Study of the effect of surface textures on piston ring-liner lubrication using OpenFOAM

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2.29 Numerical fluid mechanics final project

Introduction

- Cylinder liner : one of first successful uses of surface textures in lubrication (honing)
- Often focus on complete pattern, instead of a few pores
- Pores can be laser-etched or spray-coated on liner

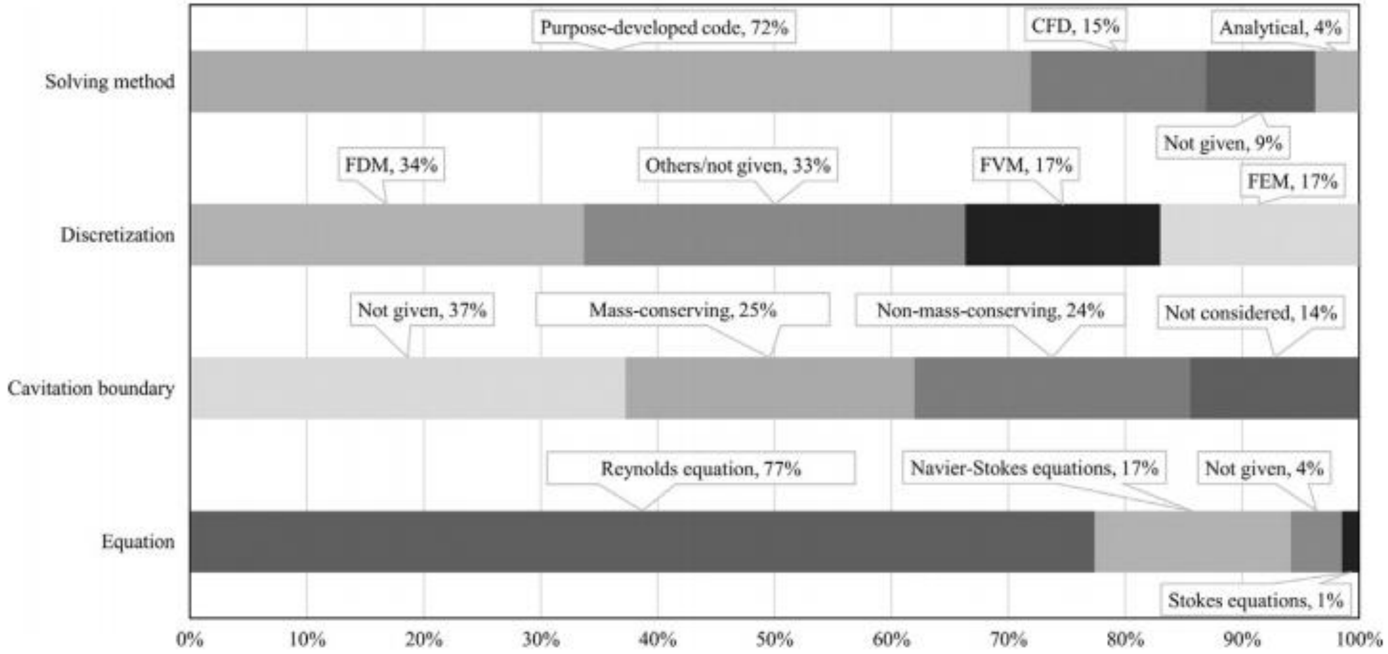
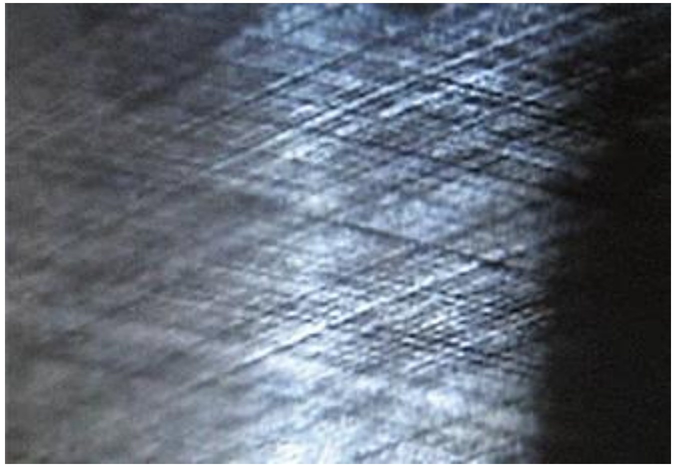


Fig. 11. Results of the literature survey on theoretical models for textured and rough surfaces.

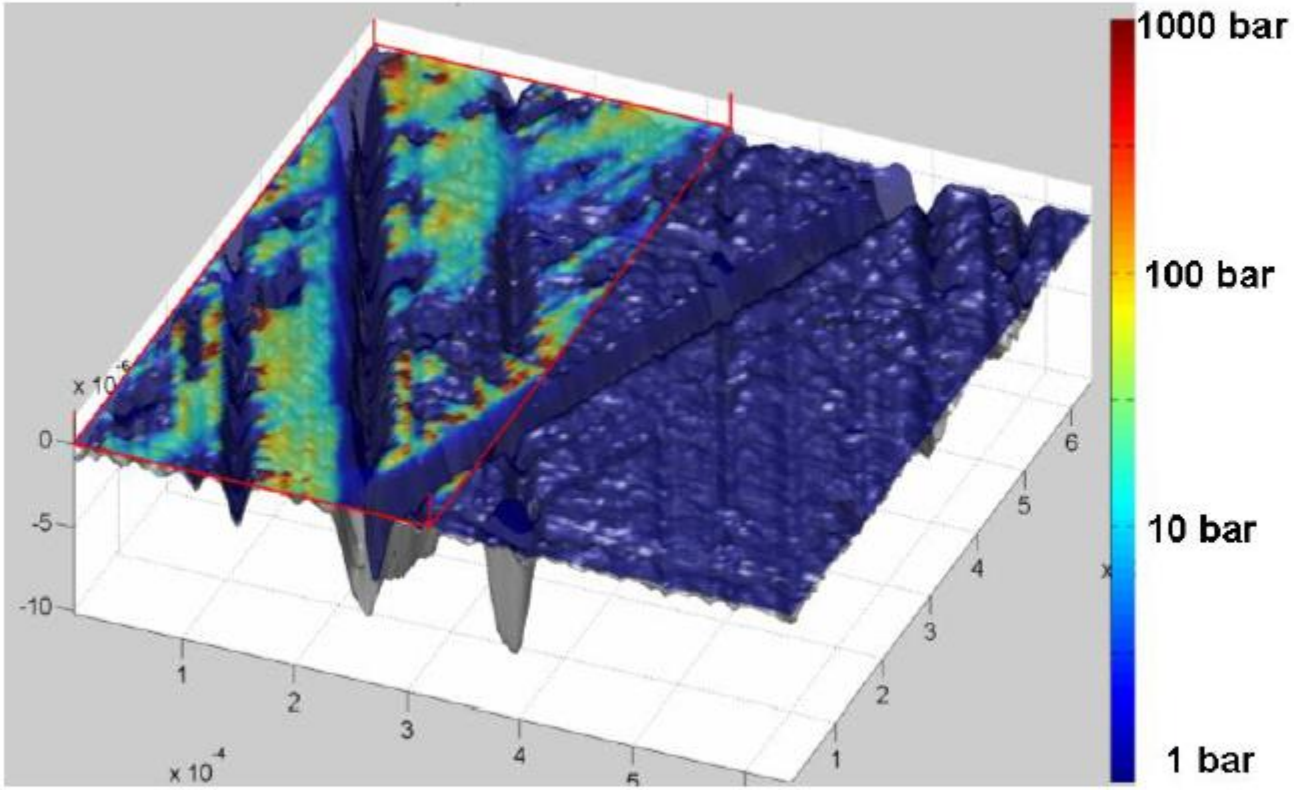
("Hydrodynamic lubrication of textured surfaces: A review of modeling techniques and key findings", Gropper et. al.)



- Eventual goals :
  - To better understand dominant mechanisms around pore and how they interact with the geometry
  - To obtain correlations given different pore, ring and liner parameters, to apply in larger model

Current ring-liner hydrodynamic model

Hydrodynamic pressure along rough liner surface



- Deterministic model utilizing a modified Reynolds equation :

$$\frac{d(\rho h)}{dt} = \nabla \cdot \left(\frac{\rho h^3}{12\mu} \nabla p \right) - \frac{V}{2} \frac{\partial(\rho h)}{\partial x}$$

$$\Downarrow$$

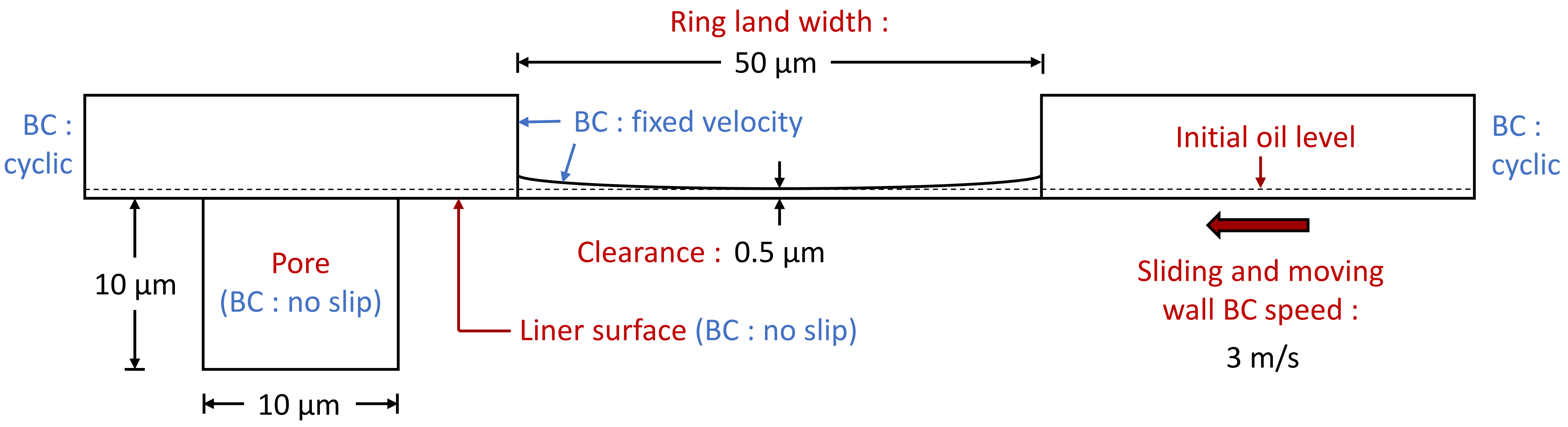
$$\frac{d(1-F)h\phi}{dt} = \nabla \cdot (\eta \nabla F \phi) - \frac{V}{2} \frac{\partial(1-F)h\phi}{\partial x} \quad , \quad \eta = \frac{p_{ref} h^3}{12\mu}$$

- Defines cavitation using a single variable ϕ for both hydrodynamic pressure and volume fraction
- Limited to ring land only

Geometric setup

- Approximation of an effective land width (where oil film exists)
- Neglects bore distortion, liner and ring roughness, piston motion
- Assumes a set clearance

- Parameters to alter :
  - Ring and pore profile shape
  - Pore depth and length
  - Piston sliding speed
  - Ring-liner clearance

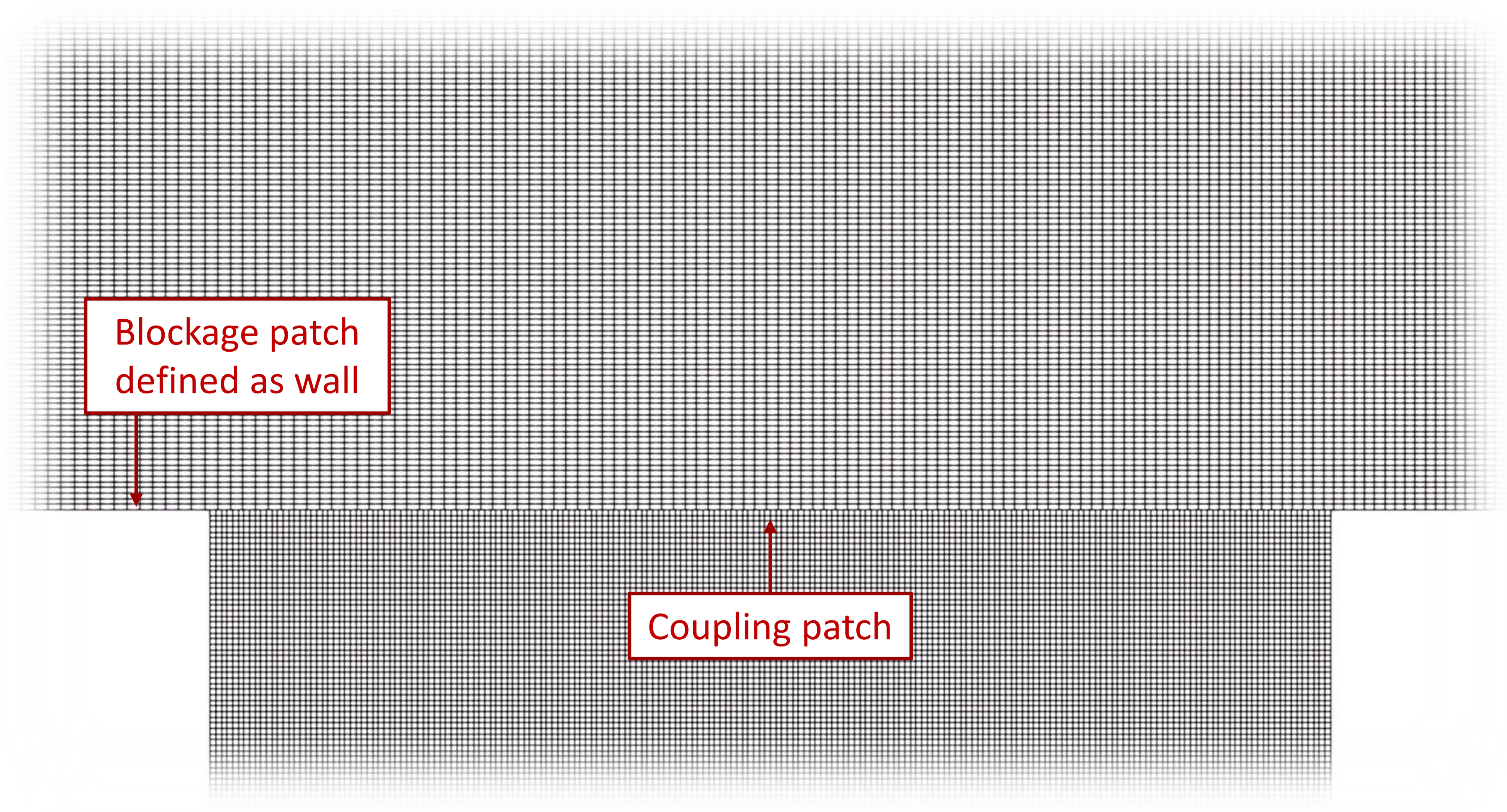


CFD case setup details

- Major assumptions :
  - Laminar
  - 2D
  - Incompressible
  - No gravity
  - Newtonian
  - Cavitation ignored
- Solver : interDyMFoam
  - Handles two fluids (oil and air) using a volume ratio, α
- Surface tension :
  - σ = 0.021 N/m
  - Constant contact angle of 45° at walls
- Time discretization :
  - Final time = 35 μs
  - Min Δx = 0.05 μm
  - Max Δt = $\frac{\Delta x_{min}}{U}$ = 0.0167 μs
  - Adjustable time step, keeping C ≤ 0.5
- Schemes used :
  - Time : Euler (1st order implicit)
  - Always Gaussian -> cell-centered
  - Diffusion : 2nd order central (linear)
  - Advection : limiter scheme vanLeer
    - Limits towards an upwind scheme for rapidly changing gradient

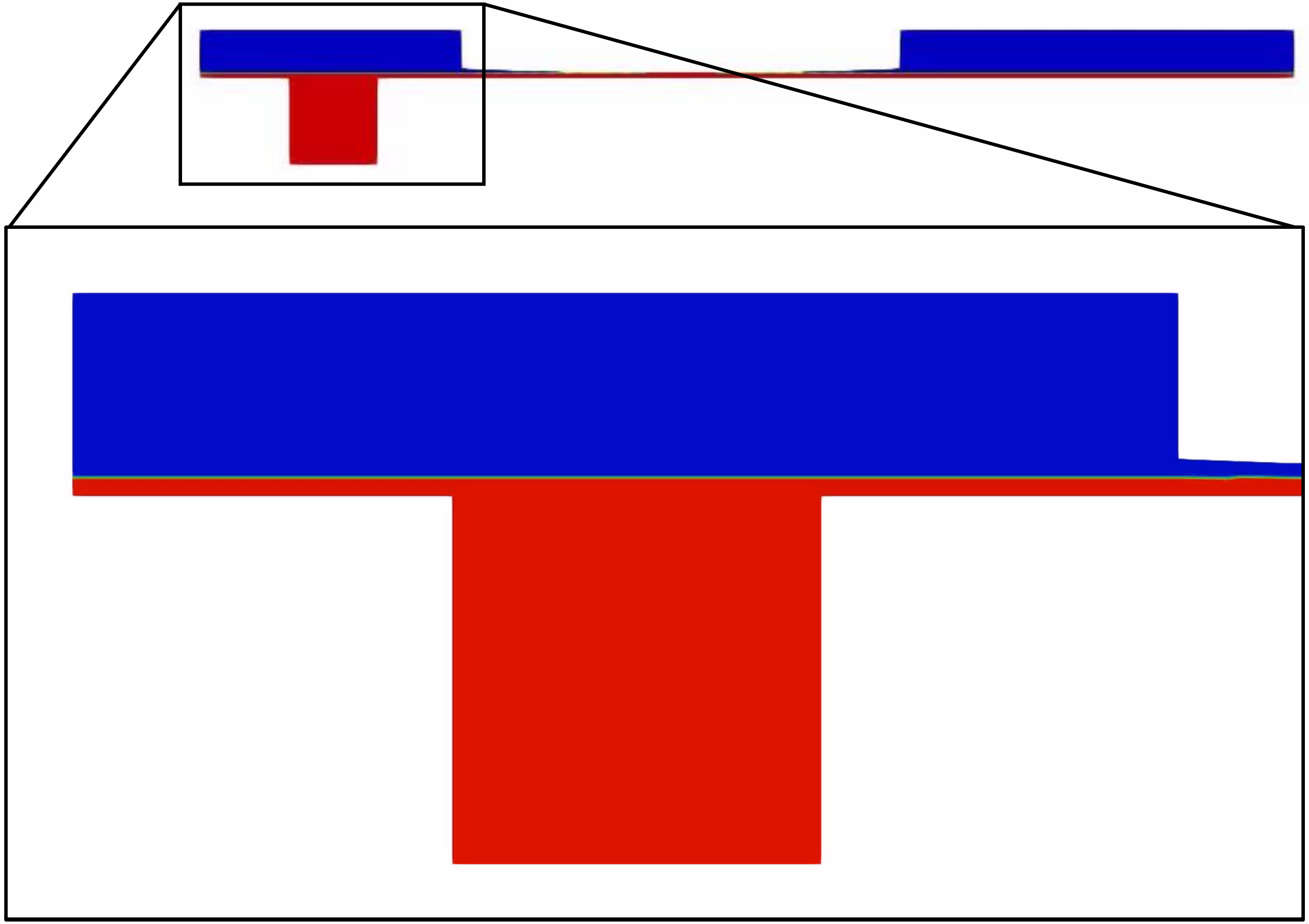
Sliding mesh in OpenFOAM

- topoSet : creates sets of blocks and patches
- createBaffles : creates ACMI (arbitrarily coupled meshing interface) patches



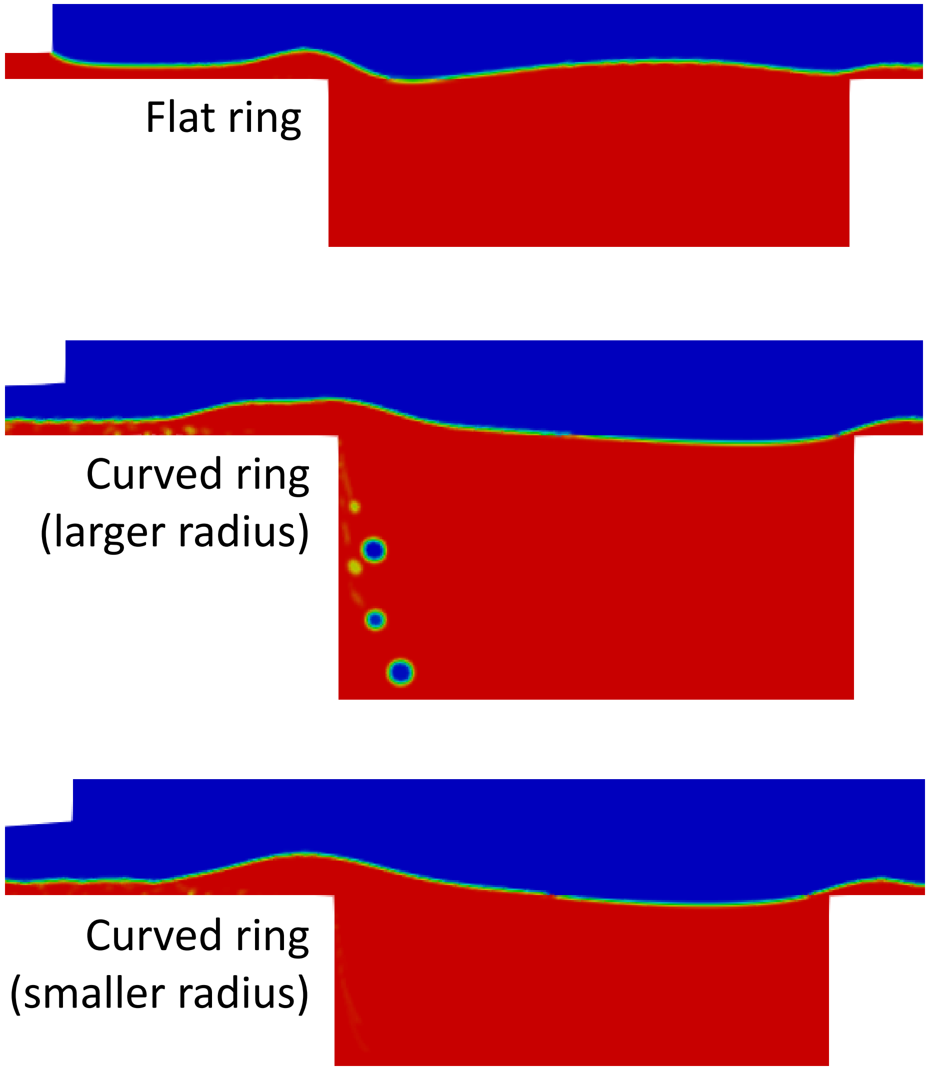
- dynamicMesh : defines the linear motion of the mesh
- U, p_rgh, alpha.oil BC's :
  - ACMI blockage defined as a wall
  - ACMI couple defined as ACMI cyclic

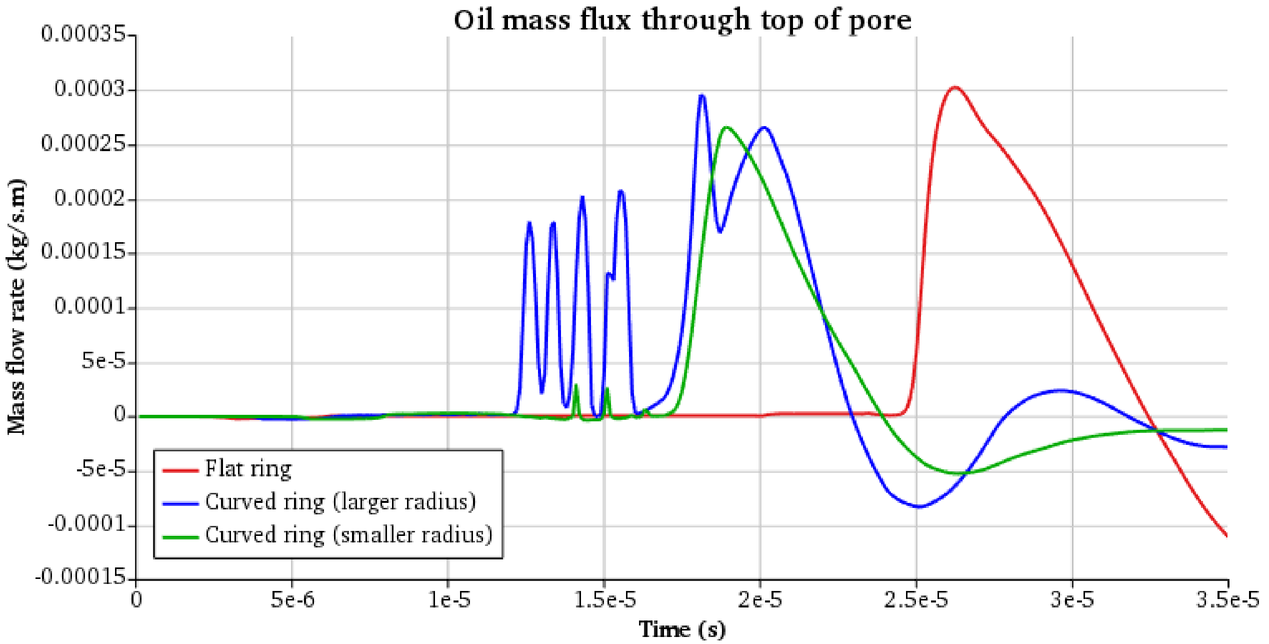
Animation of a curved ring

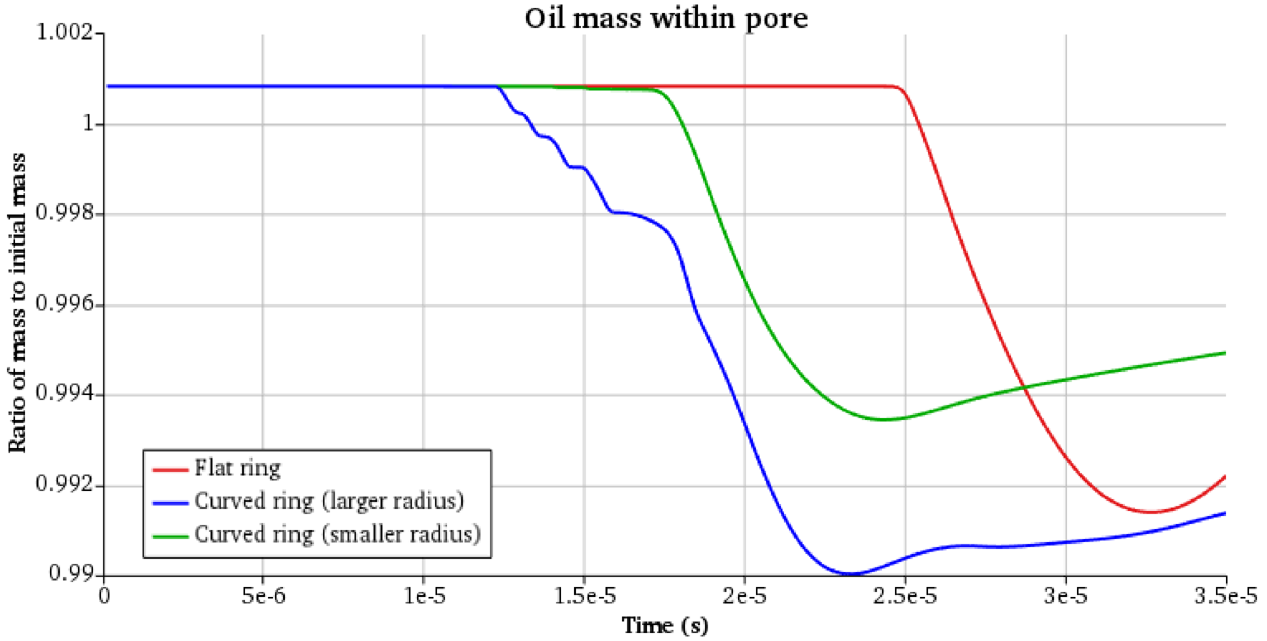


- Ring curvature allows bubbles to perform, which can later enter the pore and displace oil
- Surface tension key in dragging out oil
- Oil amassed at pore edge tends to recede back into pore—is this an issue ?

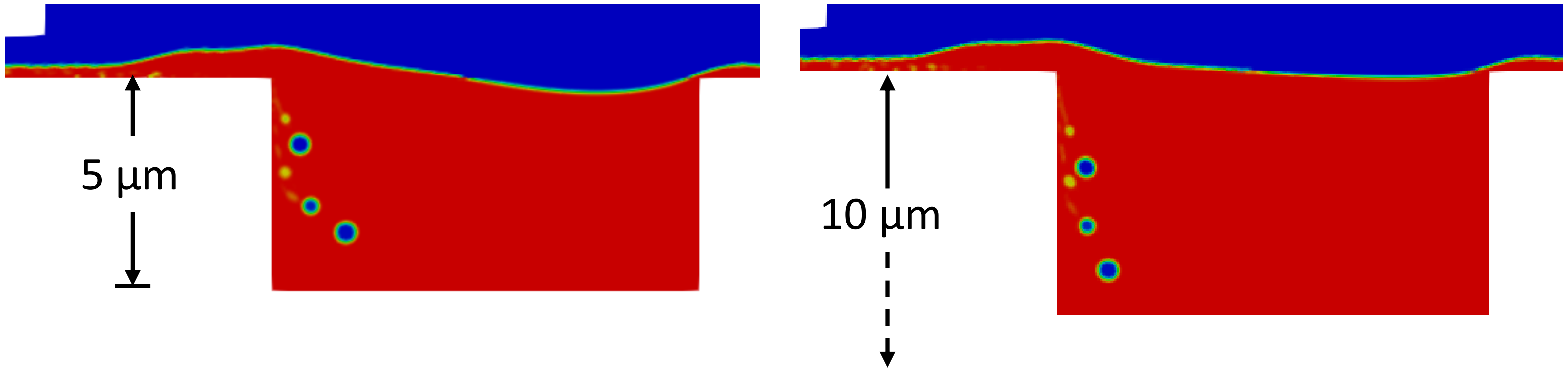
Oil transport out of pore



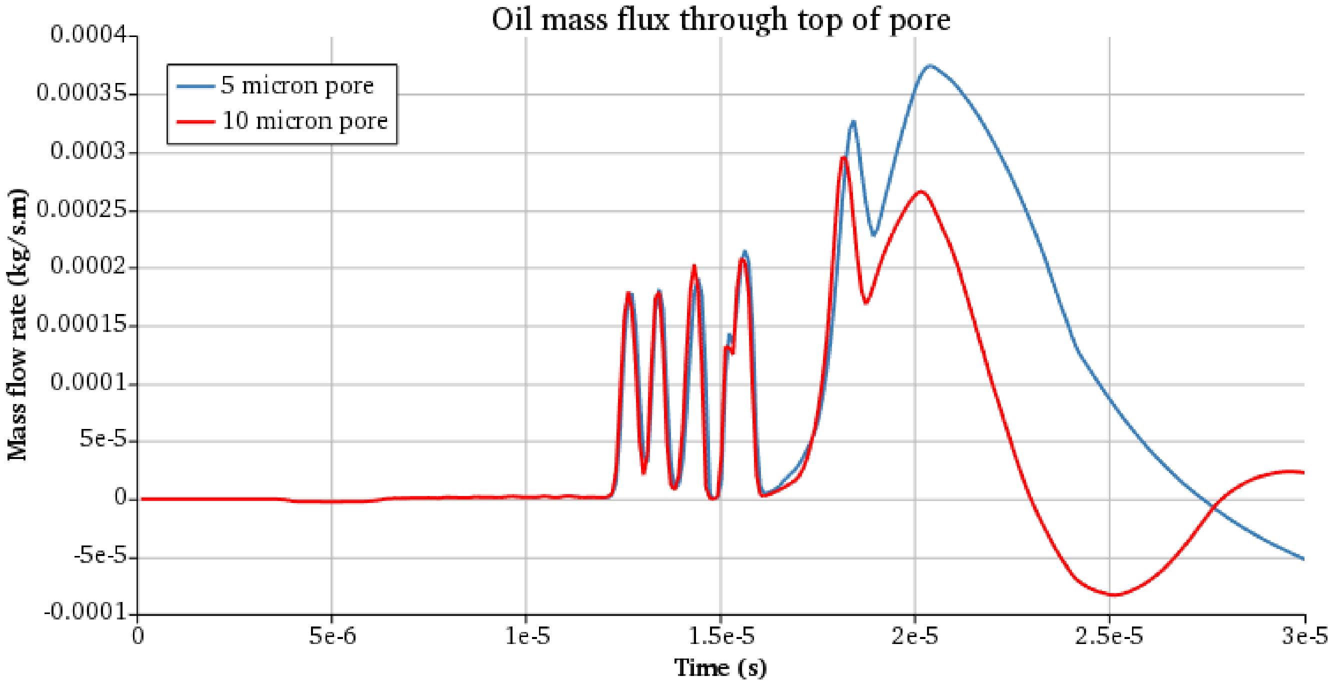




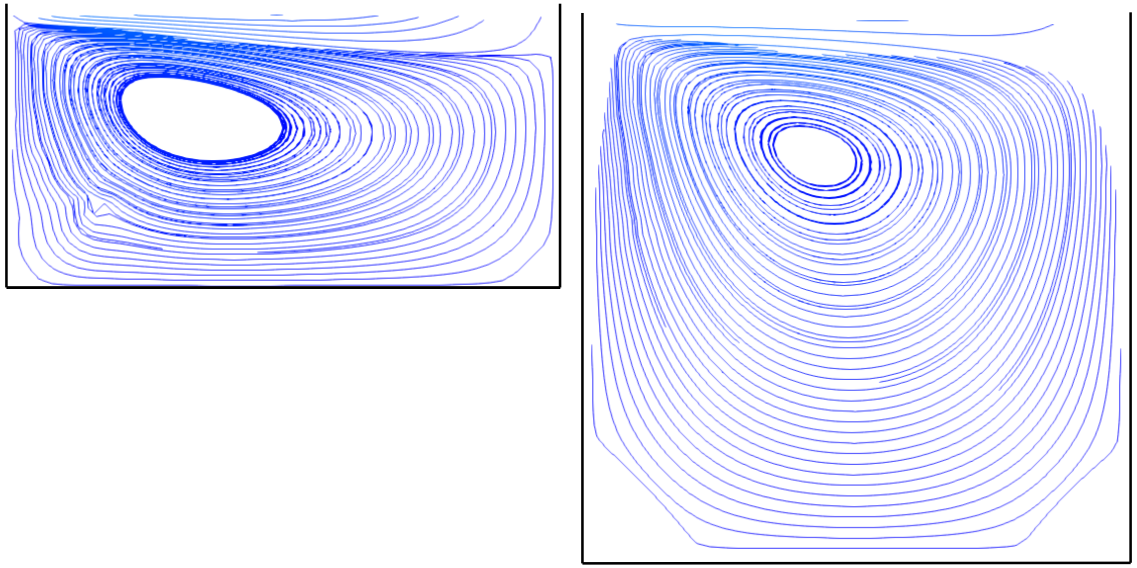
Effect of shallower pore



- Smaller pore favors a less symmetry in the streamlines
- Keeps more oil out of pore, but for how long ?

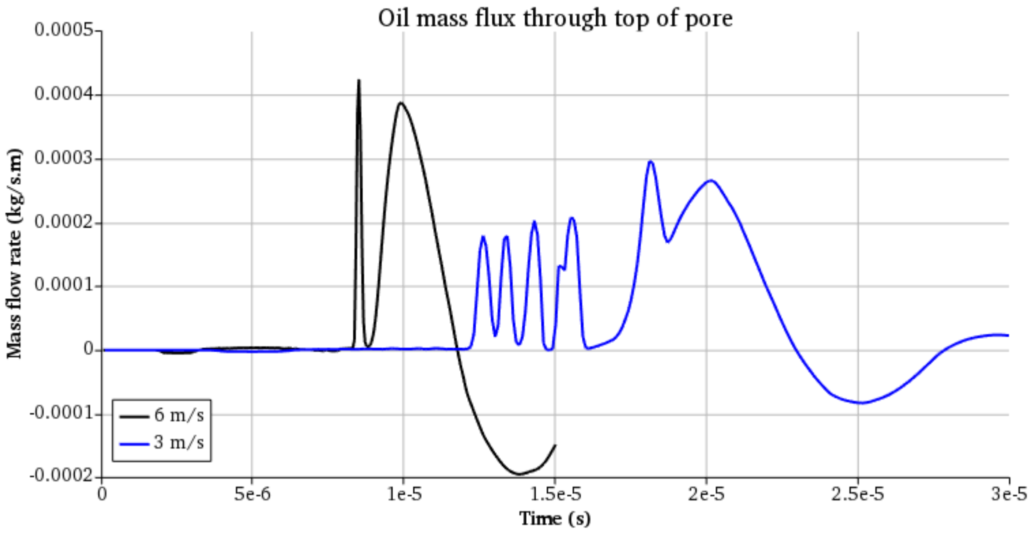


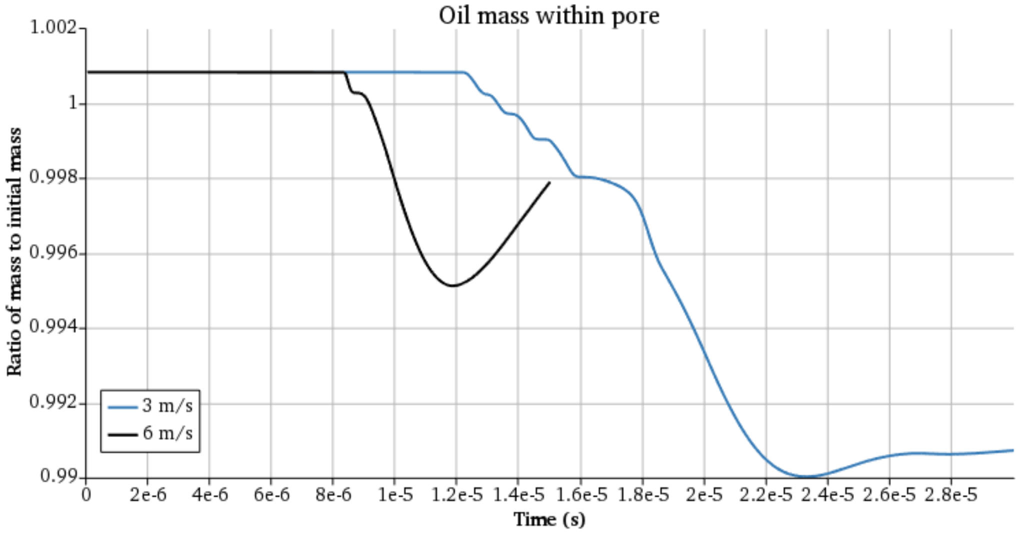
Streamlines within the pore at the end of the ring :



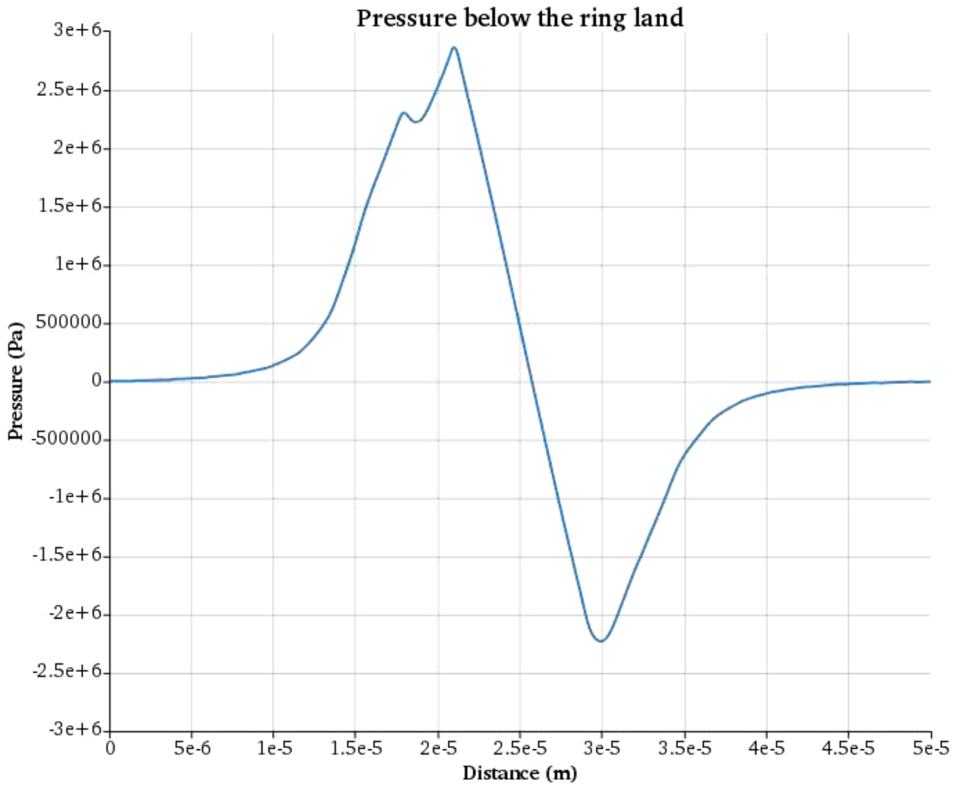
Further observations

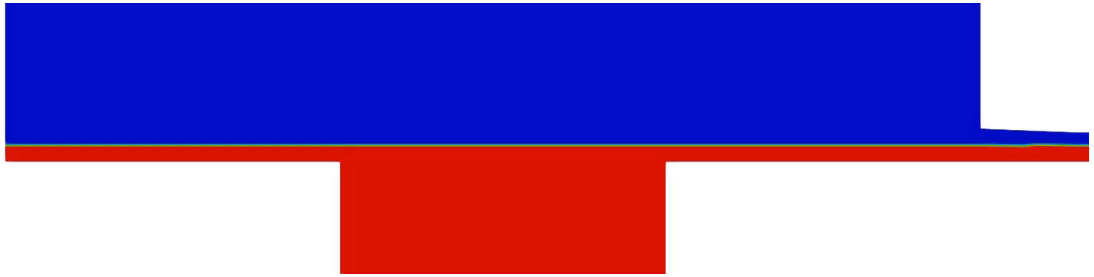
Doubled sliding speed :





Pressure variation :





Future work

- Test more variations in order to deduce correlations
  - Goal is to incorporate pore effect in larger numerical model
- Test different pore shapes, though somewhat tricky in OpenFOAM
- How does the oil on the liner evolve later in time ?
  - Effect of a second ring passing after the first
- Compare to numerical model of hydrodynamic lubrication to improve both

Questions ?