CCS network operation

6th international workshop on Offshore Geological CO2 storage

S.P.C. Belfroid, D. van Nimwegen, F. Neele

Network operation

- The expectation is in the next decade different CCS networks will be developed
- At the Dutch North Sea, the development of Porthos and Aramis start soon

- In a network there is a large difference between networks

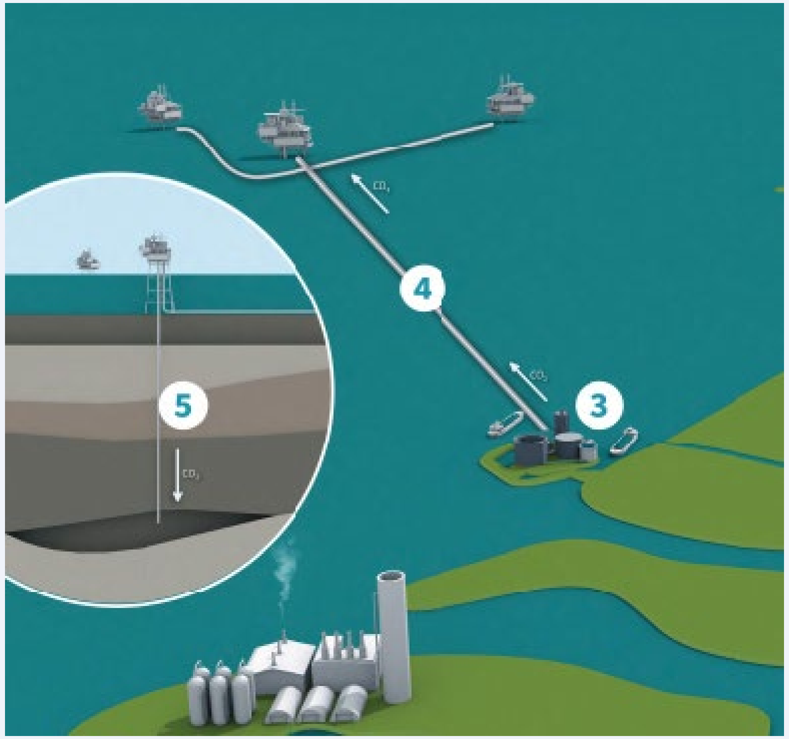
Source - Single pipeline – Single hub

vs

Backbone network with multiple Hubs from different owners

- The main questions in the more complex networks are:
  - What the best operating pressure of the network?
  - How (where) to control pressures and flow rates
  - What happens with extensions to new hubs (first fill, operating conditions)?

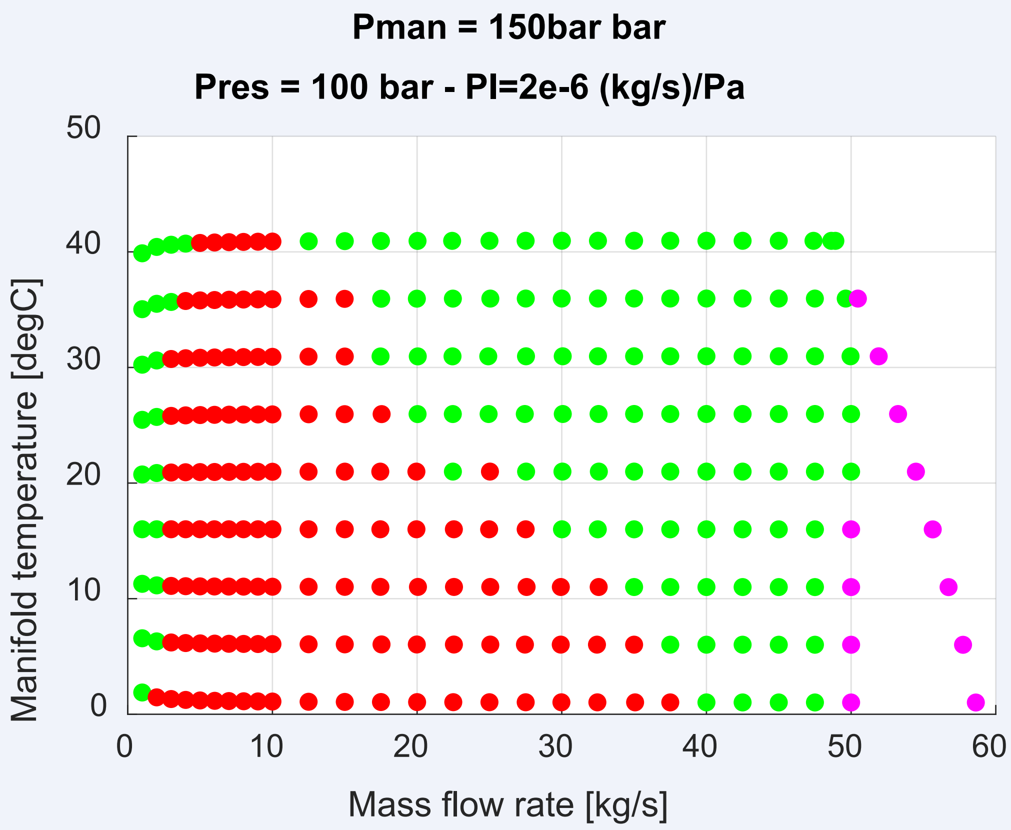
- In this presentation the focus is on the operation.



https://www.aramis-ccs.com

Well behaviour

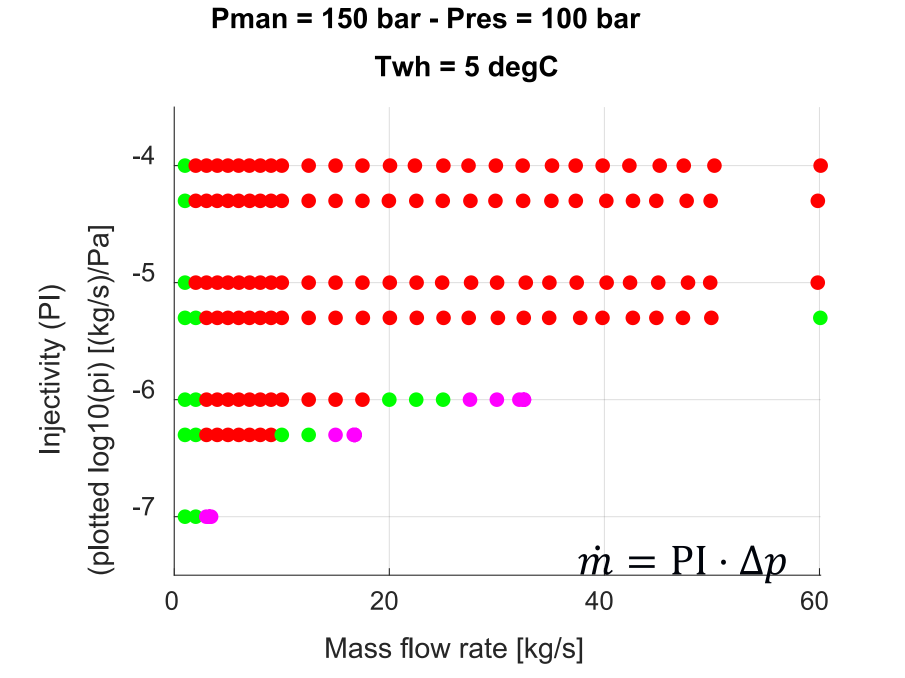
- The network behaviour is governed by the needs for the well injection.
- Well injection limitations are governed by:
  - Erosion/vibration
  - Downhole temperature (hydrate prevention, fault activation)
  - Downhole pressure (reservoir pressure drop)
  - Wellhead temperature (SSSV, freezing annulus fluids, ..)
- The operational range of a well has a minimum and maximum flow
  - Sometimes there is also region at very low flow allowed
- In most cases, the operational range is limited by the wellhead temperature due to the occurrence of two-phase conditions at low wellhead pressure

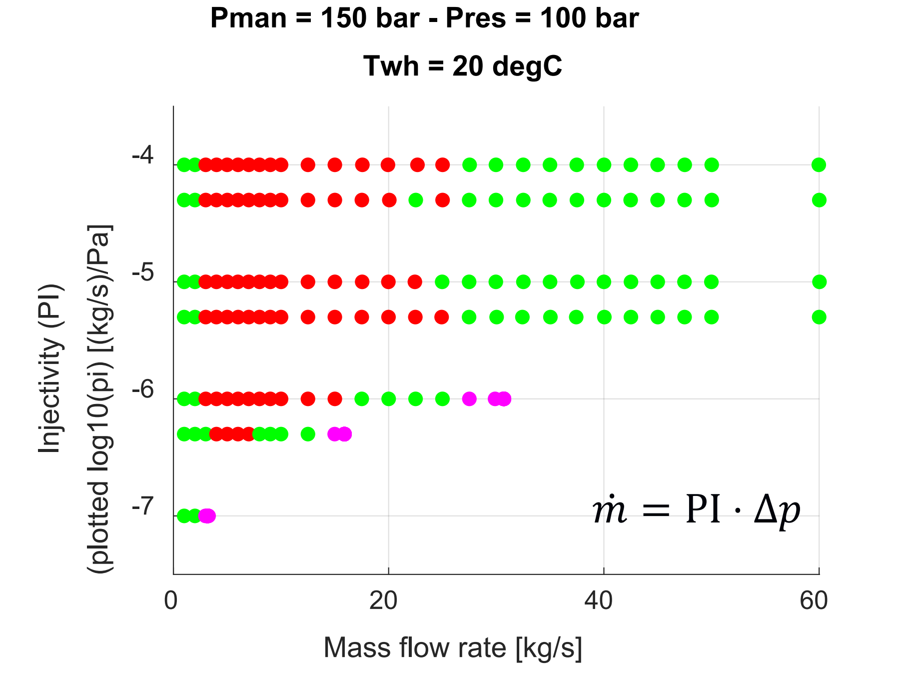


Well behaviour

- The operational range is very sensitive to
  - Manifold temperature
  - Reservoir injectivity

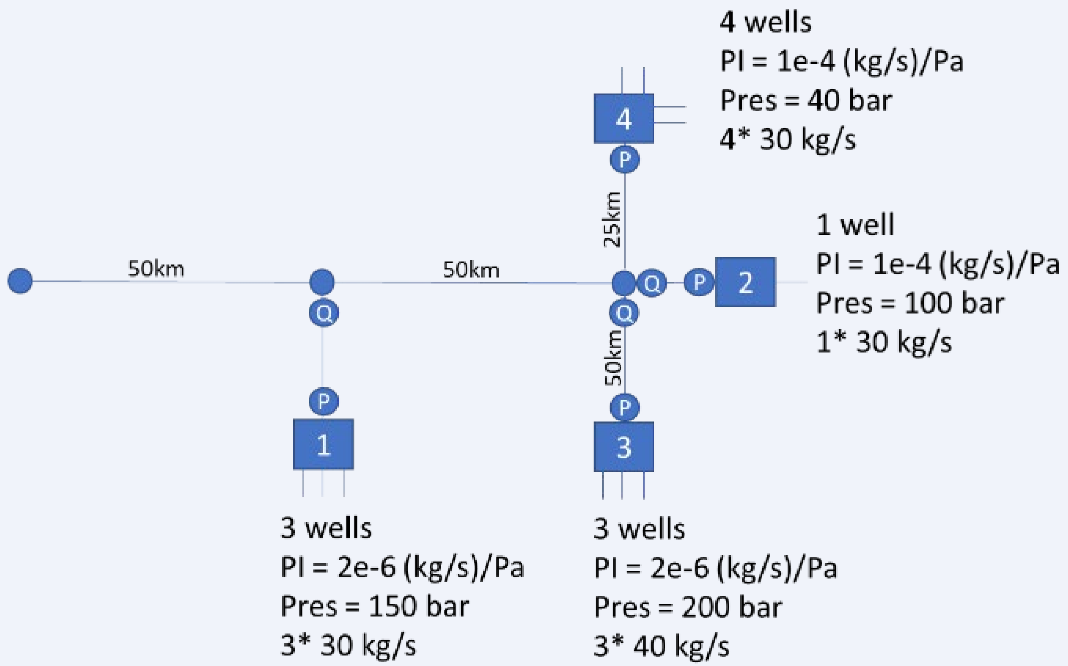
- Ways to extend operational envelope
  - Injection in gas phase (at the cost of injection rate)
  - Increase manifold temperature (insulated pipelines, heating)
  - Design well completion (tubing) such that wellhead pressure is high enough (at the cost of injection at higher reservoir pressures)
  - Downhole chokes (at the cost of very high pressure drop downhole)





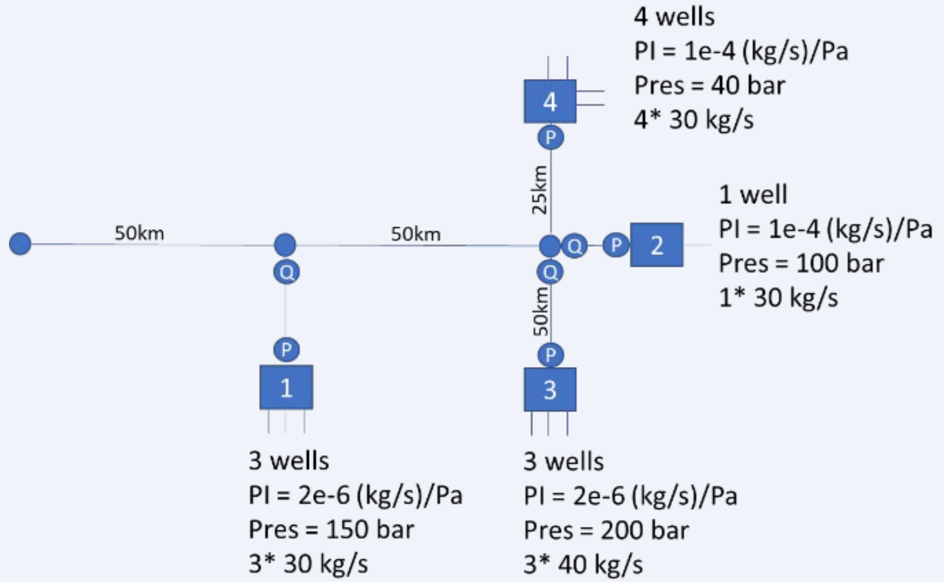
Network operation

- The main questions in network operation are:
  - What should the opening pressure of trunkline be?
  - Where is what control?
- Control
  - At each hub a pressure control must be done to keep the pipelines at (minimum) pressure
  - At Hub level there will be a desire for flow control (as Hubs can be owned by different operators with different storage contracts)
    - However, as not all hubs can be flow controlled (due to dynamics and meter accuracy, one hub must take 'the rest')



Network control

- Which hubs have flow control and which not does matter for final flow distribution.
- Example network
  - Flow control to Hub1
  - Flow control to Hub2
  - Either flow control to Hub3 and free flow to Hub4
  - Either flow control to Hub3 and free flow to Hub3
    - Aim is to have 120 kg/s to both



	Flow to Hub 3	Flow to Hub 4
Flow control to Hub3	110	130
Flow control to Hub 4	120	120

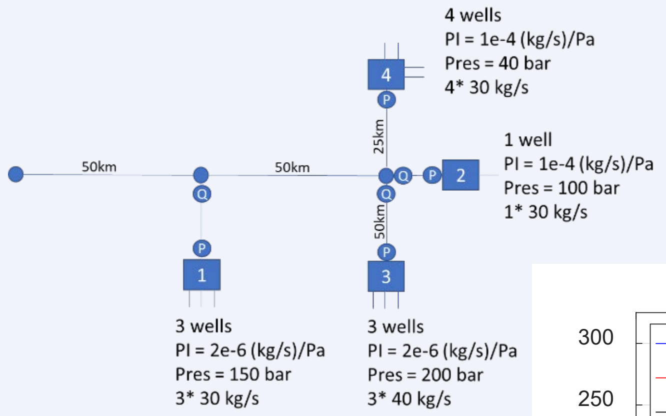
- As the flow is limited to Hub3 wells and the wells at Hub4 have 'spare capacity' the flow will be skewed
- Flow control will need to be done on hubs with spare capacity but this will lead to larger pressure fluctuations as the limiting wells will determine the pressure.

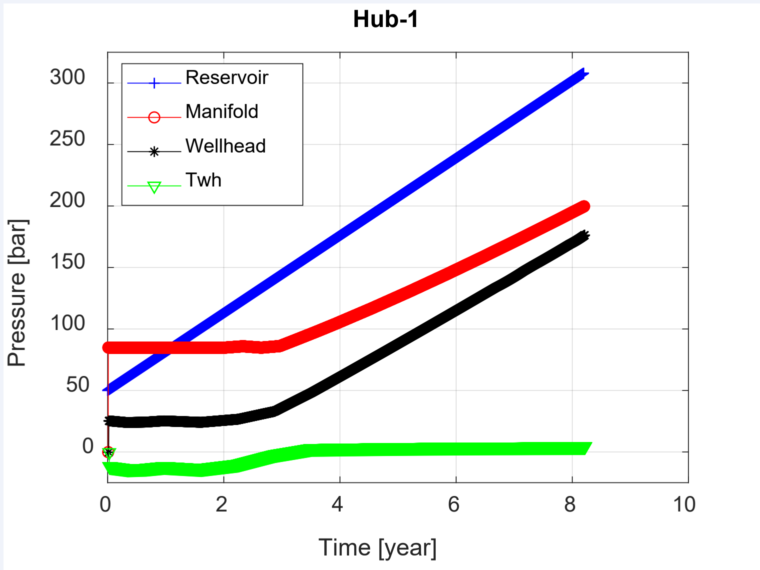
Operating pressure

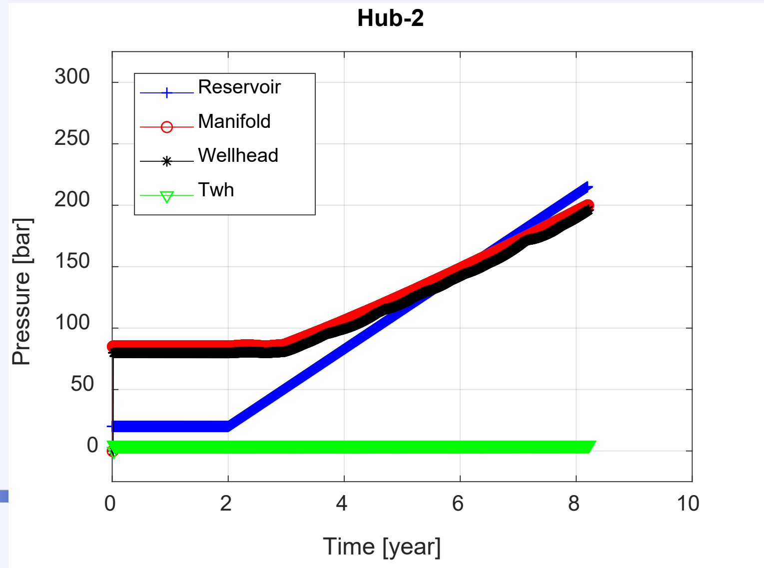
- Operating pressure
  - First minimum pressure is most common operating pressure is to keep pipeline in liquid/supercritical regime
    - Avoid two phase operation (although discussion has started on this as from experiments it has been observed that slugging conditions are difficult to induce).
    - This means minimum operating pressures of typically 85 bar

  - Second minimum operating pressure is determine by desired injection rate for 'worst' wells.
    - This can mean other wells/Hubs have too much pressure

- Important question: is it advantageous or detrimental to operate at higher pressures than the minimum required.







Operating pressure

- Higher operating pressures than required:
  - Some wells have reduced operating range at higher pipeline pressures.

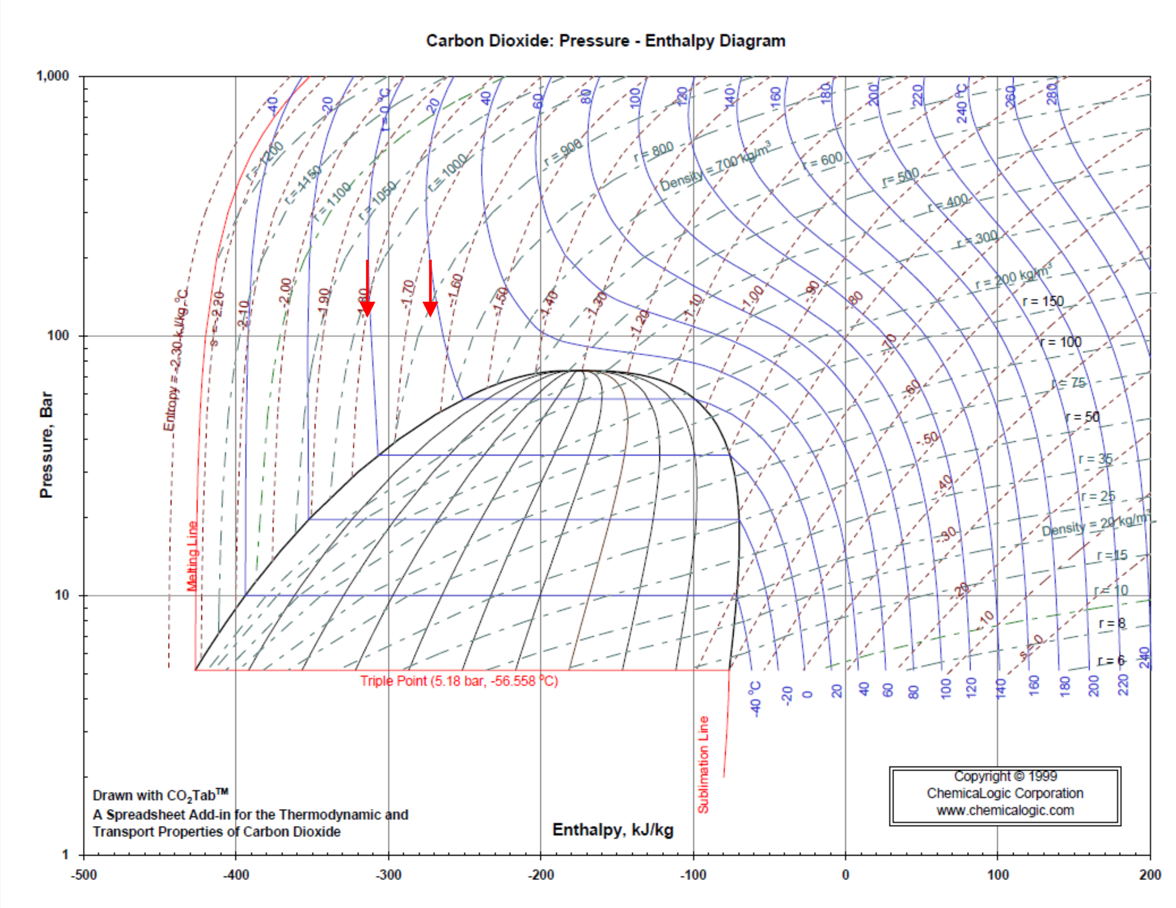
  - Depending on the composition and temperature, the pressure can be reduced without too much temperature cost

    (P=180, T = 5°C$\rightarrow$ 150 bar only costs 0.34 °C)

    (P=180, T = 20°C$\rightarrow$ 150 bar only costs 0.9 °C)

  In case of contaminants larger temperature drops are possible

- Economic downside
  - The pressure needs to be increased for the complete flow rate Example: 2Mta + 20bar ≅ 1 - 3 M (kWh)
  - Small booster pump at location of limiting wells soon economical



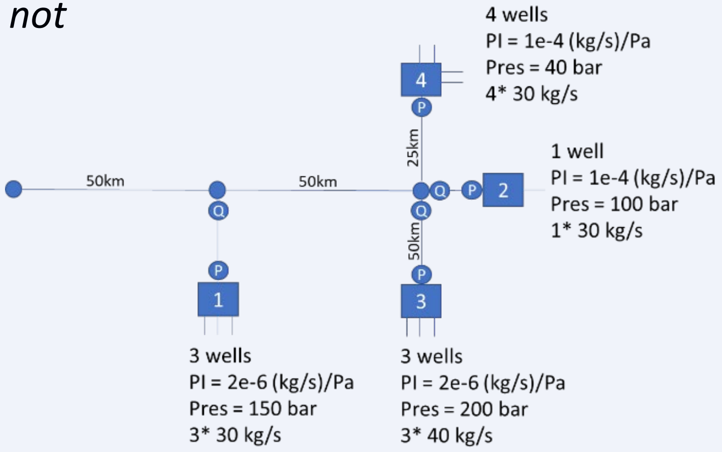
Dynamic response

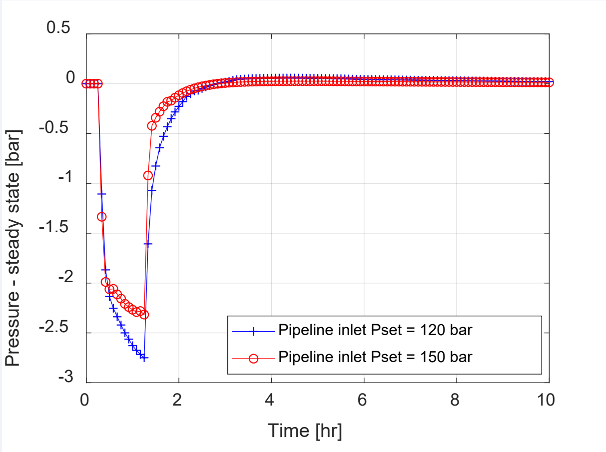
- The pipeline operating conditions must be able to handle fluctuations
- Dynamic examples are:
  - Sudden closure of one well in the network
  - Sudden increase/decrease in the inlet flow rates

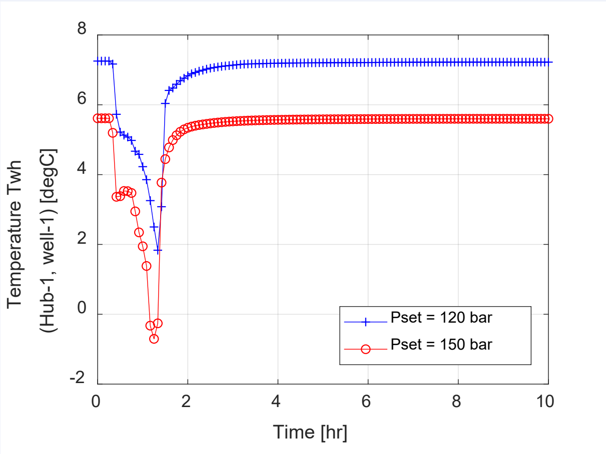
- Pipeline are essentially in liquid phase
- Response depends strongly on if wells are close to operational envelope
  - Sharp increases/decreases in pressure
  - Sharp changes in wellhead temperatures
- A higher operating pressure allows for better control

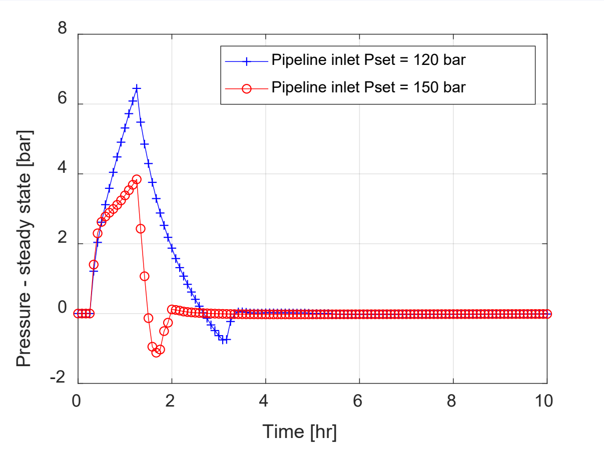
- Sidenote: even with an upset of 1 hour, it can take a day before the network is fully settled again in terms of flow rates due to temperature effects

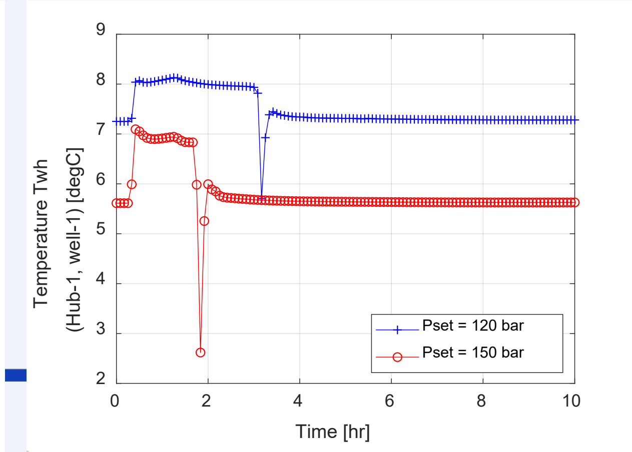
Hub3 and Hub4 not active





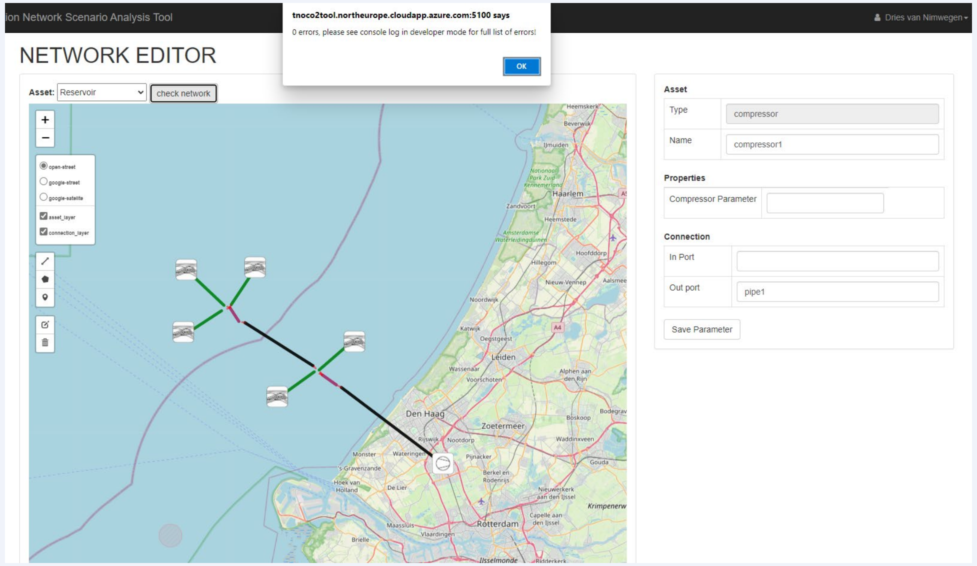


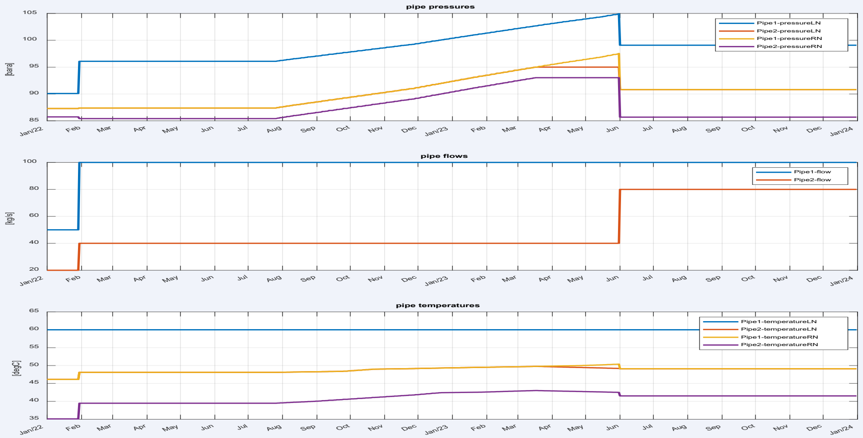




ACTION

- The performance of a network depends on all the wells in the network.
- The performance of all these wells change with time as the reservoir pressures change with injection.
- There is need to calculate the pressures and flow rates in the network for a complete injection period. This can be done based on quasi steady state (no start-up/shutin but time dependent boundary conditions).
- Within the ACT program ACTION, a steady state solver was developed which included:
  - Pipelines
  - Flow/pressure controllers
  - Chokes
  - Reservoir
- Currently extended with better proxies for the reservoir which can include the temperature front)





Conclusions

- CCS network operations can be complex:
  - Pipelines are operated essentially in liquid phase meaning the operating pressure is sensitive to dynamics
  - The minimum operating pressure is limited by the critical point to ensure single operation
  - The maximum operating pressure is determined by ‘the worst’ injection wells

  - The pipelines can sometimes be operated at an elevated pressure compared to the minimum required injection pressure for a given well
    - Downsides are economic and a somewhat reduced operating range for other wells
    - Potentially small booster pumps for ‘weak’ wells might be more beneficial
  - As the operating pressure can be determined by a small group of wells, injection optimization on network level rather than well or Hub level is rapidly advantages

  - As the network conditions change as the operating per well changes as function of reservoir pressure and total network flow rate, injection strategies need to be calculated for the complete network for the injection durations. Coordination between hubs might be beneficial for the optimum and most economic rates per wells and per hub.

Thank you for your attention

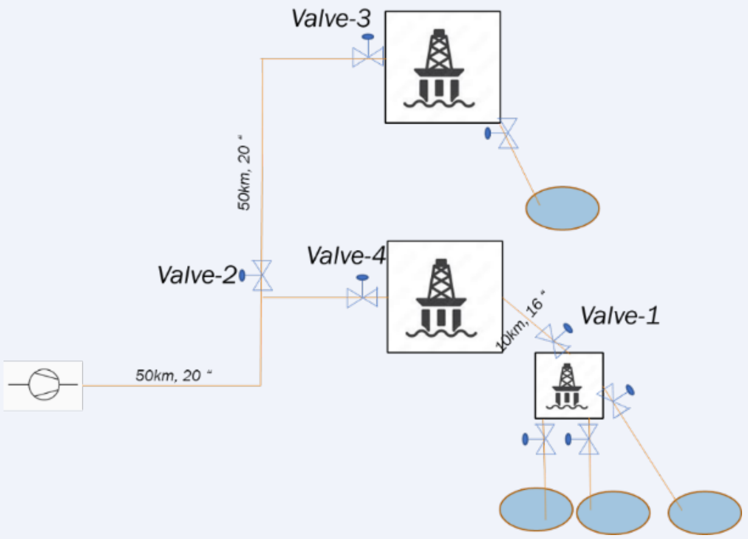
- Stefan Belfroid
- +31625561854
- Stefan.Belfroid@tno.nl

Extending network

- Extending the network results in two questions:
  - Can the new pipeline be operated at low pressure if required (for gas phase injection)?
    - Classic idea is to use the pipeline and warmer sea water to evaporate the CO_2. However, a buried pipeline is too well insulated.
    - Example: Upstream: P = 150 bar, T = 10°C
      Back pressure 30 bar, ambient water 10°C
      L = 50 km, U = 3 W/m^2K
    - A maximum flow rate of 7 kg/s can be evaporated back to gas phase

    Therefore, this strategy only works in case of

  - Can the new pipeline be filled from the high pressure part?
    - If the pipeline is commissioned it is dried and delivered at low pressure.
    - However, pressurizing the pipeline via the high pressure section (back filling from the wells might not be allowed and can lead to water entering the pipeline.
    - First fill might require temporary heater till the pressure is high enough (~10 bar) or partial (dry) air or N2 filling.



Steady state control

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