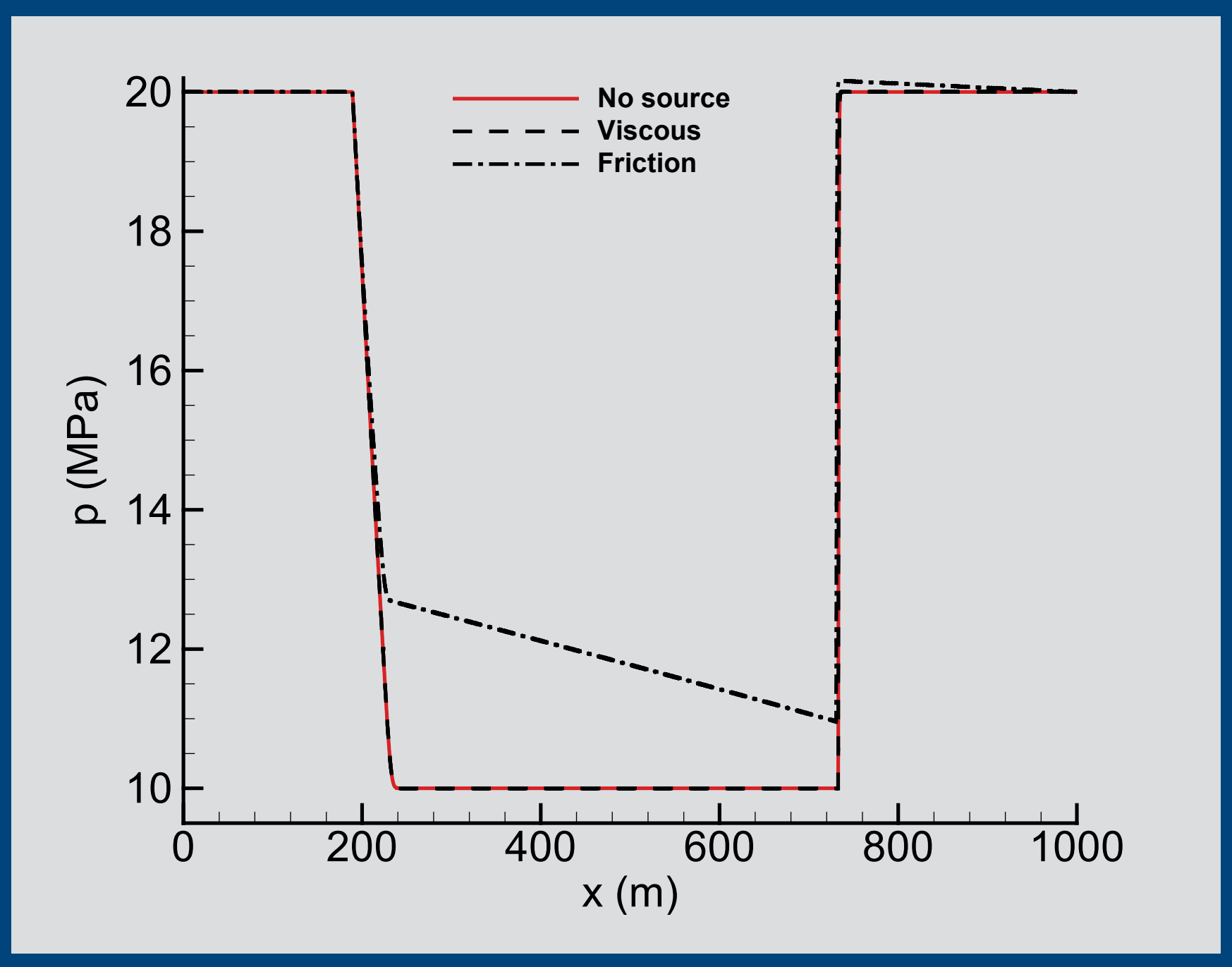
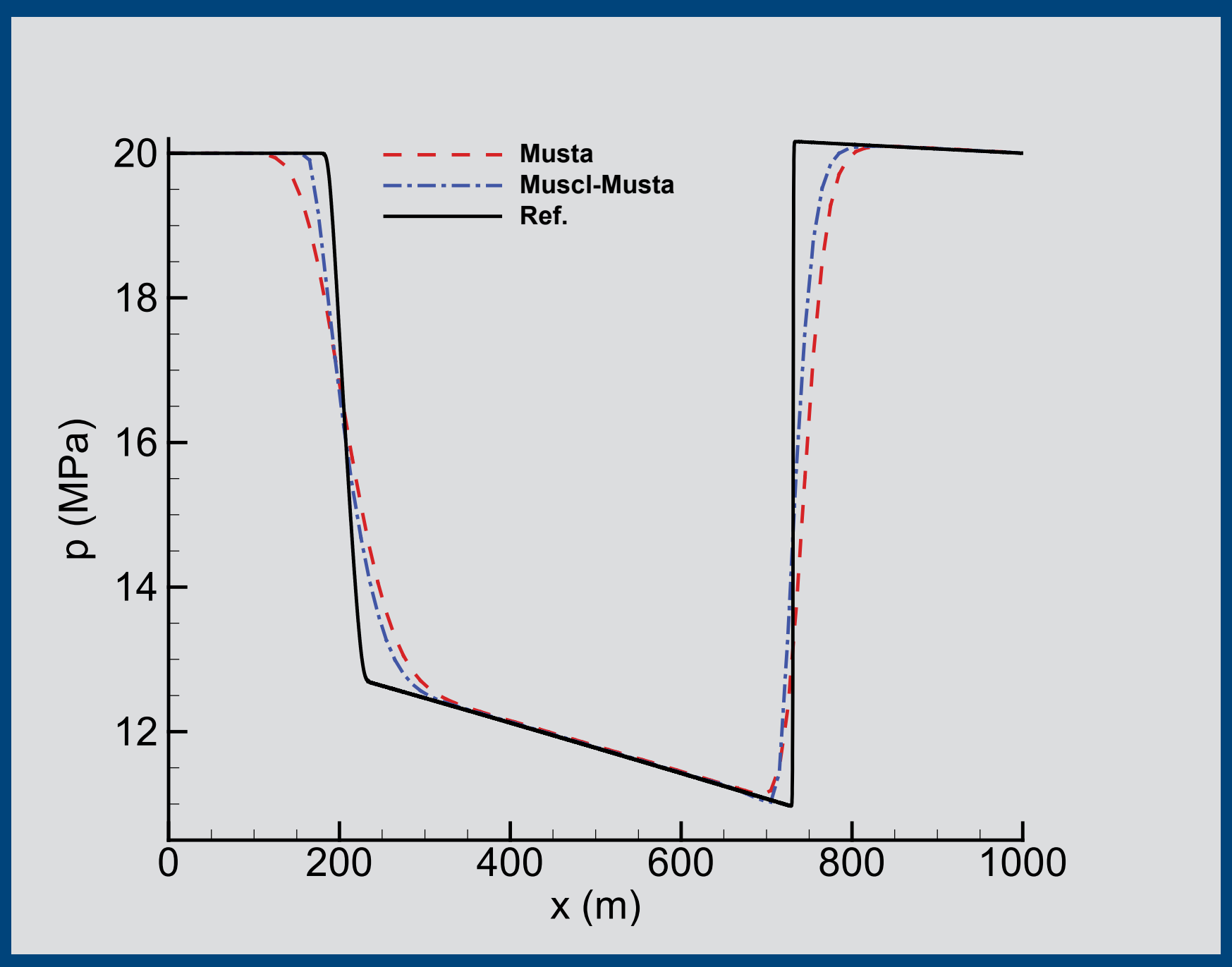
CO_2 Dynamics

Fundamental aspects of transport and injection of CO_2 with impurities

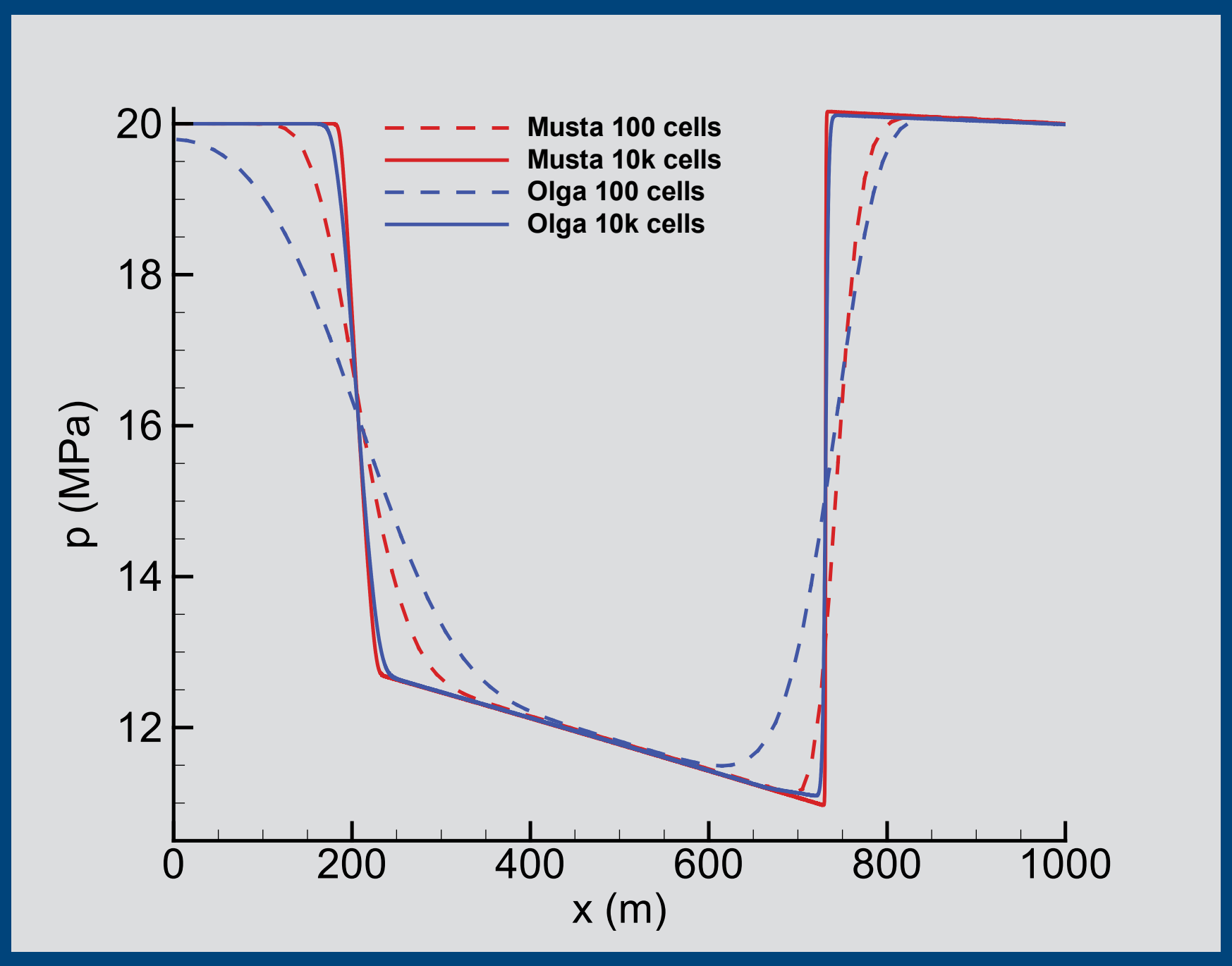
Effect of sub-models



Effect of second-order scheme



Comparison between OLGA and MUSTA



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Depressurization of CO_2 – a numerical benchmark study

Motivation

- Important in CO_2 transport:
  - Safe procedures for injection into reservoirs, first fill and depressurization of pipelines
  - Pipeline integrity analysis
- A depressurization of a CO_2 pipeline will normally lead to phase transition
- There is a need for numerical methods that are able to capture pressure waves in a robust and efficient manner.
- Benchmark of numerical methods: Need to consider the same model.
- OLGA: Industry standard. Here: Version 5.3.2.
- MUSTA method: Robust and relatively accurate. Independent of equation of state (EOS).

Models

- 1D single-phase compressible flow:

$$\begin{aligned}\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x} &= 0,\\ \frac{\partial(\rho u)}{\partial t}+\frac{\partial(\rho u^2)}{\partial x}+\frac{\partial p}{\partial x} &= \frac{4}{3}\frac{\partial}{\partial x}\left(\mu\frac{\partial u}{\partial x}\right)-F_w,\\ \frac{\partial E}{\partial t}+\frac{\partial\left[(E+p)u\right]}{\partial x} &= \frac{4}{3}\frac{\partial}{\partial x}\left(\mu u\frac{\partial u}{\partial x}\right)-uF_w.\end{aligned}$$

Total energy: $E = \rho(e+1/2u^2)$

Wall friction: $F_w = \frac{f(\mathrm{Re},\varepsilon)}{d}\frac{1}{2}\rho u^2,$

Where f is the Colebrook-White friction factor

- Stiffened-gas equation of state $p(\rho,e)=(\gamma-1)\rho e-\gamma p_\infty$

  and $T(\rho,e)=\frac{1}{c_v}\left(e-\frac{p_\infty}{\rho}\right),$

Numerical simulations

- Pipe of length 1000 m and inner diameter 0.3 m. Closed at left-hand side
- Initially motionless CO_2 at p = 20 MPa and T = 300 K.
- At t = 0, the pressure at the right-hand side is reduced to 10 MPa and then set back to 20 MPa at t = 1 s.
- CFL = 0.9 for both OLGA and MUSTA
- A rarefaction wave followed by a shock wave propagate to the left.
- Results shown at t = 1.51 s.

Parameters

- Equation-of-state parameters →
- Dynamic viscosity: $\mu = 8.4 \times 10^{-5}$ Pa s
- Relative pipe roughness: $\varepsilon = 1.67 \times 10^{-4}$

Quantity	Symbol (unit)	
Specific-heat ratio	γ (–)	1.4
Spec. heat at const. pres.	c_p (J/(kg K))	2400
Reference pressure	p_∞ (Pa)	1.5×10^8

Effect of sub-models

- MUSCL-MUSTA
- CFL=0.5, 5000 cells
- Viscous term has nothing to say
- Wall friction gives pressure drop, but does not smear waves

Effect of second-order scheme

- MUSTA vs. MUSCL-MUSTA
- 100 cells
- Ref: MUSTA, 10000 cells
- Second-order scheme enhances resolution

Comparison between OLGA and MUSTA

- The methods appear to converge for fine grids, above 10000 cells
- The wave speeds agree with each other and the reference speed of sound (530 m/s)
- MUSTA gives a sharper wave resolution on coarse grids

Conclusions

- Due to the thermophysical properties, pipeline transport of CO_2 poses new challenges compared to transport of natural gas.
- An accurate and efficient numerical method is one important building-block of a CO_2 pipeline simulation tool
- In this work, numerical results from the commercially available OLGA code have been compared to calculations using the multi-stage (MUSTA) centred scheme
- The two numerical methods appear to converge on fine grids, but on coarse grids, the method in OLGA produced more smeared-out results
- A smearing-out of pressure waves might lead to an underestimation of the water-hammer effect and pipe cooling during depressurization
- Future work will include a benchmark case accounting for phase transfer