New CFD-based method for erosion prediction in control valves

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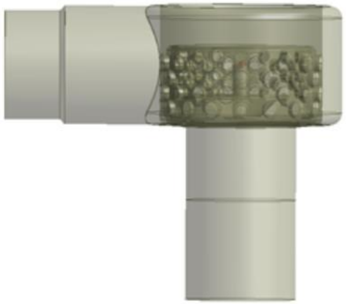
The impact erosion issue in control valves

What is the impact erosion?

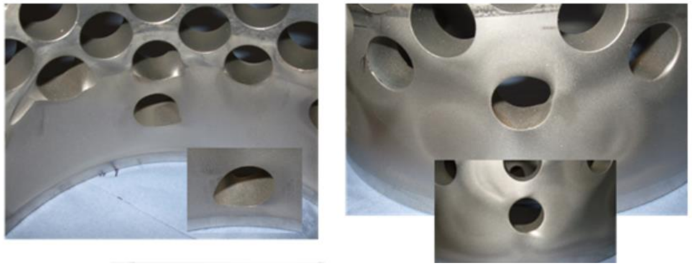
The **impact erosion** is the loss of material from a surface subjected to the impingements of solid particles (even very small) dragged by a fluid.



Why it is a relevant problem in control valves?

Eroson may cause:

- Change of the valve's performace
- Valve's life reduction
- Management issues
- Service downtime



Gharaibah et al., OTC 2013, Paper No 24271

Main engineering concerns:

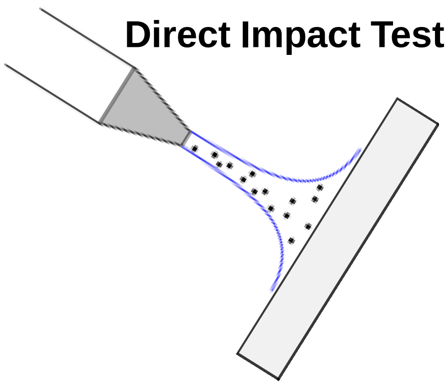
- Identification of the **erosion hotspots** locations
- Erosion rate estimation

Proper valve service management

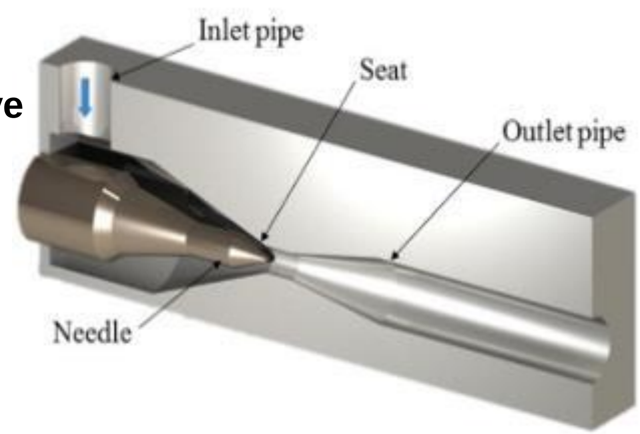
Presentation outline

- Available practical approaches to erosion
- How is erosion estimated via CFD ?
- Our method
- First benchmark cases
  - Direct Impact Test
  - Needle & Seat choke valve
- Conclusion and future developments

Direct Impact Test



Choke Valve



Available practical approaches to erosion

Experimental Approach → Direct evaluation of the material losses:

- Expensive
- Limited testable device sizes
- Not generalizable results

Numerical Approach (two steps)

→ Evaluation of particle parameters via CFD

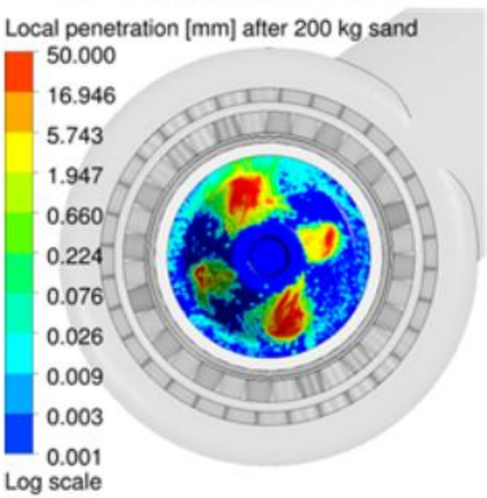
→ Empirical erosion model

- Applicable only to dilute flows (concentration <0.1%)
- No quantitative prediction
- No geometry changes

Why these limitations ?

Actually, the excessive computational cost …

Available practical approaches to erosion



Just an example…

Erosion in a choke valve (Gharaibah et al., 2013)

Part	Exp. [g]	Sim. [g]	Ratio*
Guide	15.7	3.21	4.89
Lower guide	18	4.67	3.86
Plug head	325.2	118.1	2.75
Plug nose	32.9	1.61	20.40
Seat	8	0.35	23.15
Proposed scaling factor for simulation results		5	

*: Ratio of experimental to predicted weight loss.

$$\frac{\text{Exp.}}{\text{CFD}} \approx 4\text{-}20!!!$$

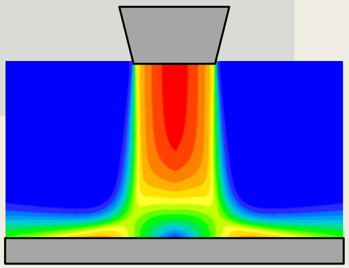
The main deviations (R=20-23) are imputable to the geometry changes

How is the erosion estimated via CFD ?

Dilute flows only (C<0.1%) → «one way coupling» assumption (particles don't affect the fluid flow)

Fluid simulation

RANS equations

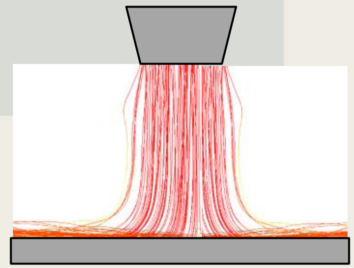


$$\mathbf{U}, P, k, \varepsilon, \ldots$$

Numerical solution of the Reynolds-Averaged Navier-Stokes Equations (RANS)

Particle Tracking

Newton's 2nd law

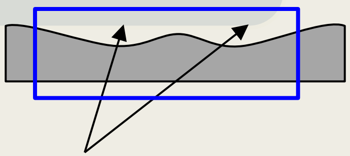


$$m_p \frac{d\mathbf{v}}{dt} = \sum \mathbf{F}$$

Numerical determination of all particles' trajectories

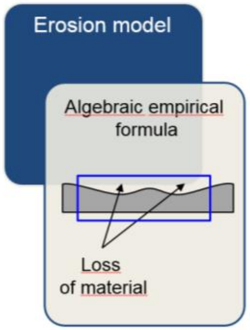
Erosion model

Algebraic empirical formula

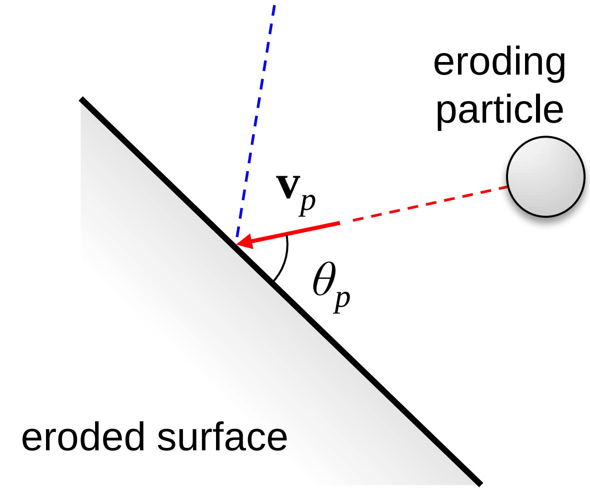


Loss of material

How is the erosion estimated via CFD ?



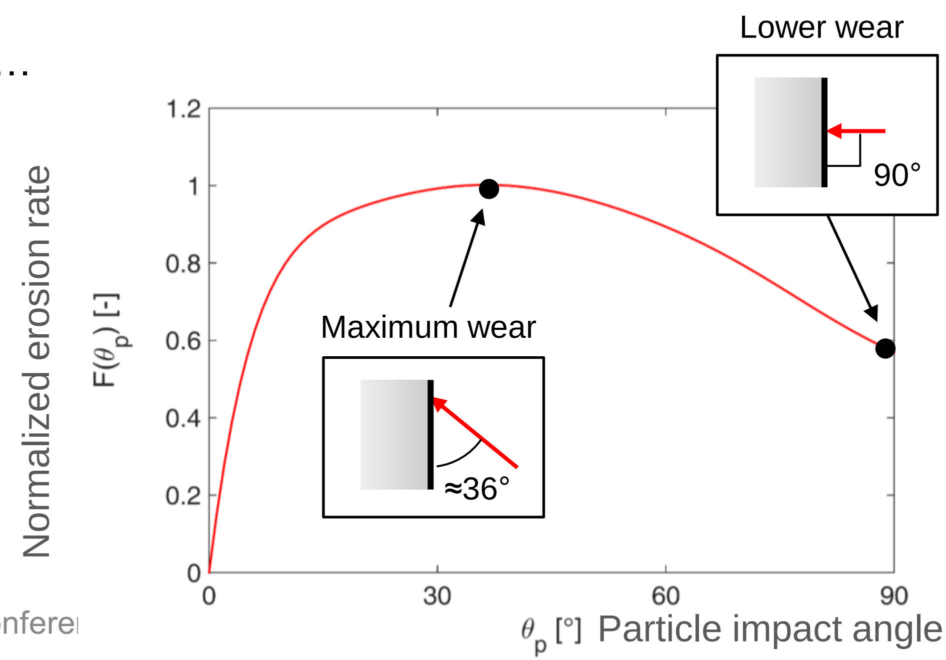
Empirical estimation of material loss



Main input parameters (by the particle tracking):

- Particle impact velocity v_p
- Particle impact angle θ_p
- Particle mass m_p
- Material properties: density, hardness, …

Effect of the impact angle



Our method

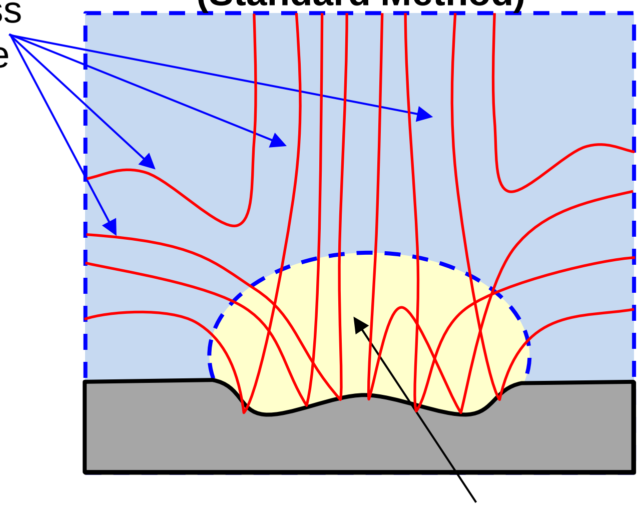
Goal → the reduction of computational burden

Idea → do heavy calculations only where needed

How → with same numerical tricks

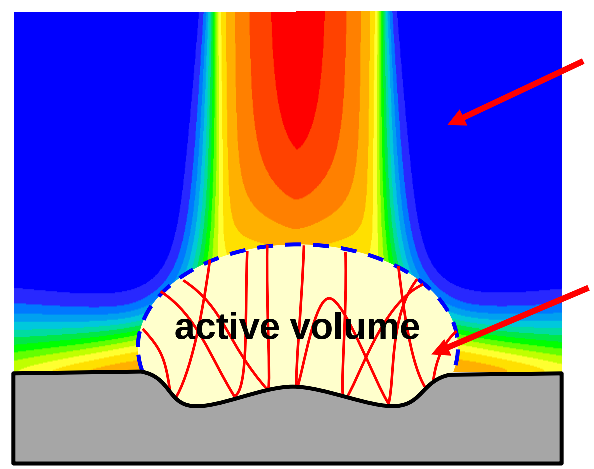
(EE simulation + active volume + interface laws)

FULL Eulerian-Lagrangian (Standard Method)



Eulerian-Eulerian simulation

NEW METHOD



Our method

EE simulation (mean solid flow)

$$\nabla\cdot\left[\rho_f\left(1-\Phi_{EE}\right)\mathbf{U}_{EE}\right]-\nabla\cdot\left(\rho_f\overline{\phi'_{EE}\,\mathbf{u}'_{EE}}\right)=0$$

$$\nabla\cdot\left(\Phi_{EE}\rho_p\mathbf{V}_{EE}\right)+\nabla\cdot\left(\rho_p\overline{\phi'_{EE}\,\mathbf{v}'_{EE}}\right)=0$$

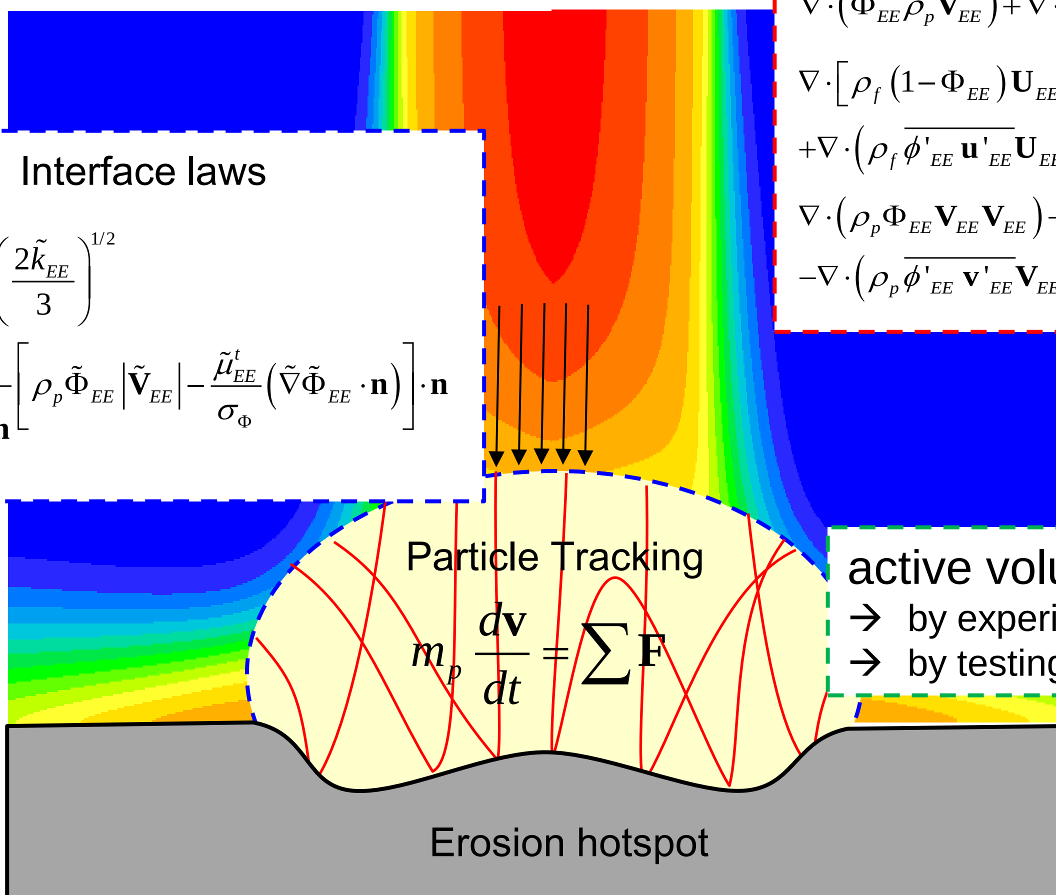
$$\nabla\cdot\left[\rho_f\left(1-\Phi_{EE}\right)\mathbf{U}_{EE}\mathbf{U}_{EE}\right]-\nabla\cdot\left[\left(1-\Phi_{EE}\right)\left(\mu+\mu_{EE}^{t}\right)\nabla\mathbf{U}_{EE}\right]=$$
$$+\nabla\cdot\left(\rho_f\overline{\phi'_{EE}\,\mathbf{u}'_{EE}}\mathbf{U}_{EE}\right)=-\left(1-\Phi_{EE}\right)\nabla P_{EE}+\mathbf{M}_{EE}$$

$$\nabla\cdot\left(\rho_p\Phi_{EE}\mathbf{V}_{EE}\mathbf{V}_{EE}\right)-\nabla\cdot\left(\Phi_{EE}\mu_{EE}^{t}\nabla\mathbf{V}_{EE}\right)+$$
$$-\nabla\cdot\left(\rho_p\overline{\phi'_{EE}\,\mathbf{v}'_{EE}}\mathbf{V}_{EE}\right)=-\Phi_{EE}\nabla P_{EE}-\mathbf{M}_{EE}$$

Interface laws

$$\mathbf{v}_i=\tilde{\mathbf{V}}_{EE}+\xi\left(\frac{2\tilde{k}_{EE}}{3}\right)^{1/2}$$

$$\dot{m}_P=\frac{A_P}{\frac{\tilde{\mathbf{V}}_{EE}}{\left|\tilde{\mathbf{V}}_{EE}\right|}\cdot\mathbf{n}}\left[\rho_p\tilde{\Phi}_{EE}\left|\tilde{\mathbf{V}}_{EE}\right|-\frac{\tilde{\mu}_{EE}^{t}}{\sigma_\Phi}\left(\tilde{\nabla}\tilde{\Phi}_{EE}\cdot\mathbf{n}\right)\right]\cdot\mathbf{n}$$



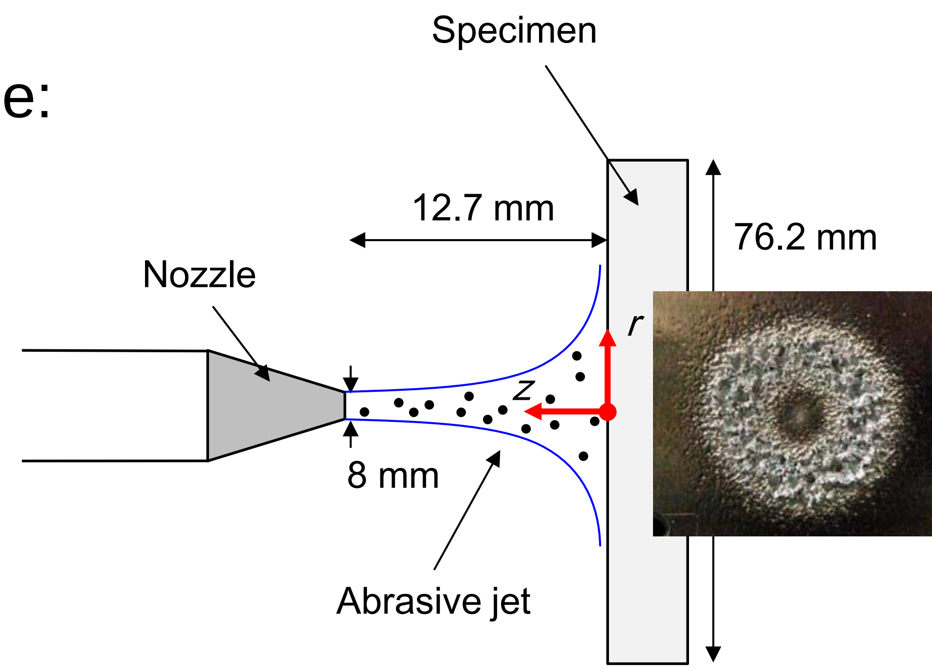
$$m_p\frac{d\mathbf{v}}{dt}=\sum\mathbf{F}$$

active volume definition
- → by experience
- → by testing particles

First benchmark case: direct impact test

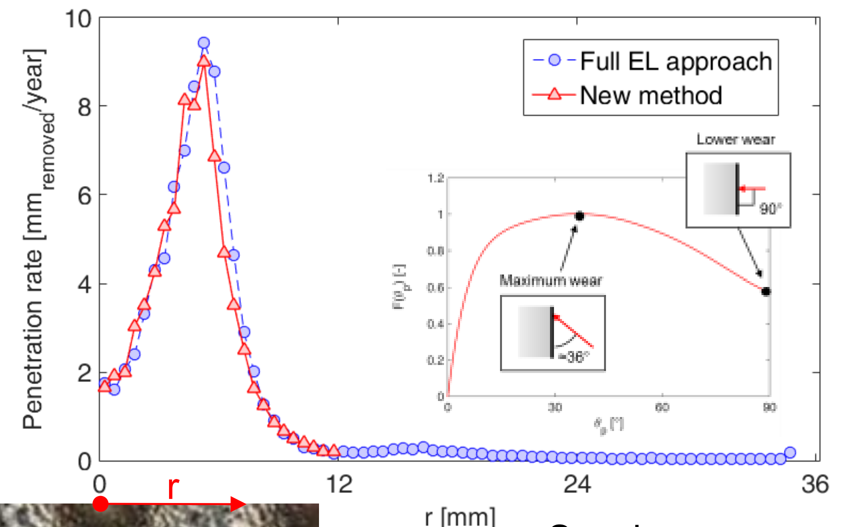
Preliminary tests concerned the normal impingement of an **abrasive submerged jet** against a specimen of erodible material.

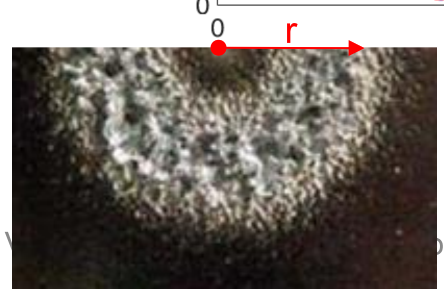
- sand particles with d_p=120 μm
- volume fraction = 0.1%
- 2D, axisymmetric domain



Compared to the full Eulerian-Lagrangian approach:

- **-60% disk space**
- **-55% CPU time for particle tracking**

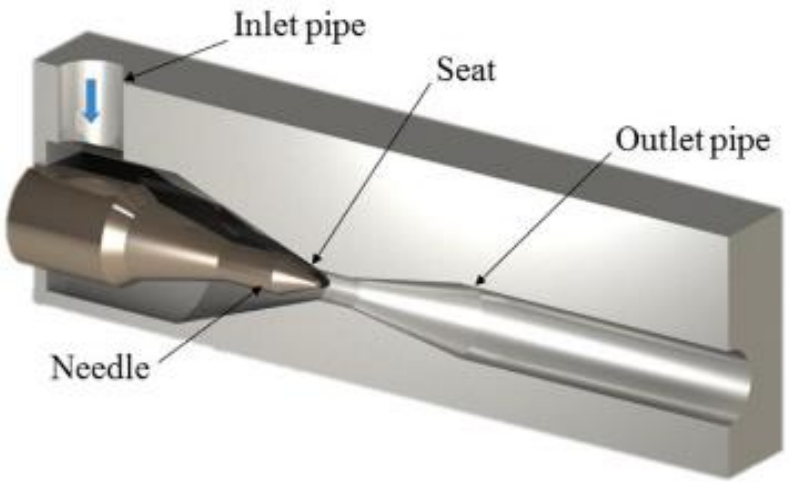




Specimen

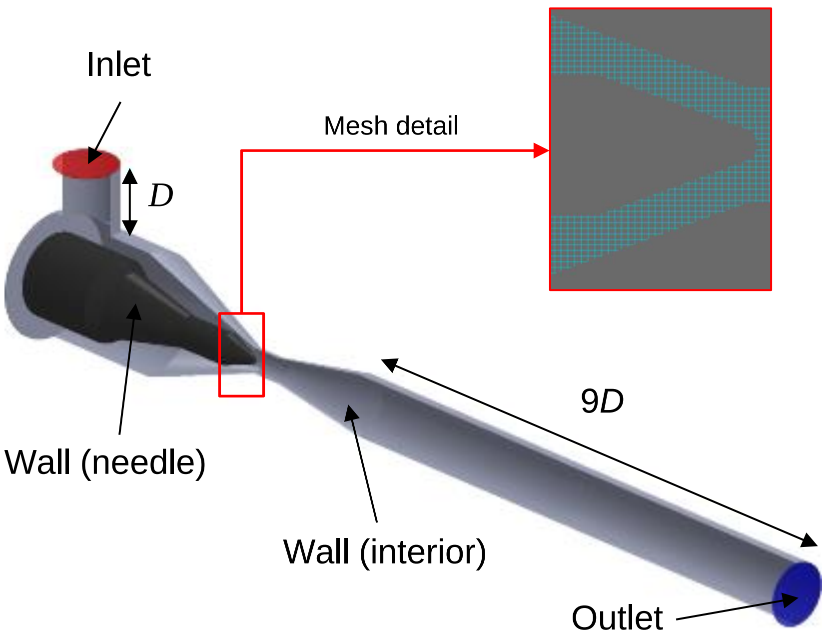
Second benchmark case:
Needle & Seat choke valve

Benchmark description



Valve and Flow features:

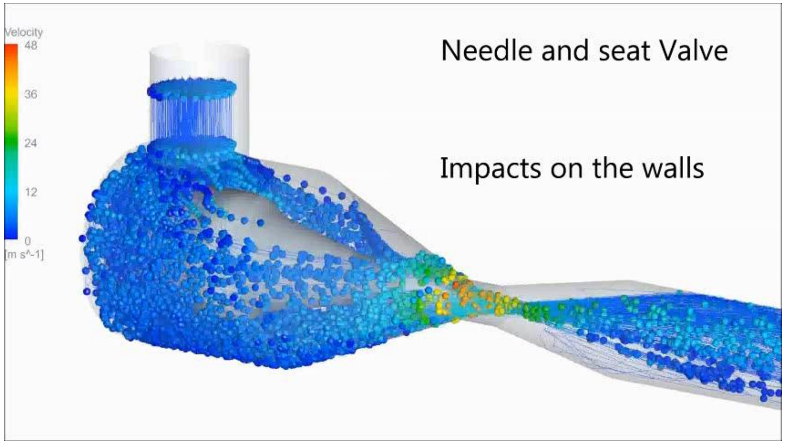
- valve size = 2 in.
- water flow rate = 14.2 l/s (7 m/s in the inlet pipe)
- sand particles with d_p=400 µm
- particle concentration = 0.1%



Simulation details:

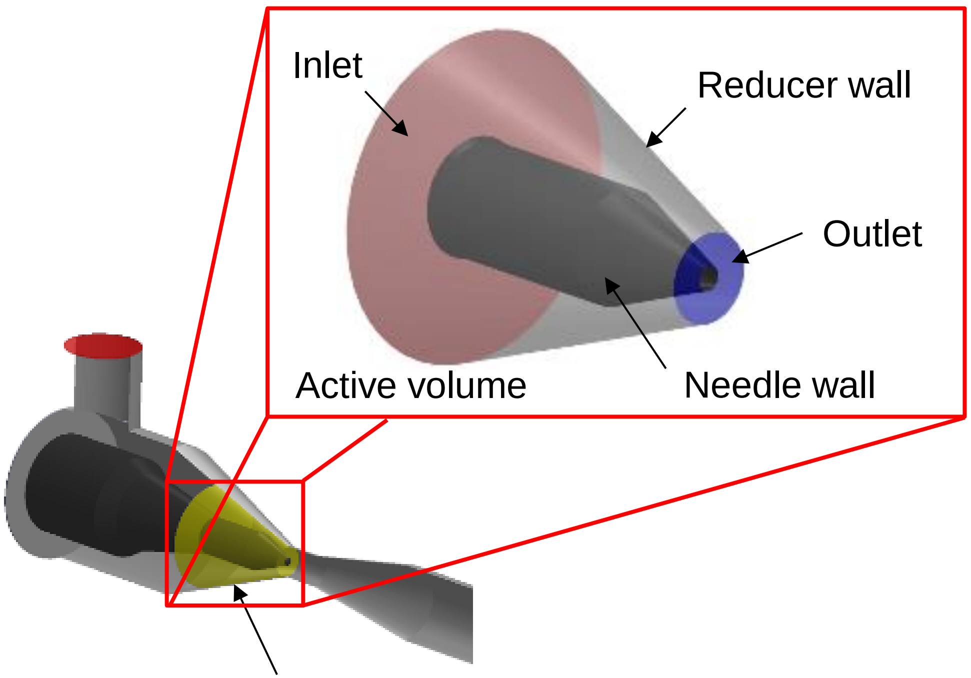
- PHOENICS 2011 CFD code employed
- Turbulent, incompressible RANS model
- Standard k-ε turbulence model
- IPSA EE model of Spalding (1980)
- GENTRA particle tracker 2010 version
- Structured mesh of about 4.7M cells

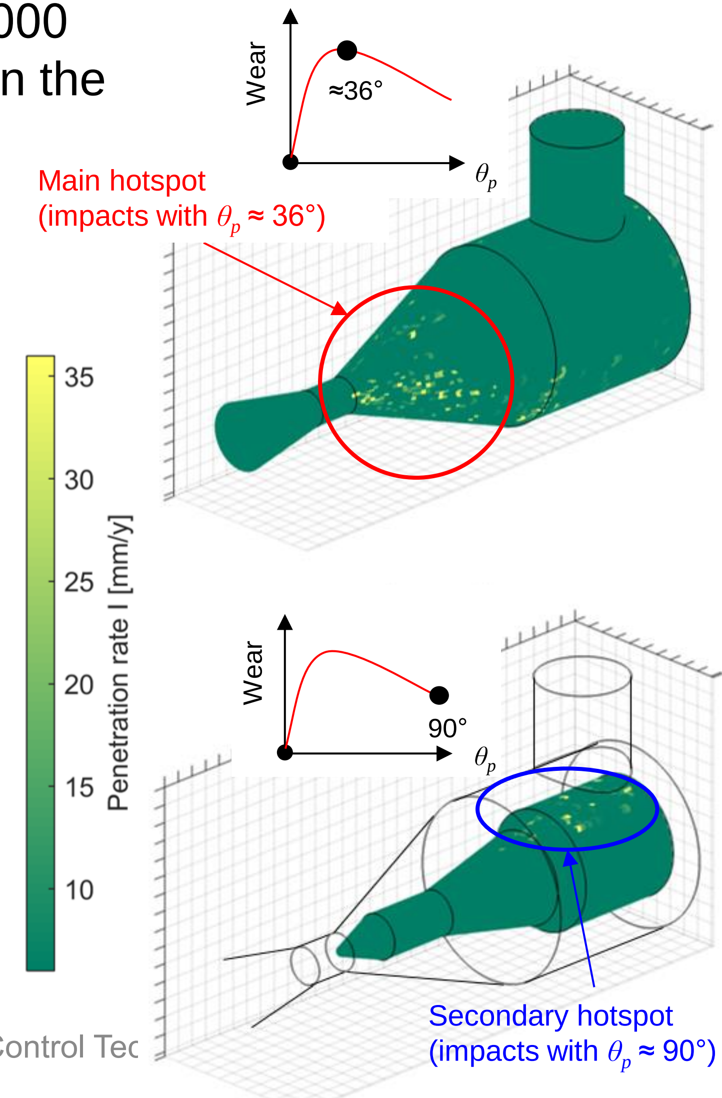
Second benchmark case: Needle & Seat choke valve



Active volume definition…

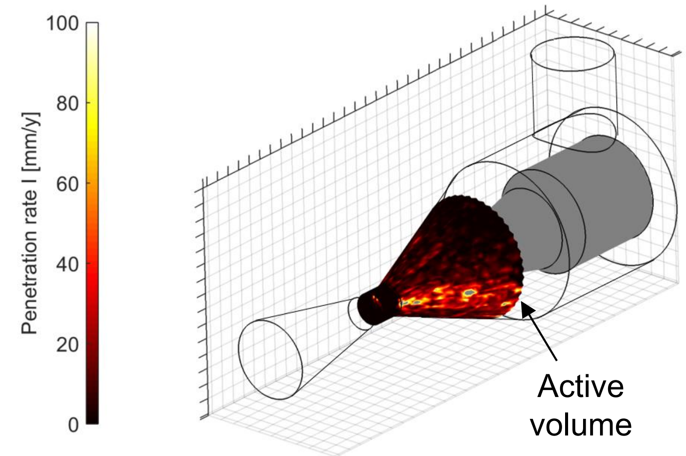
…by releasing 1000 testing particles in the flow domain.

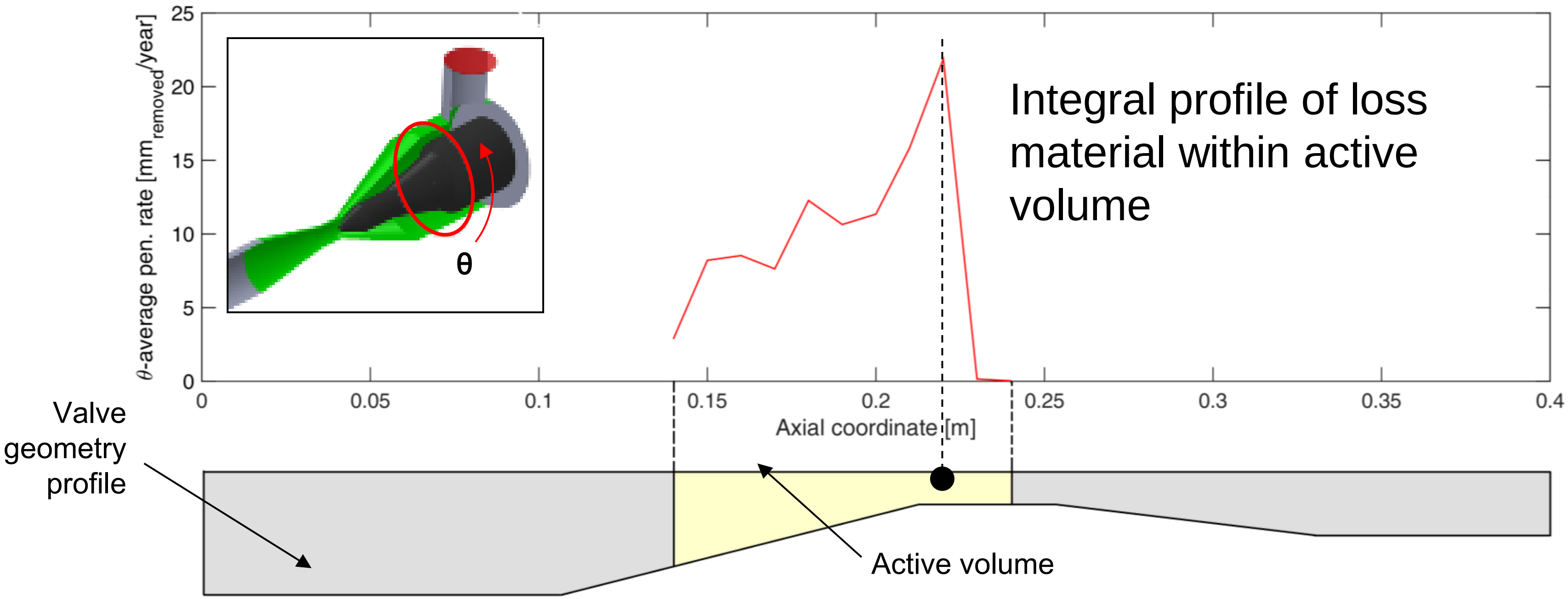




Second benchmark case: Needle & Seat choke valve

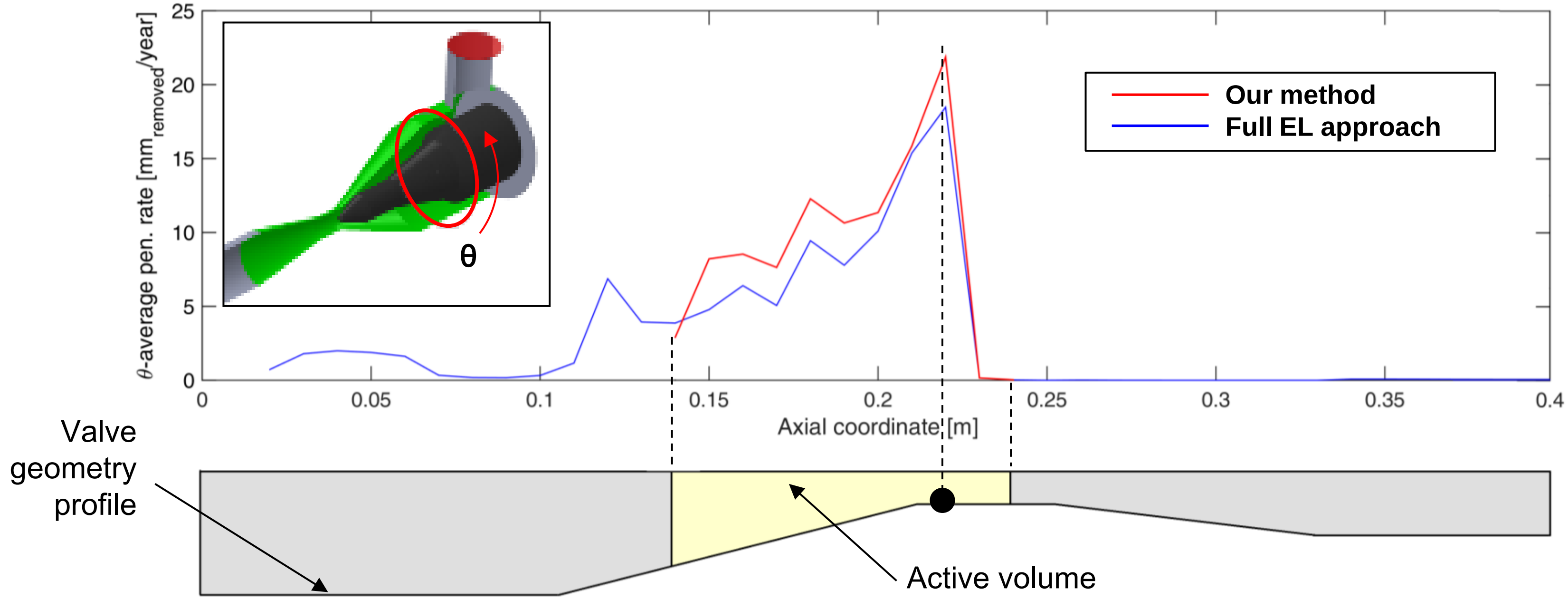
Erosion estimation





Second benchmark case: Needle & Seat choke valve

Comparison with full Eulerian-Lagrangian approach



- **Comparable results**
- **-77% disk space**
- **-63% CPU time for particle tracking**

Conclusion and future developments

- ✓ **We presented a new CFD-based methodology for erosion prediction in control valves.**
- ✓ **Our method allow results comparable with standard methods but with a significant reduction in computational burden on dilute flows.**

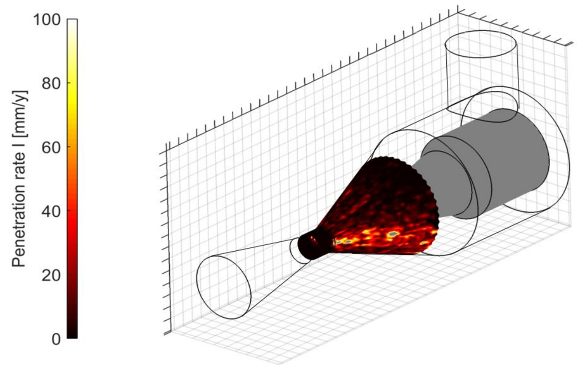
Solid concentration =0.1%
Disk space reduction > 70%
CPU time reduction > 60% (tracking particles)

- ✓ **This result allows to overcome the actual computational limits and to use the numerical approach in practical applications**

→ **Increase the solid concentration** (computational advantage increase with concentration)
→ **Quantitative erosion can be provided**
→ **Geometry changes can be considered**

- ❑ **A next important step is the <u>validation of erosion models</u> which became reliable with our model.**
To do this we are designing a slurry test plant for control valve in our hydraulic lab

Thank you for the kindly attention



…. any questions?

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