Depressurization of CO_2 pipelines – models and methods

Motivation

- Depressurization of a high-pressure CO_2 pipeline will cause phase change
- Phase change will cause a significant temperature drop
- Low temperature will cause the steel pipe to become brittle
- A brittle pipe could cause a rupture and severe damage
- We wish to estimate the temperature drop during a depressurization

Fluid dynamics

Mass conservation: $$\frac{\partial \rho}{\partial t} + \frac{\partial \rho v}{\partial x} = 0$$

Mixture density: $$\rho = \alpha_g \rho_g + \alpha_l \rho_l$$

Momentum conservation: $$\frac{\partial \rho v}{\partial t} + \frac{\partial (\rho v^2 + p)}{\partial x} = 0$$

Mixture energy: $$E = \rho(e + \frac{v^2}{2})$$

$$e = \alpha_g \rho_g e_g + \alpha_l \rho_l e_l$$

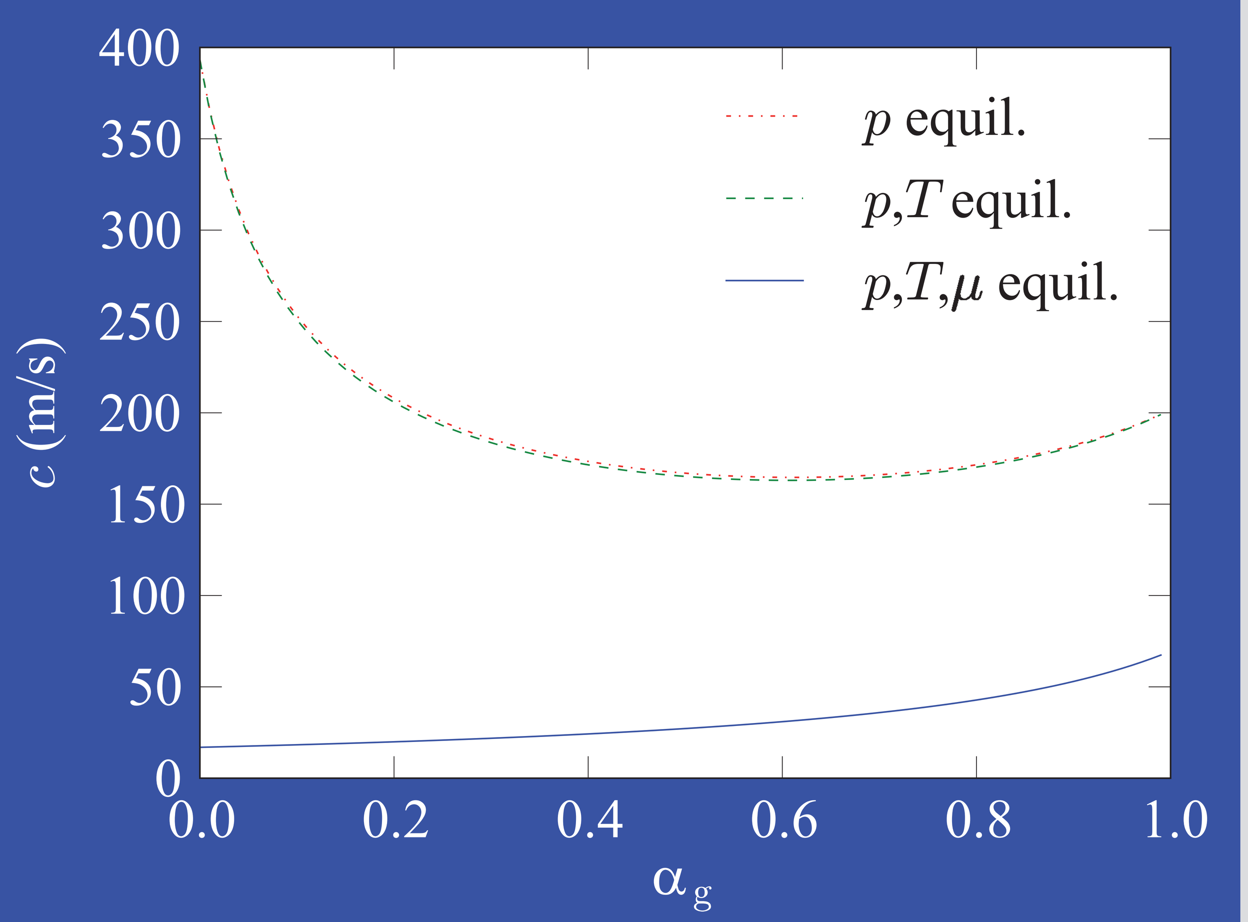
Energy conservation: $$\frac{\partial E}{\partial t} + \frac{\partial [v(E+p)]}{\partial x} = 0$$

Thermodynamics

We use the stiffened-gas equation of state (EOS) as our thermodynamical model.

Sound velocity

We assume full equilibrium (pressure, temperature and chemical potential between the two phases), which gives a discontinuous sound velocity.



Sound velocities for models with different equilibrium conditions

Numerical method

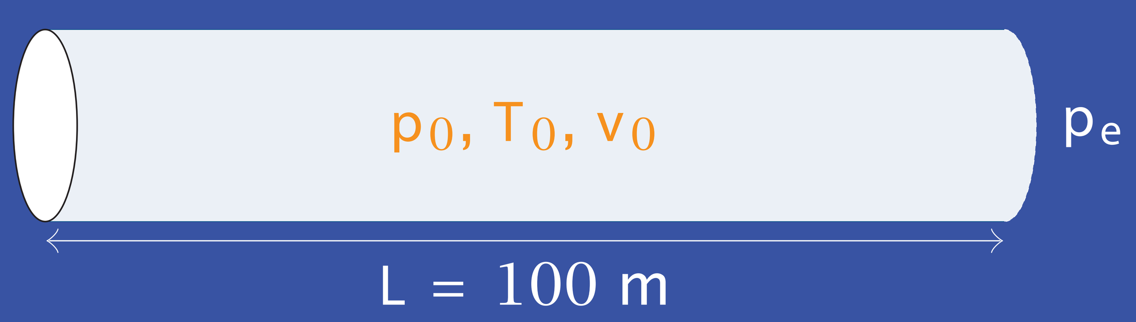
To solve the model numerically, we need a proper numerical method.

We solve the equation system with a finite-volume scheme, in which one divides the domain into control volumes.

Numerical schemes

We compare two numerical schemes:

- The upwind Roe scheme, which propagates each wave in the appropriate direction. It is based on transforming the equation system to a quasi-linear system: $\boldsymbol{q}_t + \hat{A}_{i+1/2}\, \boldsymbol{q}_x = 0,$
- The centred MUSTA scheme, which does not resolve the wave structure. It finds the flux at each cell interface by solving the equations on a fine local grid, and then uses the local flux in the global grid.



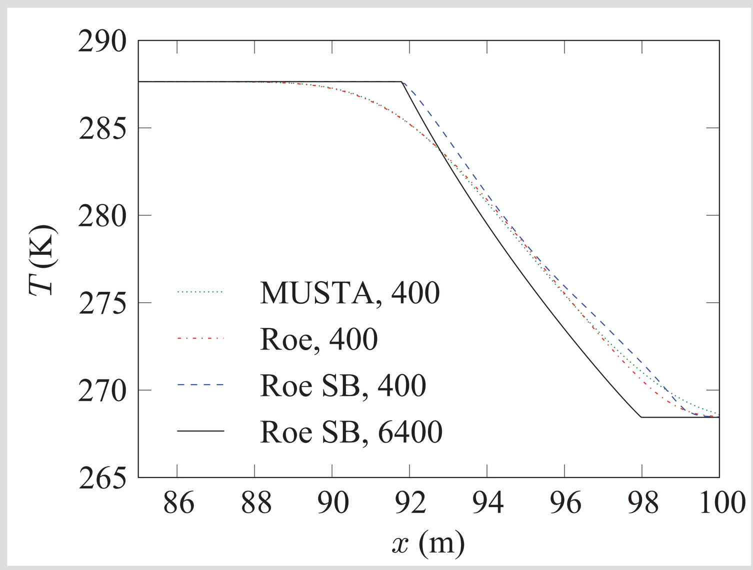
Initial conditions

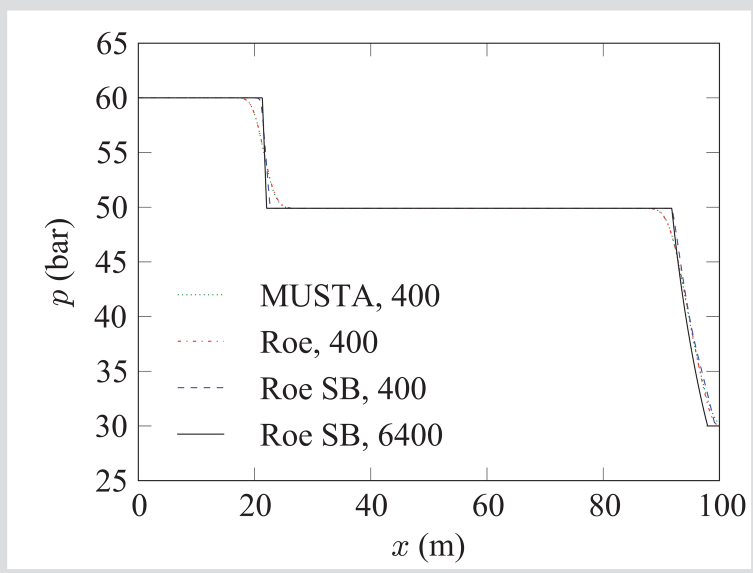
Depressurization results

Initial conditions in a 100 m pipe:

- Pressure p_0 = 60 bar
- Temperature T_0 = 288K ≈ 15 °C
- Velocity v_0 = 0 m/s
- Liquid CO_2

At time t=0, the right end of the pipe is opened and exposed to an external pressure of p_e=30 bar.





Temperature and pressure after t = 0.2 s.

Conclusion

- The Roe scheme with Superbee limiter performs well
- The MUSTA scheme is more diffusive
- The depressurization wave splits in two due to the discontinuous sound velocity
- Further work may model the phase transfer as a source term

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