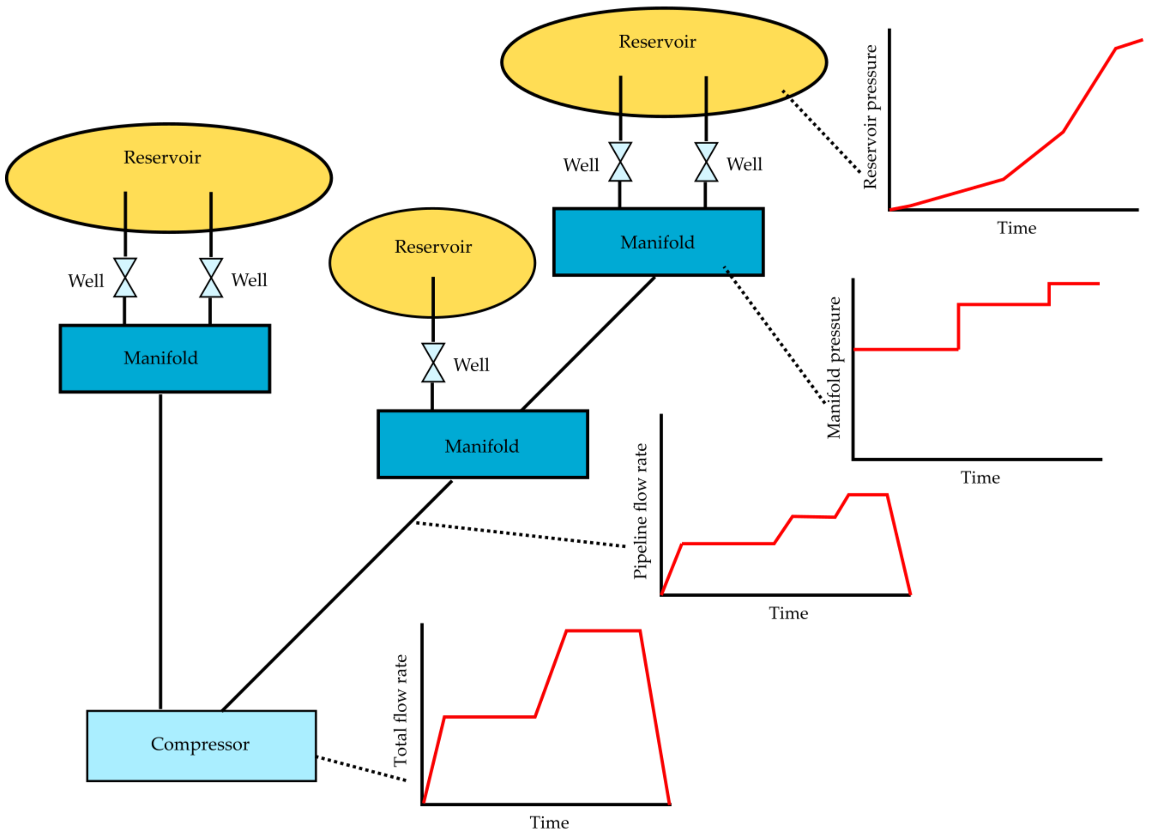
CO2 network operation challenges

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

03 December 2024



Introduction - Network operation

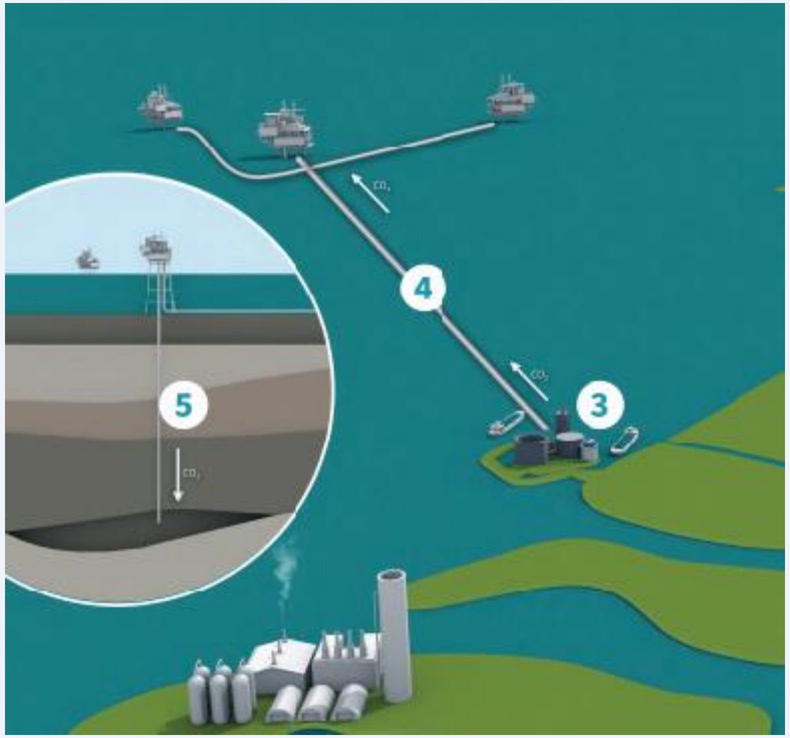
- A large number of CCS injection sites are being developed. Often linked via a common transport network. For example, at the Dutch North Sea, Porthos is being build and Aramis is the development phase.

- Network transport and injection issues special for CCS
  - Corrosion/safety (impurities)
  - Temperature (low cycle fatigue, hydrate, fault activation, equipment)
  - Depressurisation
  - Network control/operations

- Network operations:

  - Steady state:
  - Can the stores be filled over time?
    - What network operating conditions are required?

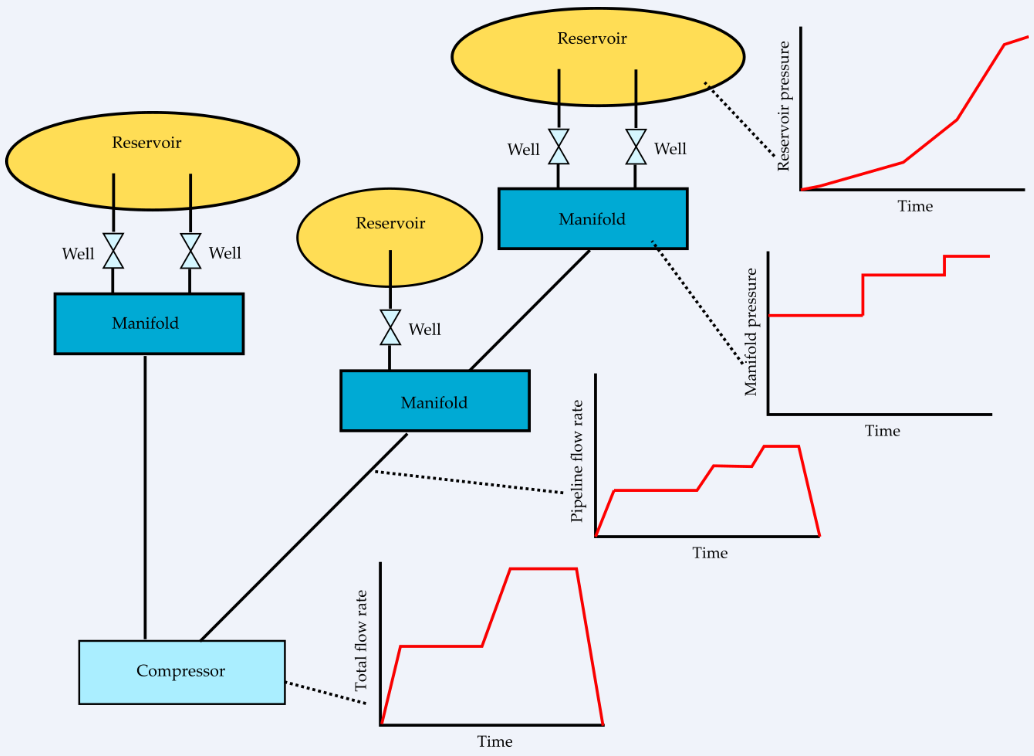
  - Dynamic operations
  - How can the flow be controlled to the different Hubs (as per contract store – emitter). Especially in case of different Hub owners.
  - What is the required control/operating conditions to be to handle upsets such as drop in emitter flow or sudden stop of a well?



https://www.aramis-ccs.com

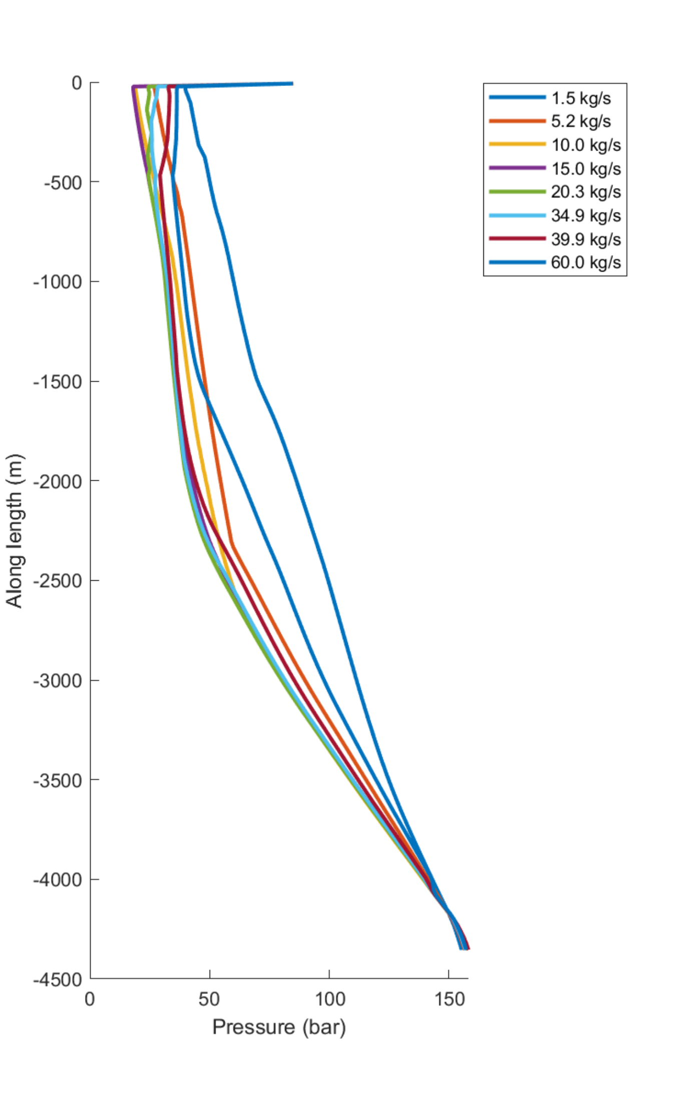
Introduction - Network operation

- Particularities of CO_2 transport network:
  - Network can link stores with very different characteristics
    - Depleted gas/oil fields with high injectivity wells
    - Depleted gas/oil fields with low injectivity wells
    - Aquifers
  - For depleted fields, the boundary conditions vary much over time due to reservoir pressure increase
  - Networks can exists of Hubs with different owners with their own economic contracts
  - Main operational mode is in liquid/dense phase
    - Low buffer capacity and fast response to dynamic events



Influence well characteristic

- Well injection limitations are governed by:
  - Downhole pressure/pressure drop (reservoir pressure drop)
  - Erosion/vibration
  - Downhole temperature (hydrate prevention, fault activation)
  - Wellhead temperature (SSSV, freezing annulus fluids, ..)
- For most wells, this means that the operational range has a minimum and maximum flow
- In most cases, the operational range is limited by the wellhead temperature due to the occurrence of two-phase conditions at low wellhead pressure

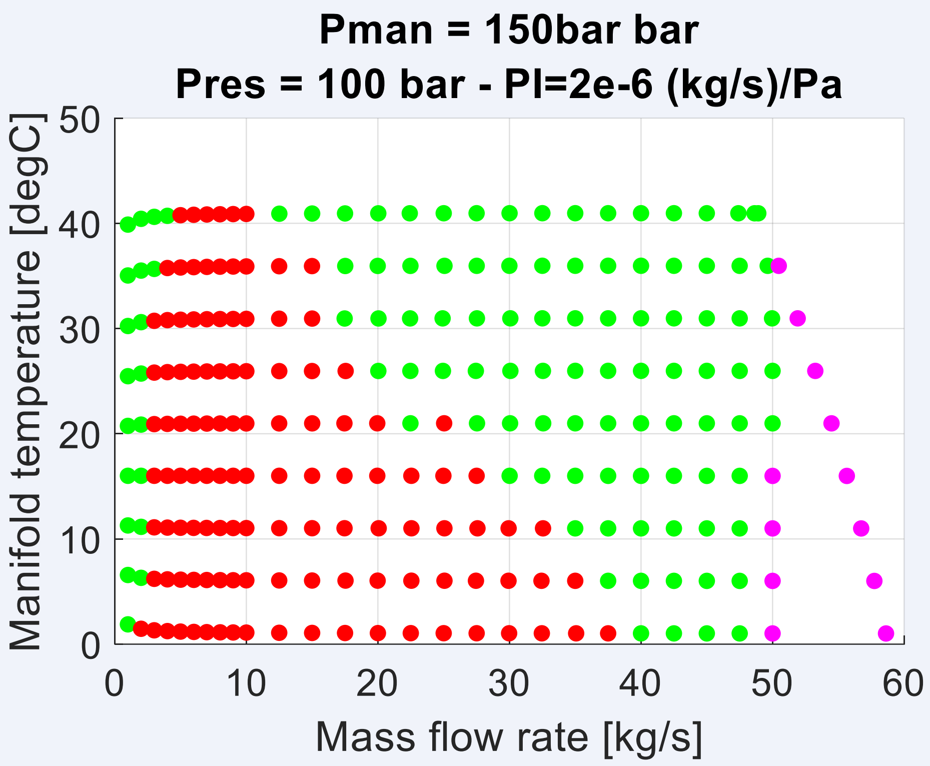


Influence well characteristic

$$\dot{m} = \mathrm{PI} \cdot \Delta p$$

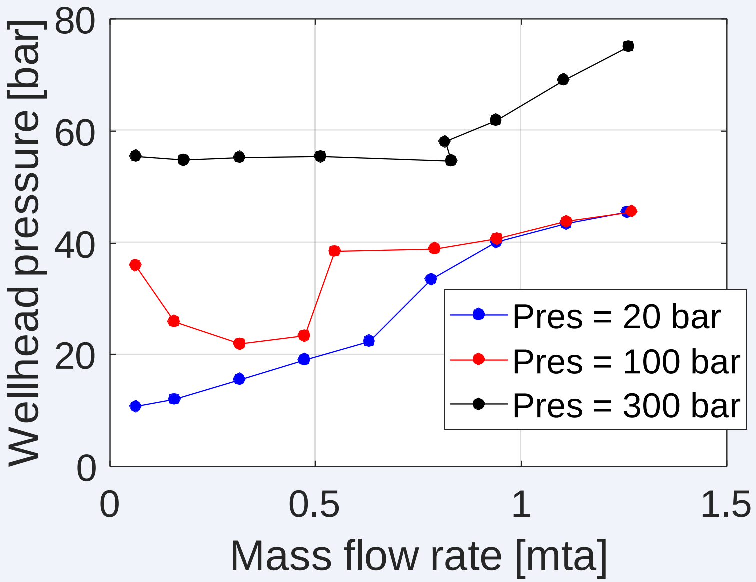
- The operational range is very sensitive to
  - Manifold temperature
  - Reservoir injectivity

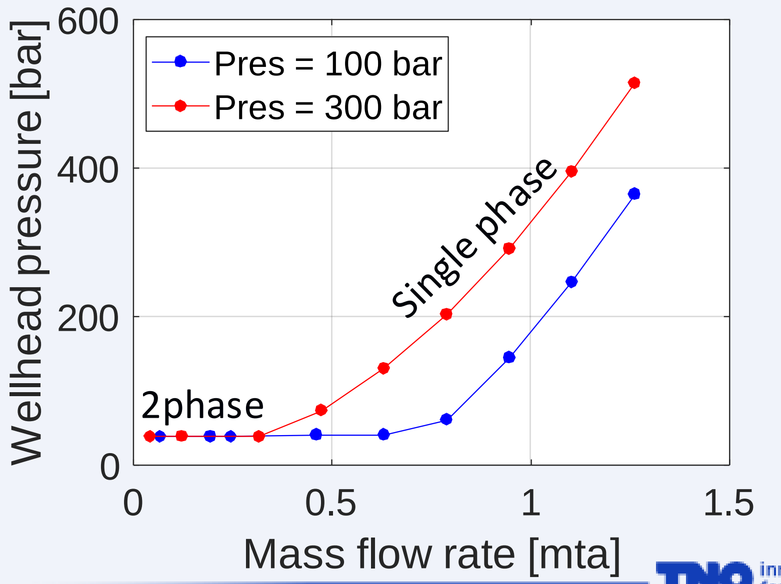
- Ways to extend operational envelope
  - Injection in gas phase (at the cost of injection rate)
  - Increase manifold temperature (insulated pipelines, heating)
  - Design well completion (tubing) such that wellhead pressure is high enough (at the cost of injection at higher reservoir pressures)
  -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



Influence well characteristic

- Wells in the network can therefore be divided into two characteristics
- Wells with two-phase operation
  - Low temperature are avoided by high manifold temperatures
  - Wells have minimum/maximum flow rate but have a relative large operating range
- Wells with single-phase operation
  - The well is essentially in friction control (or high pressure drop across choke)
  - Wells have a limited operating envelope
    - Too low flow leads to fall-off frictional pressure drop and lead to low temperatures
    - Too high flow leads to high required manifold pressures

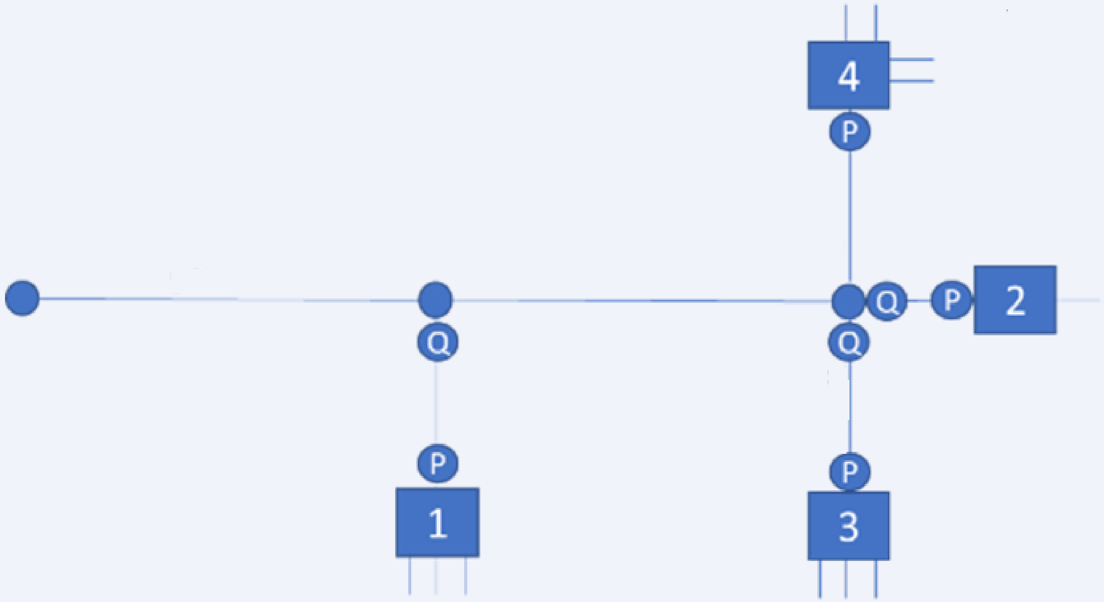




Steady state control

- Control options/requirements
- **Inlet flow control**
  - Via compressor/pump
- **Flow control at Hub and well level**
  - Issues are measurement uncertainties, dynamic event

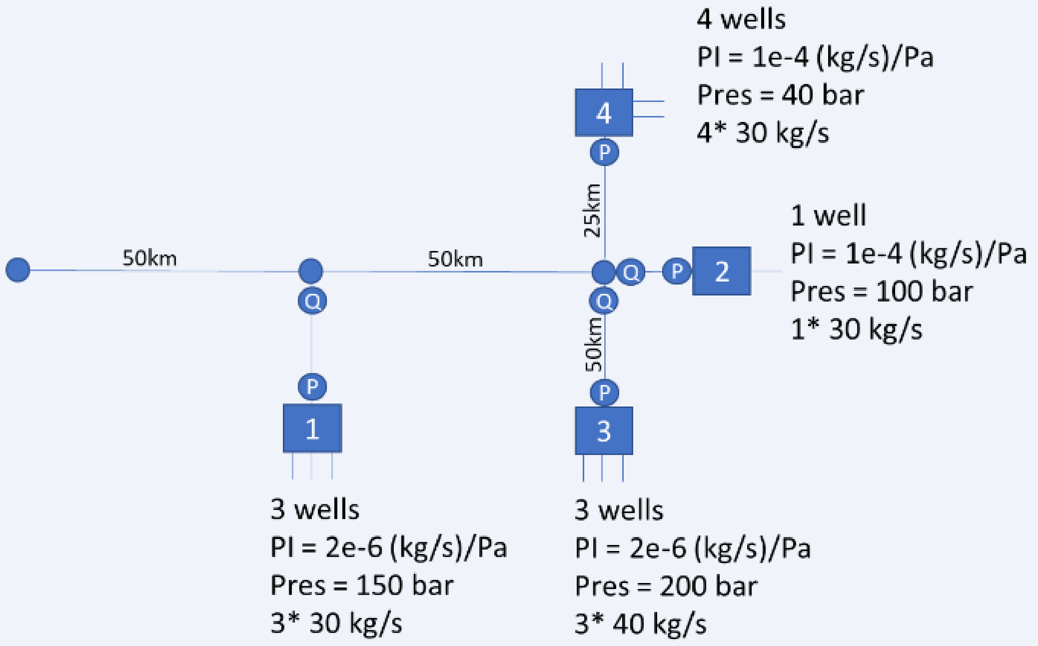
  Due to this, ‘free’ wells are advised
- **Pressure control**
  - A minimum pressure is usually set to avoid two-phase conditions
  - The actual operating pressure can be potentially let free
    - In case the wells are in friction control and operate as desired, the network operating pressure will balance. But poses risks in case of upsets and if Δp in wells/reservoir is not as expected



Steady state control

- The minimum operating pressure in the network can be determined by a single a single low injectivity Hub/well.
- Disadvantages
  - High network pressure might be disadvantages for other wells (higher pressure drop can lead to lower temperatures for high injectivity wells)
  - Increasing the overall network pressure for only a single well/hub is an economic cost for all (local pump might be beneficial
- Surprising by-effect
  - If there are hubs with spare allocation and hubs who are at the maximum flow, the flow distribution might still end up skewed
  - Control needs to be done on hub with spare capacity

If mean operating pressure is set higher than required the flow control can be optimized



	Flow to Hub 3	Flow to Hub 4
Desired rate to Hub3 and Hub4	120	120
Flow control to Hub3	110 (valve to Hub-3 full open)	130
Flow control to Hub 4	120	120

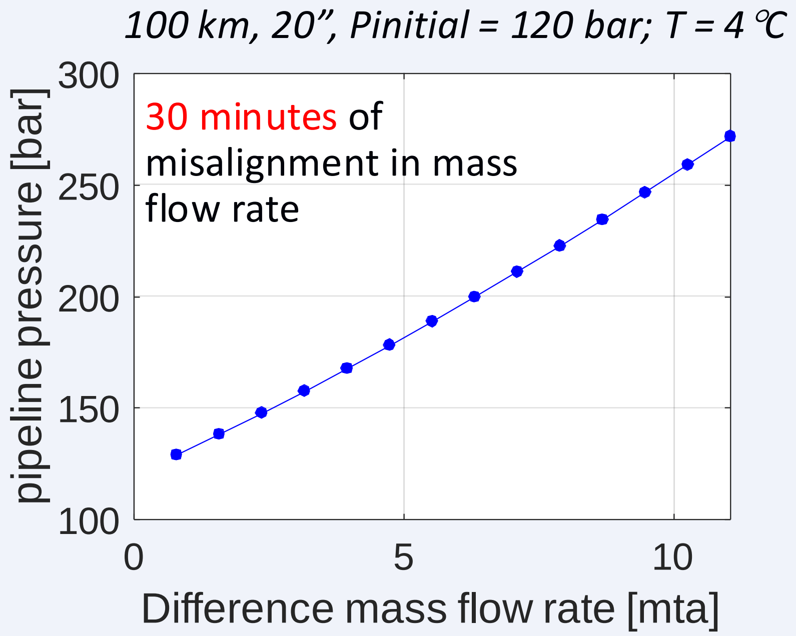
Dynamic operation

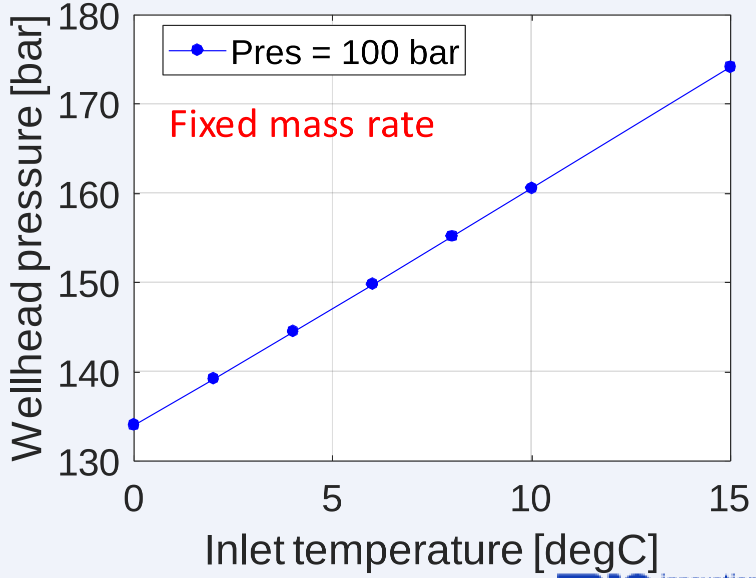
- Higher operating pressure and pressure control is also better in case of dynamic upsets
- Dynamics have large consequence
  - Friction wells
  - Liquid/dense operations
  - Influence temperature

- Slow dynamics depending on emitter type
  - Day – day cycles
  - Seasonal cycles

- Critical dynamic events
  - Sudden stop/increase in emitter flow
  - Sudden stop of well injection

- For wells and reservoir # well closures needs to be limited





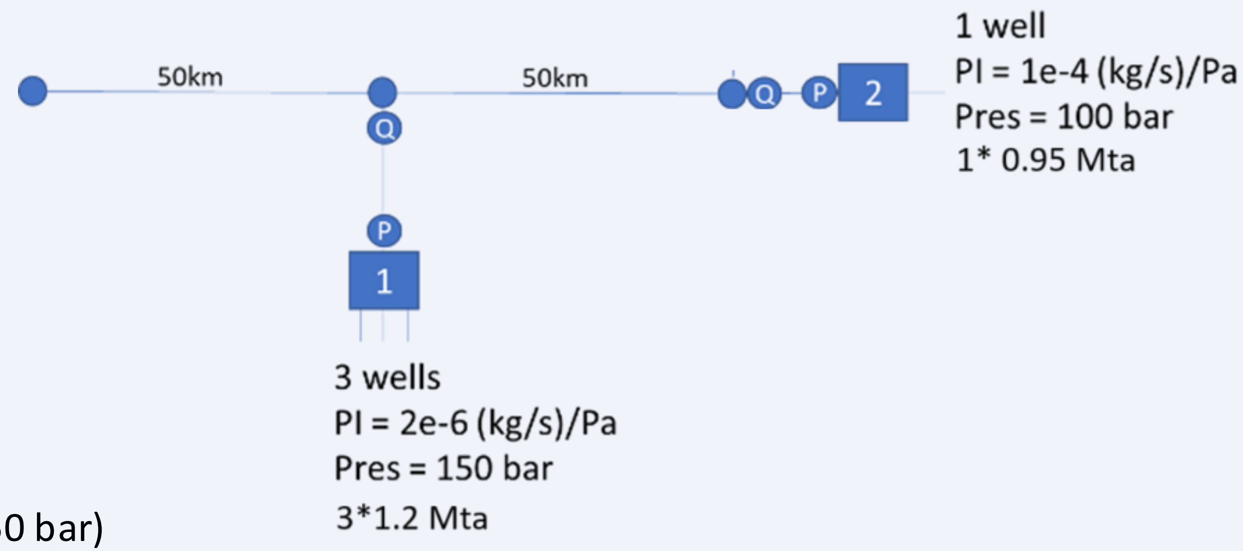
Dynamic operation

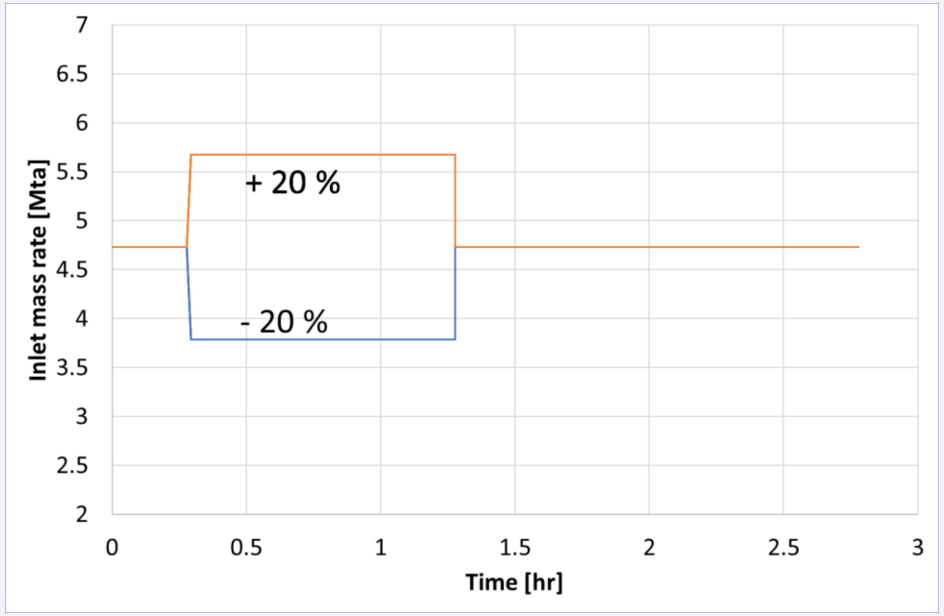
- Example
- Hubs
  - Hub1: 3 wells Pres = 150 bar
    3* 1.2 Mta
  - Hub2: 1 well Pres = 100 bar
    1* 0.95 Mta

- Pipeline: total length 100 km, 20” (buried)
  - Minimum pipeline pressure control at the Hubs (either 120 or 150 bar)
  - Flow control to Hub-2 (Hub-1 takes remainder)
  - At hub-1, two wells at flow control, one well ‘free’

- At 120 bar, all the wells are at ‘maximum’ flow at these conditions. That means at the wells the well chokes are full open.

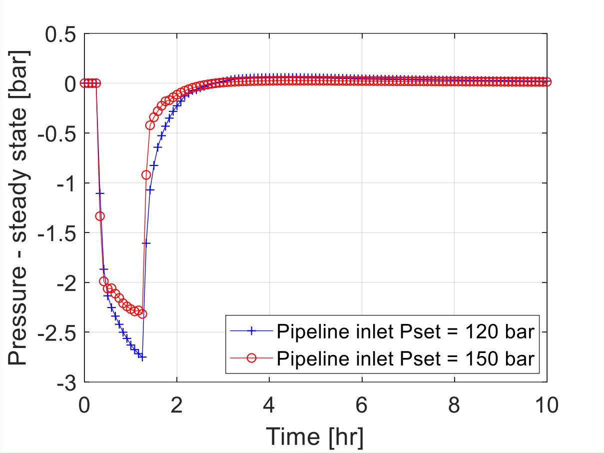
- The mass flow rate at the compressor is changed with
  - +- 20 %
  - Period for 1 hours (short term, unplanned upset)

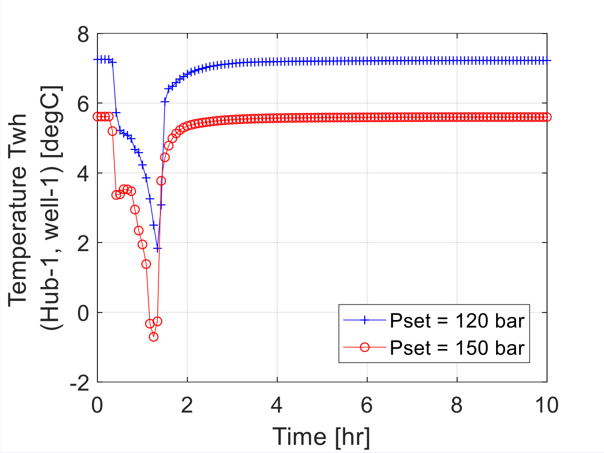


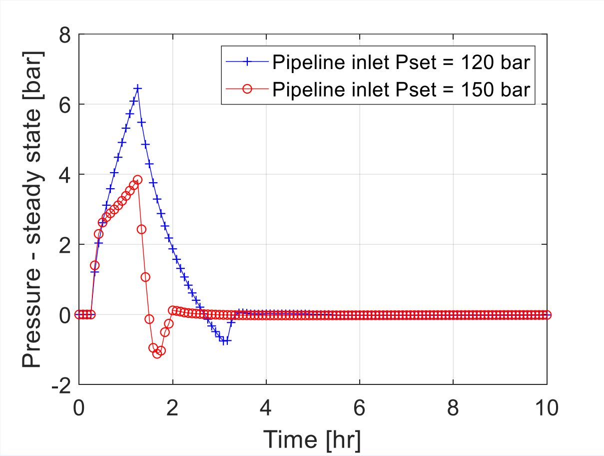


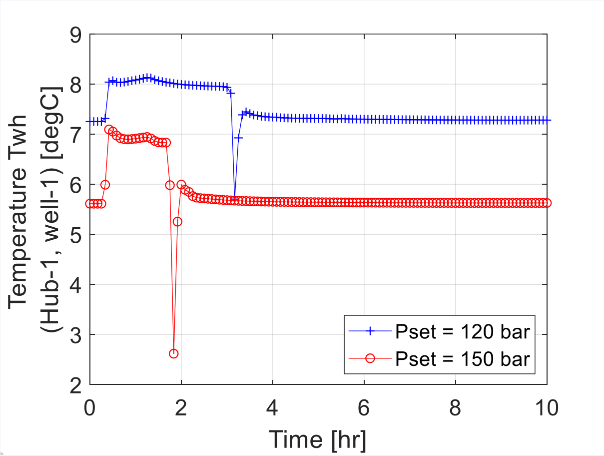
Dynamic operation

- Plotted results
  - Pipeline inlet pressure compared to steady state
  - Temperature of uncontrolled well at Hub-1. At hub-2 the flow control helps in stabilizing the well flow
- At the change in inlet mass flow rate:
  - Very sharp decrease/increase in pipeline pressure (several bars in a few minutes)
  - At 150 bar minimum pressure, the pressure swing is less than at 120 bar.
  - Sharp changes in wellhead temperatures due to reduced flow
- Pressure stabilization relatively fast after upset (~2 hours)
- Full temperature stabilization ~ 20 hours. So in practice the network is always in dynamic state









Conclusions

- CCS network operations can be complex even for simple networks:

  - Different well types impose different boundary conditions
  - For extended networks, flow control to Hubs will be required
    - However due to dynamics and measurement uncertainty, some hubs/wells will need to take flexibility

  - A common 'arche' type is that the wells are at full liquid operation
    - Limited operational range and strong influence required injection pressure on flow rate
    - This makes the network operating pressure sensitive to small changes in flow rate

  - At steady state, a limited number of low injectivity hubs/wells can dominate the required operating pressure and also therefore the response to flow dynamics

  - The time and length scales of the network are
    - Short with respect to pressure (low buffer capacity)
    - Very long with respect to temperature and therefore mass flow rates
    - Networks will be in continuous dynamics due the dynamics at emitters/stores

- A higher network pressure does allow for better distribution and control but comes at economic cost

- Collaboration between Hubs can lead to lower pressure requirements and network stabilisation

Acknowledgments

This work was done as part of the NCC program Task 11

Thank you for your attention