NETWORK DESIGN AND FLEXIBILITY FOR LOW-PRESSURE DEPLETED GAS RESERVOIRS: HOT OR COLD CO2?

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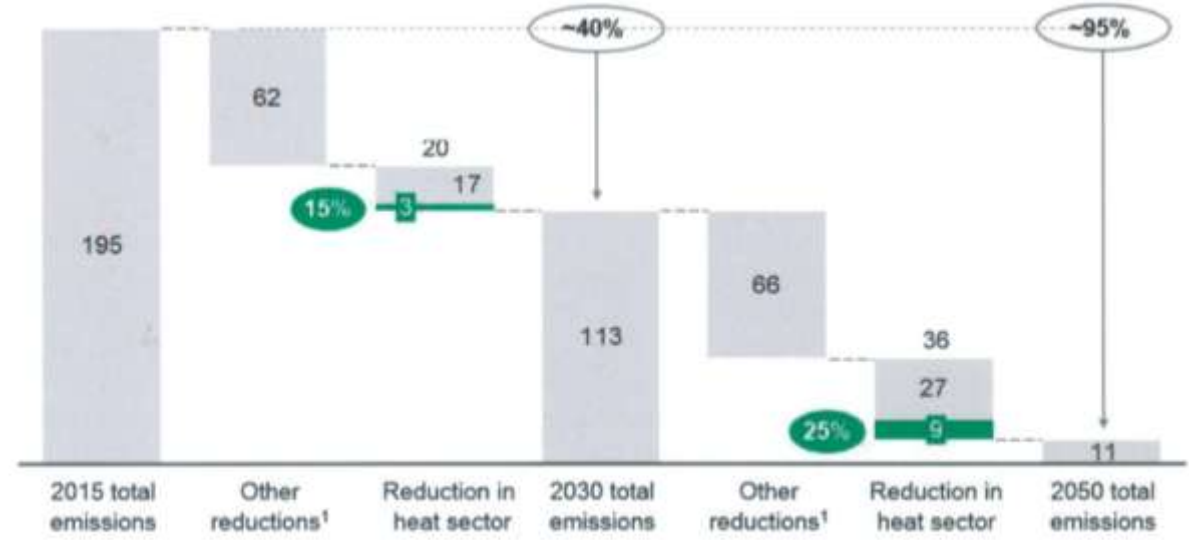
DUTCH CLIMATE AGREEMENT

- 2030 ➔ Reduction of 40%
- 2050 ➔ Reduction of 93%
- Need CO_2 storage
  to reach these targets



1 Including reduction due to decreasing demand for heat

SOURCE: Coalition Agreement 2017-2021

LOCATION, LOCATION, LOCATION

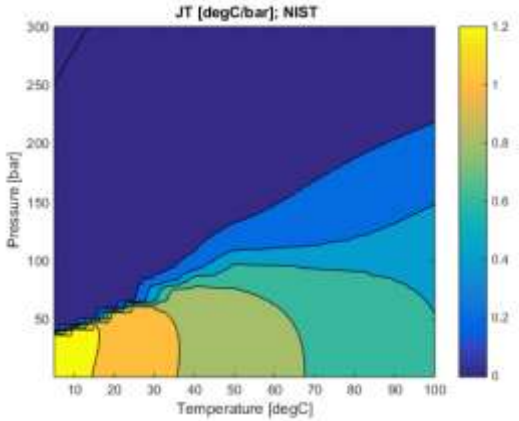
- Vast potential storage capacity beneath the North Sea (fields and formations)
- Prospective industry CCS operators require:
  - increased confidence in availability
  - sufficient capacity
  - realistic costs and timing of storage provision.
- Increase operator certainty in future storage provision
- Re-use of existing infra structure
- Injection profiles

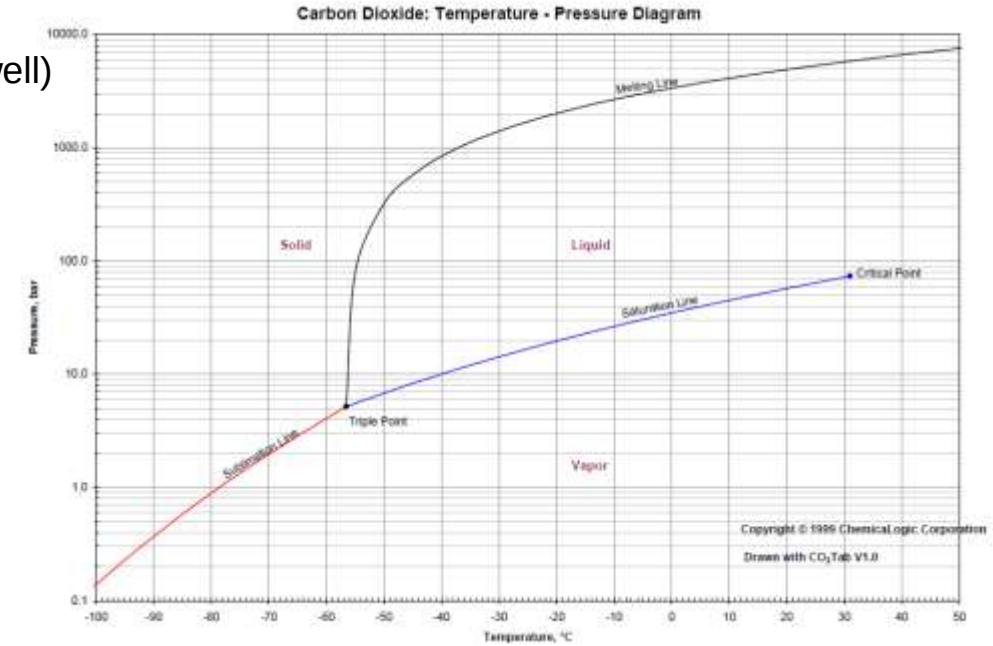
OPERATIONAL CONSTRAINTS

- Desired flow rates 15 – 170 kg/s (0.5- 5.3 Mta) (through pipeline); preferred up to 70 kg/s per well
- Start reservoir pressure 20 bar; maximum Pres = 300 bar
- Pipeline Constraints
  - Single phase flow (cool down)
  - Minimum discharge pressure compressor
- Well Constraints
  - Downhole temperature T > 15 °C (hydrate formation in reservoir)
  - Topside piping T > -10 °C (material specs)
  - (Tubing vibrations; thermal/mass flow rate constraints for reservoir, thermal gradients in well (radial and axial))

CO2 INJECTION

- Large J-T coefficient (low temperatures top of well)
- Injection at two-phase flow leading to low temperature downhole





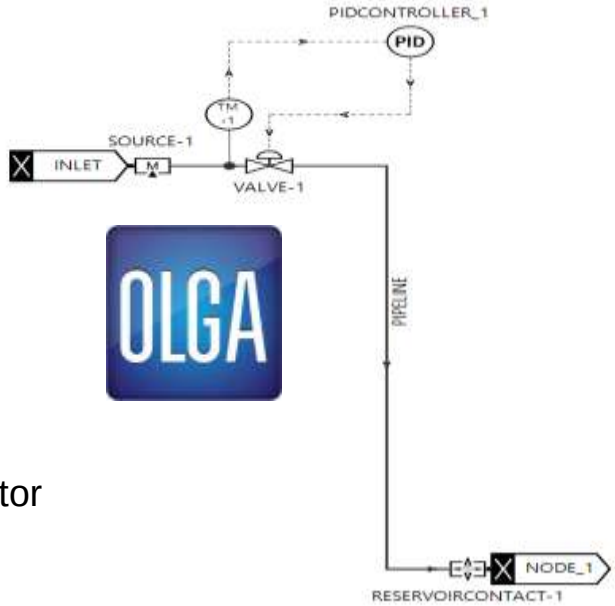
OPERATIONAL QUESTIONS?

- Hot or Cold injection?
  - Insulation of the transport pipe line
    - Feasibility vs costs of installation
    - Length of the pipeline
  - Lower well head temperatures ➔ higher injection rates (same injection pressure)

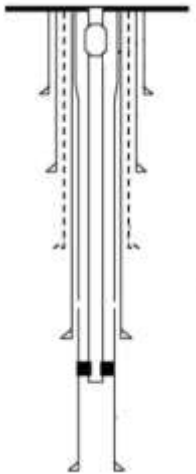
  But
  - Higher well head temperatures ➔ higher temperatures in the well and reservoir
- Diameter well
  - Larger well → lower injection pressure

  But
  - Lower pressures – lower BH temperatures in 2 phase conditions
- Well Shut-in
  - P-T profiles

CASE SETUP



- Pipeline
  - Massflow inlet
  - U value: 1.5/ m2-K
  - T_{amb}=10 °C
- Well
  - Typical for Dutch Sector
  - TVD 3.5 km
  - U value: 9.5/ m2-K
- Reservoir
  - Modelled as a PI
  - Initial pressure of 20 bar
  - 120 °C

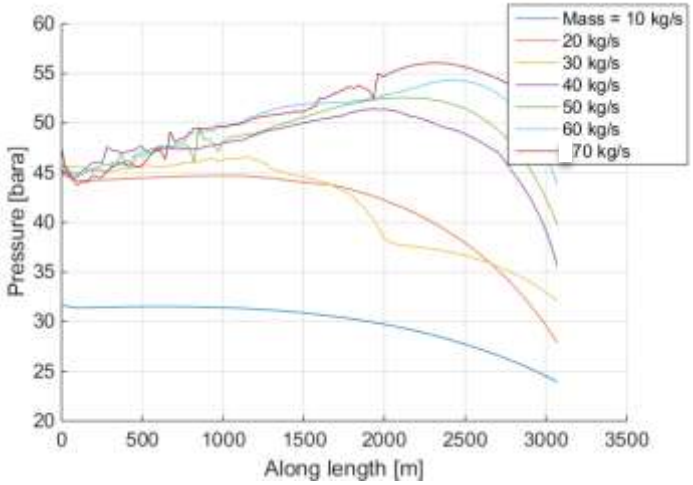


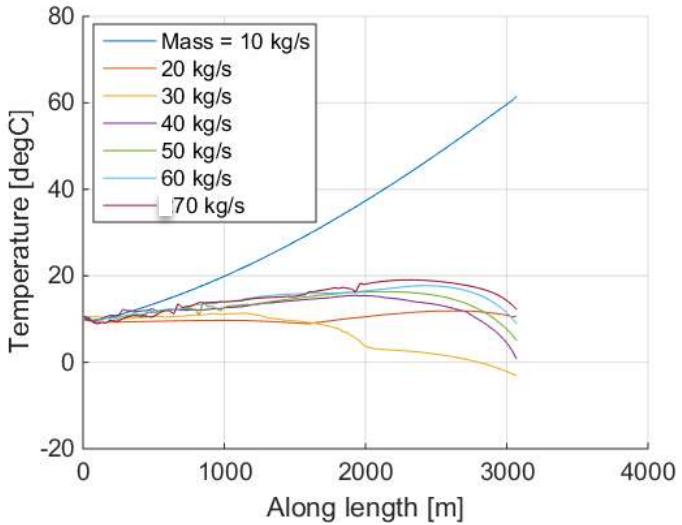
kh~8000 [mD m]

Reservoir pressure [bara]	Injectivity index [(kg/s)/Pa]
20	2.53e-5
60	4.04e-5
100	6.14e-5
200	0.000109
300	0.000129

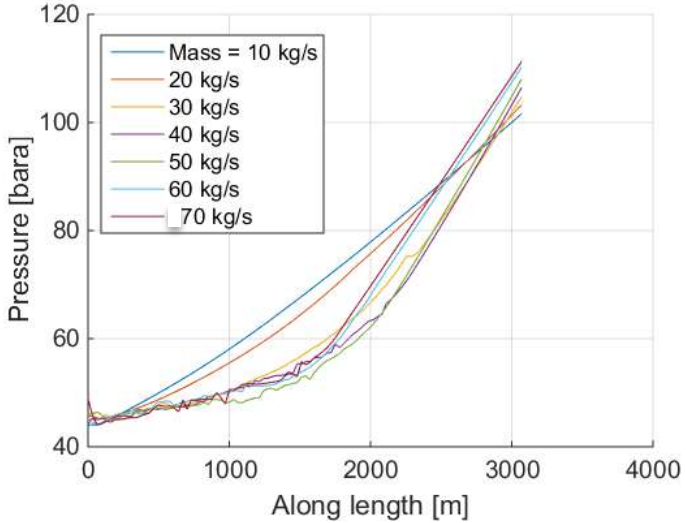
WARM OR COLD?

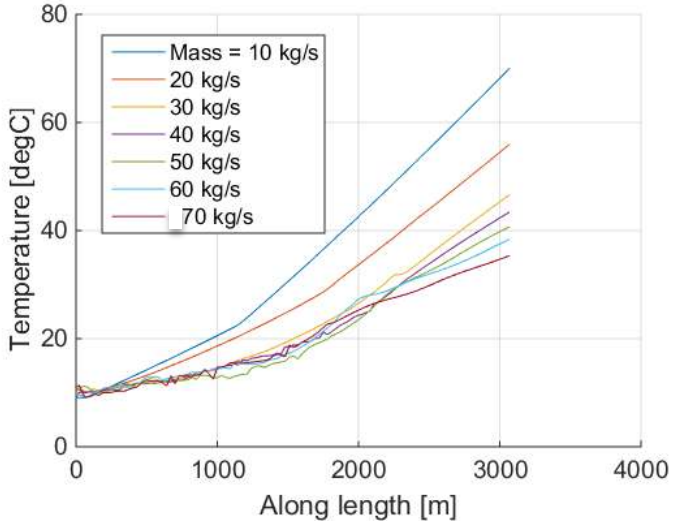
COLD INJECTION
T10 °C, PRES=20 BAR



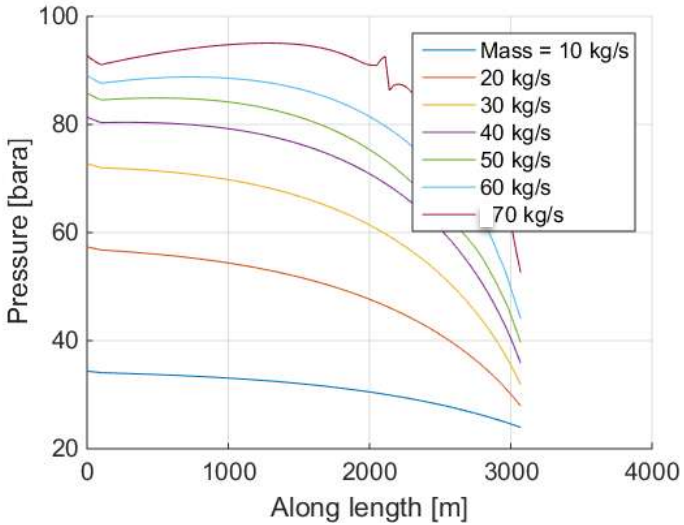


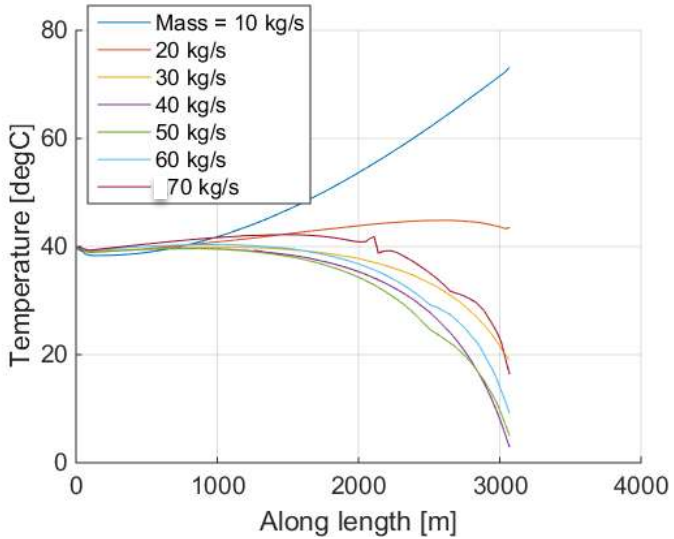
COLD INJECTION
T10 °C, PRES=100 BAR





WARM INJECTION
T40 °C, PRES=20 BAR





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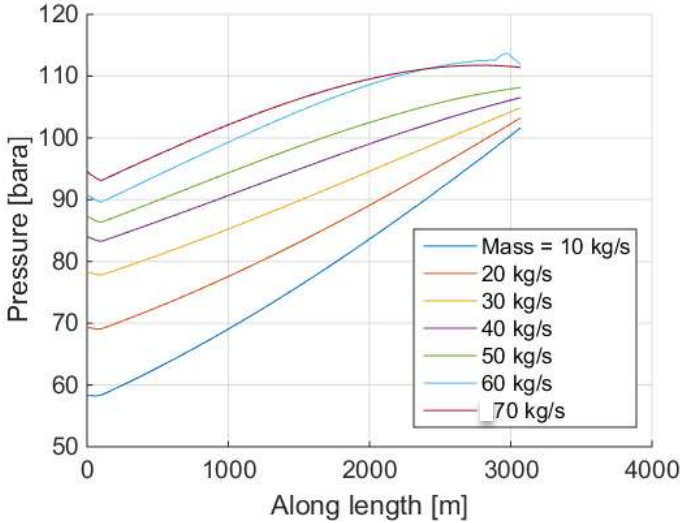
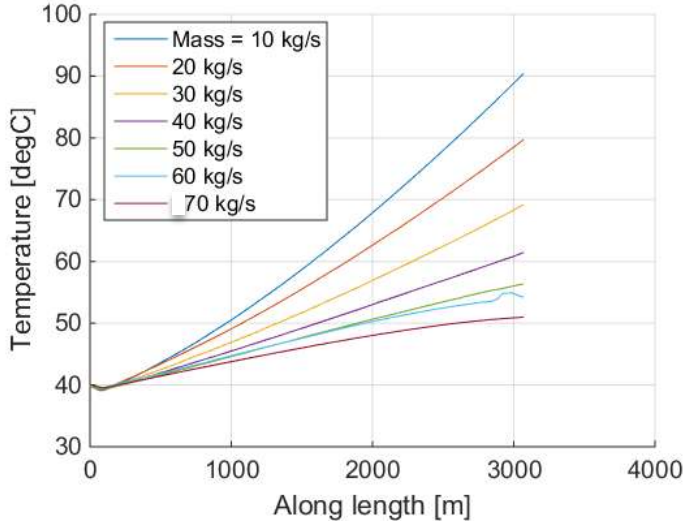




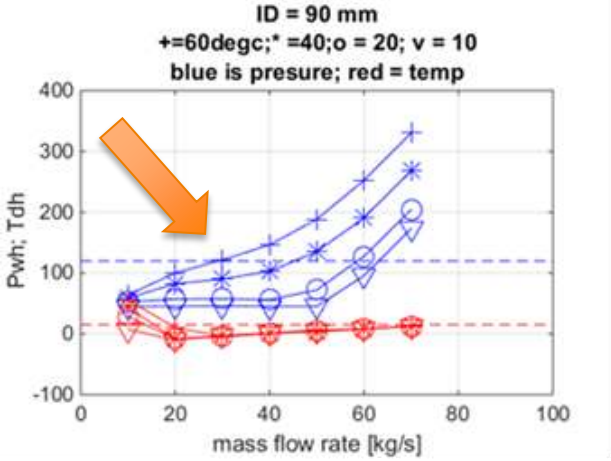
OBSERVATIONS

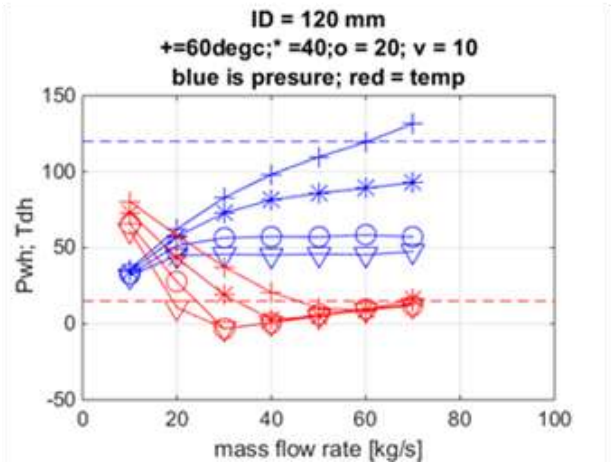
- Low reservoir pressure
  - Cold injection more difficult
  - ➔ Well in 2 phase condition
  - The range of downhole temperatures higher than 15°C increases with increasing wellhead temperature.

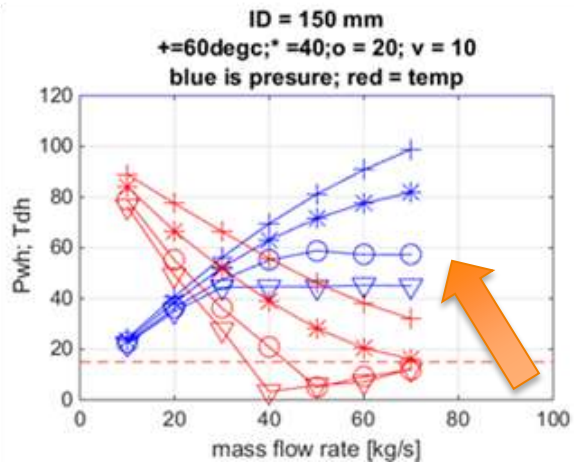
- High reservoir pressure
  - Cold injection
    - Well head pressure independent of mass flow , when in 2 phase condition
  - Warm injection
    - High injection pressure

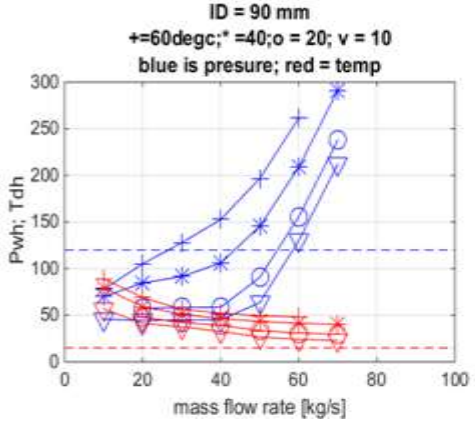
DIAMETER EFFECT

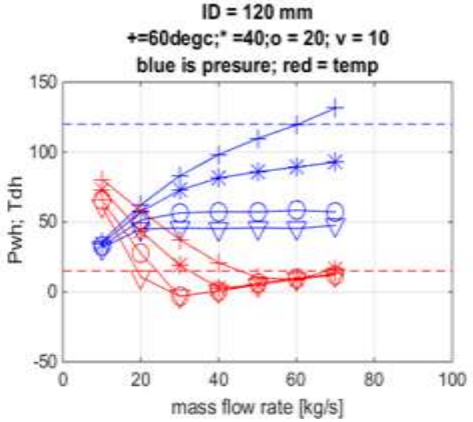
RESERVOIR 20 BAR

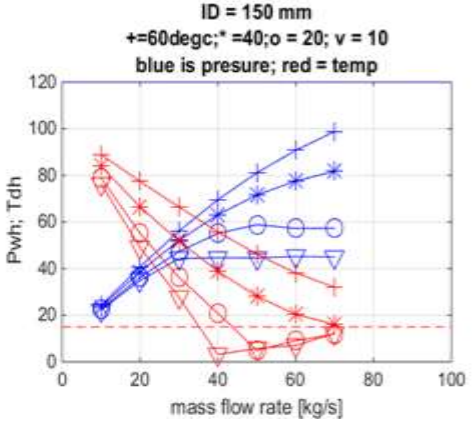




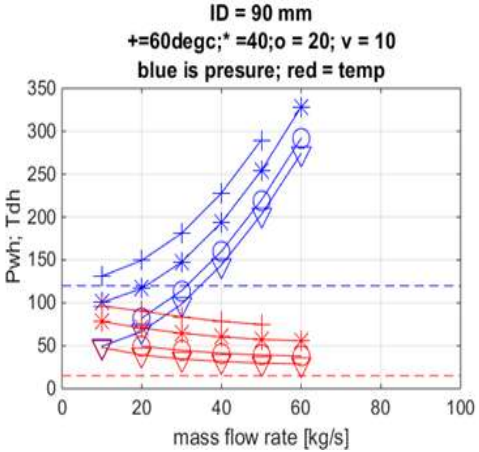


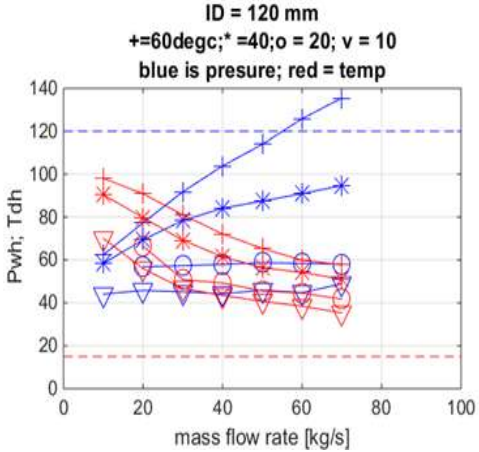


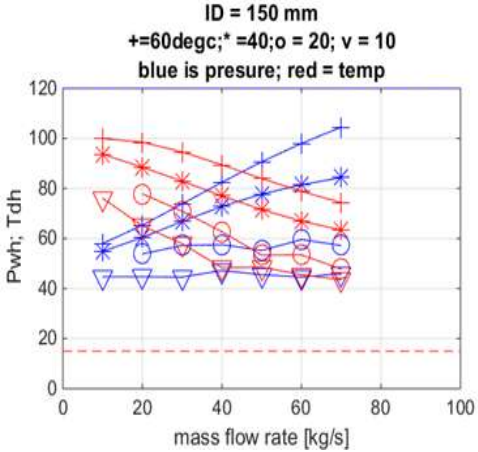




100 bar







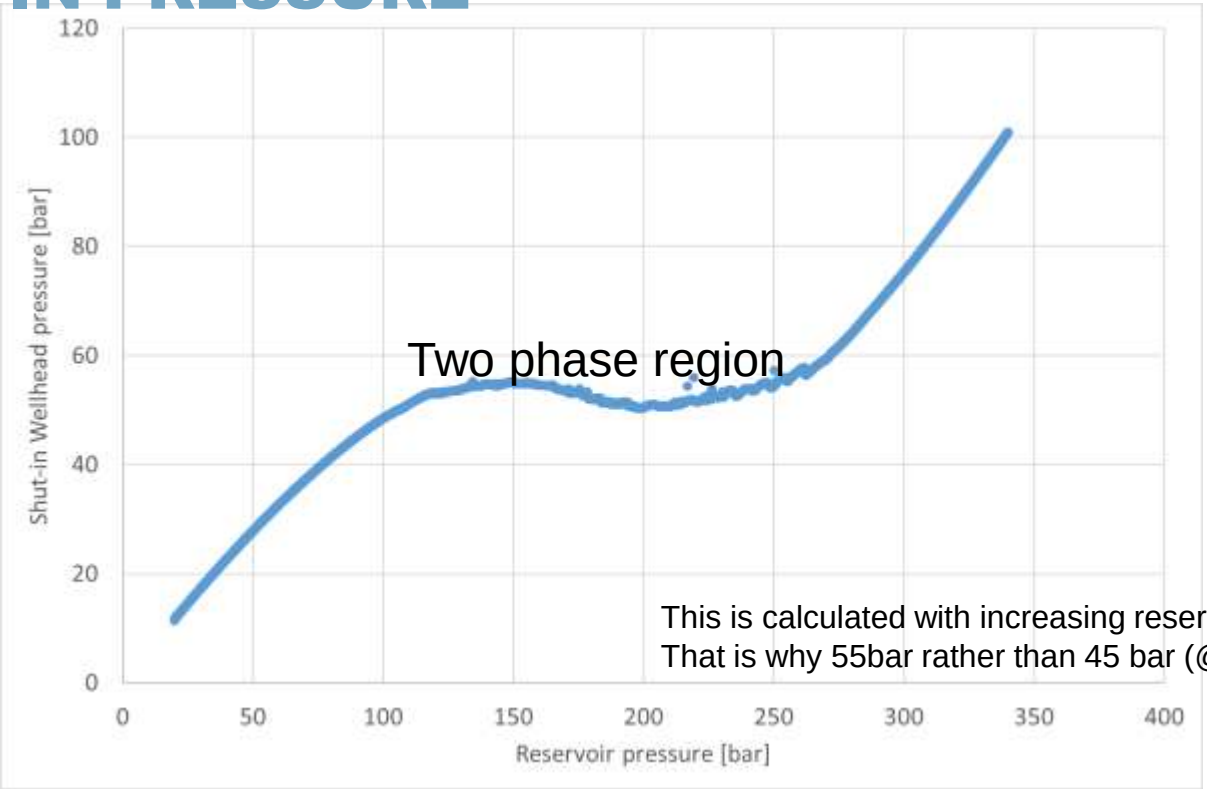
300 bar

OBSERVATIONS

- Smaller diameter
  - Higher pressure drop
  - Higher temperatures in 2 phase conditions
  - ➔ advantage for low reservoir pressures

- Larger diameters
  - Lower pressure drop
  - Lower temperatures in 2 phase conditions
  - ➔ advantage for high(er) reservoir pressures

SHUT-IN PRESSURE

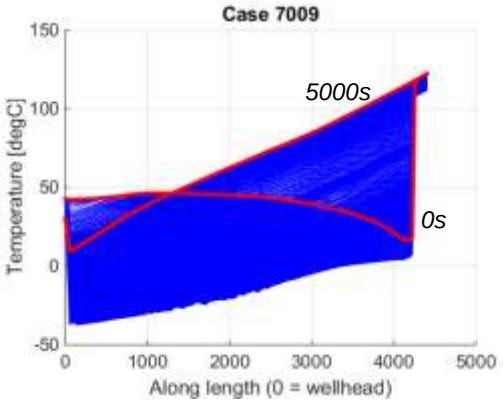


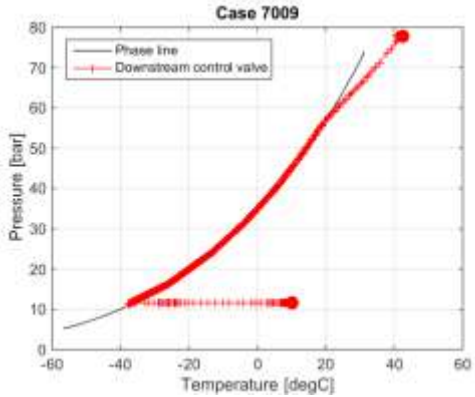
This is calculated with increasing reservoir pressure in time
That is why 55bar rather than 45 bar (@ 10deg)

WELL SHUTIN

- Shut-in
  - Reservoir pressure 20 bar (30 kg/s)
  - Well shut in (~20 s)
- Red lines t = 0s & t = 5000s
- Blue lines 1 s interval

- Lowest temperatures -37 °C
  - Corresponding to phase line
  - Almost complete well drops down in pressure and therefore temperature





CONCLUSIONS

- When well is in 2 phase flow → P & T are closely coupled
  - WHP no measure for flowrate or BHP
    - Mass flow controllers to monitor the flowrate
- Above reservoir pressure of 50 bar no issues with temperature
- Several counteracting phenomena observed
  - e.g. larger diameter well lower injection rate
- Specific design required with mix of wells to be flexible at all stages of injection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