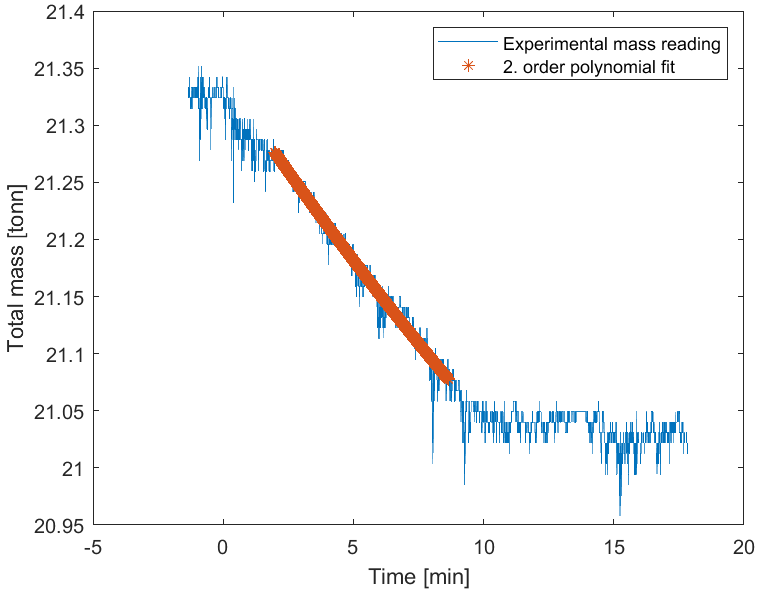
Pressure-volume (left) and temperature-entropy plots for **liquid hydrogen** following the states in Test 10. The Evaporator compression curve includes a mass flow from liquid phase to gas phase leading to a small drop in entropy.



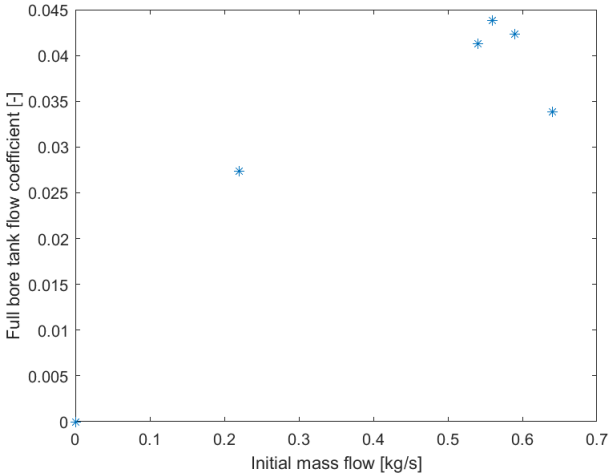


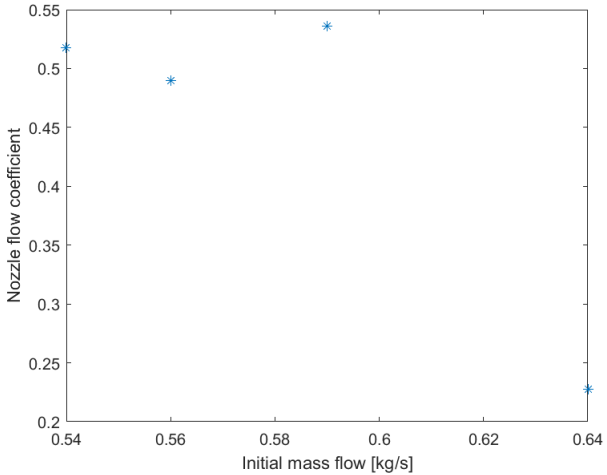
Significant pressure drop from tank to P1

Mass flow:


Experimental mass reading
2. order polynomial fit
Total mass [tonn]
Time [min]
21.4
21.35
21.3
21.25
21.2
21.15
21.1
21.05
21
20.95
-5
0
5
10
15
20

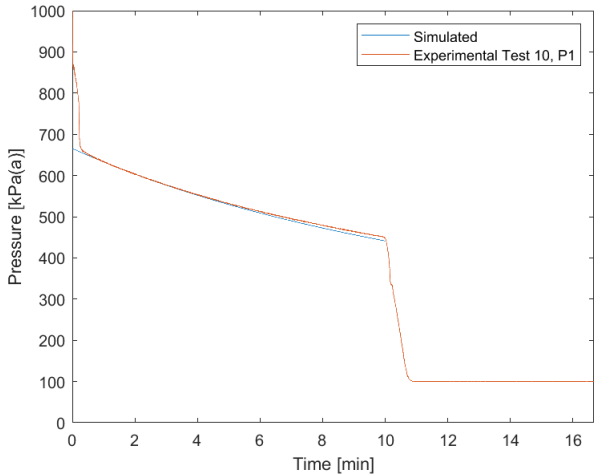
Estimate flow coefficients

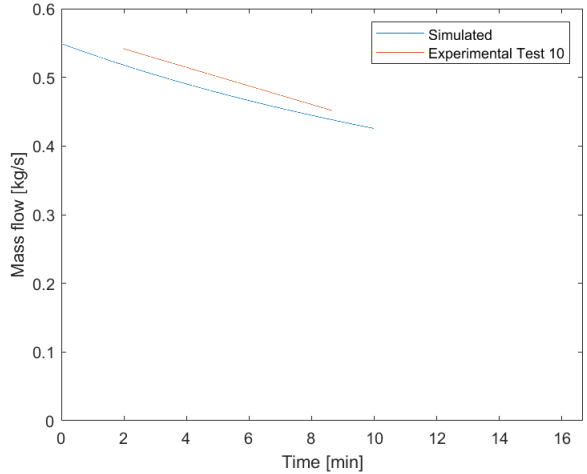




$$C = \frac{\dot{m}}{A\sqrt{2\rho\Delta p}}$$

Simulated pressure history and mass flow

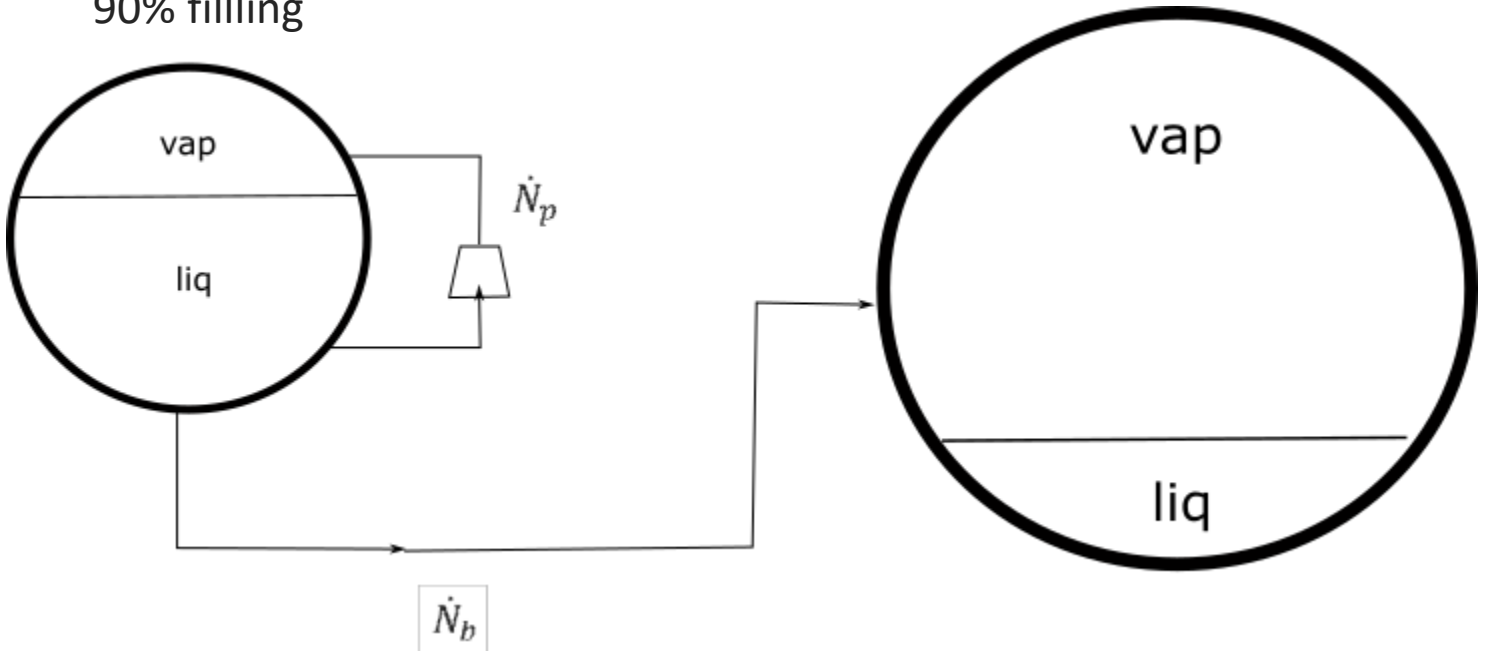


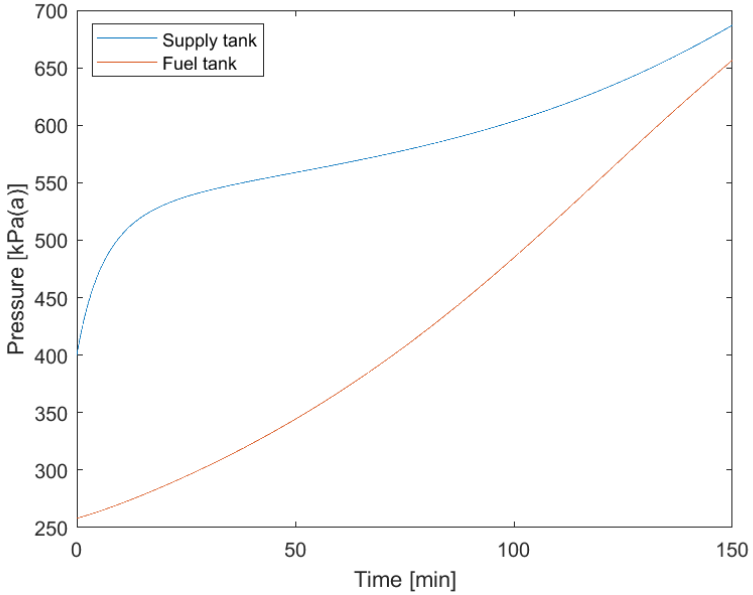


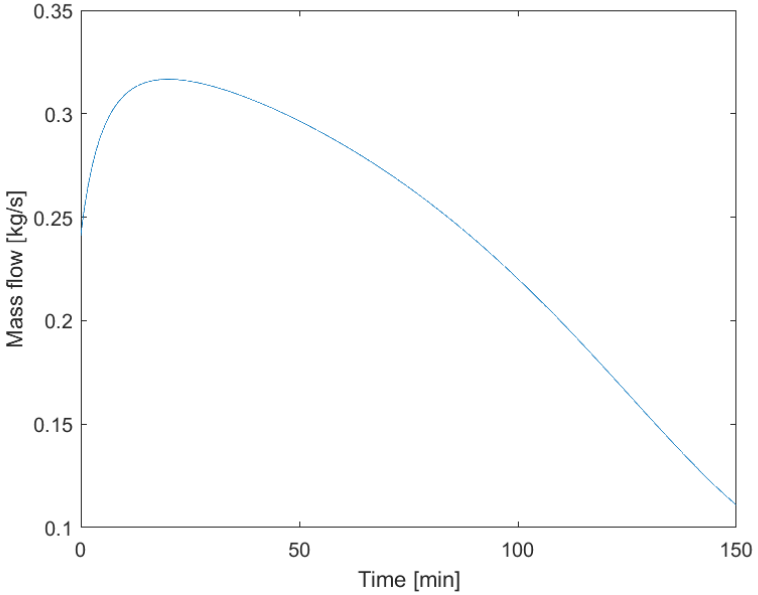
Example: bunkering

40’ ISO-tank
T_0 = 22K
90% fillling

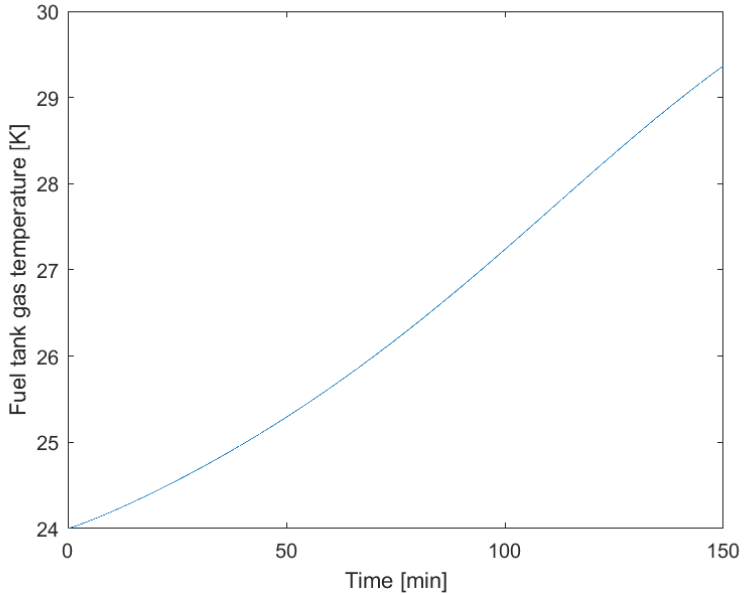
80 m^3 ship tank
T_0 = 24K
10% fillling

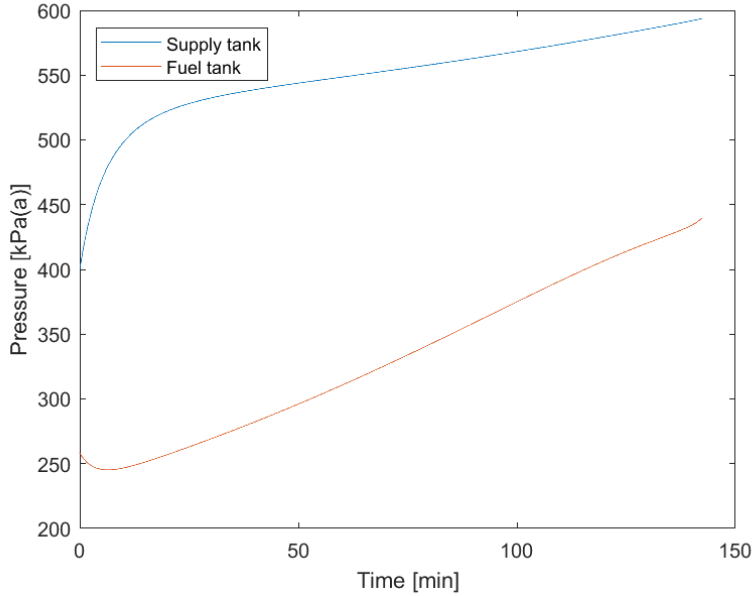


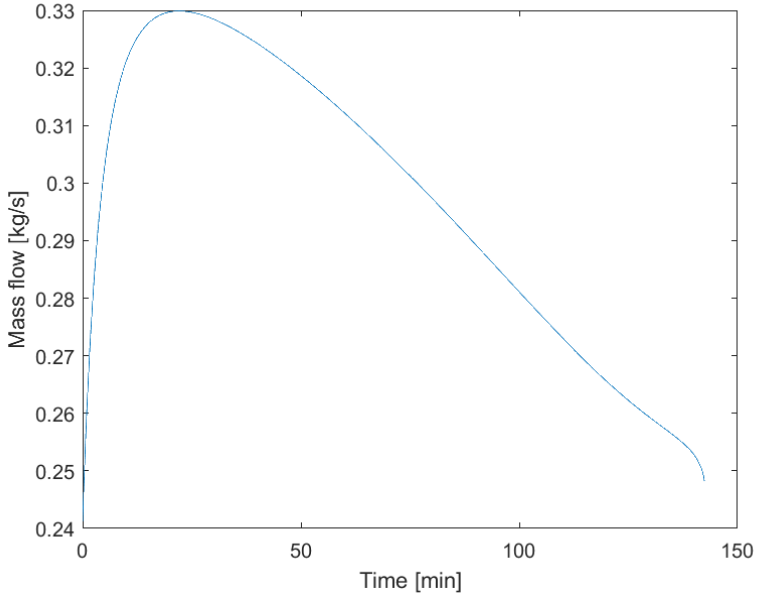




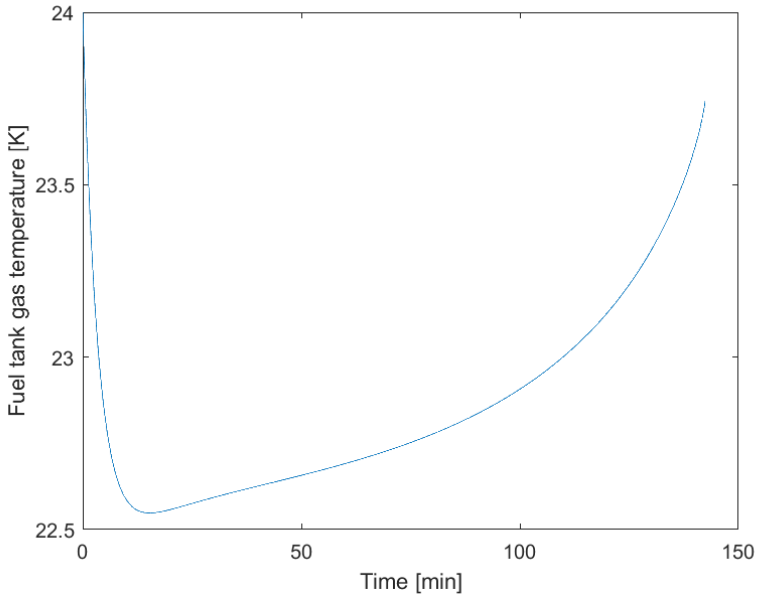
Evaporator/compressor consumes 30 g/s, no cooling of gas phase


30
29
28
27
26
25
24
Fuel tank gas temperature [K]
0
50
100
150
Time [min]





Evaporator/compressor consumes 30 g/s, «sparging» of gas phase


24
23.5
23
22.5
Fuel tank gas temperature [K]
0
50
100
150
Time [min]

Thank you!