Presented at the COMSOL Conference 2009 Milan

The Full-System Approach for Elastohydrodynamic Lubrication

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Comsol Conference, Milan 2009

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October 16th 2009

Outline

Problematic : Elastohydrodynamic lubrication

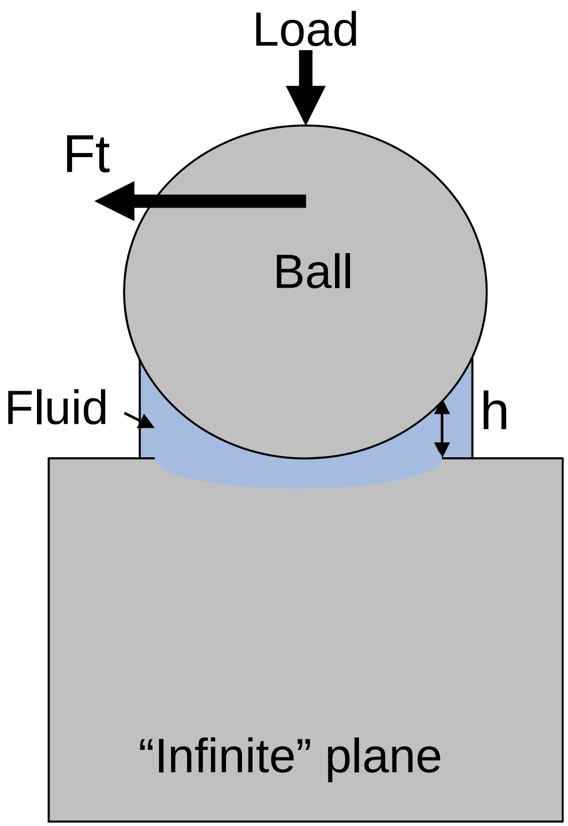
- Isothermal analysis & Newtonian lubricant
  (a basic model)

- Thermal analysis & non-Newtonian lubricant
  (an advanced model)

Problematic

A lubricated ball-on-plane contact → EHL

- $S \sim 0.1\ mm^2$
- η ↑↑ (piezo-viscous)
- $P \sim 10^9$ Pa
- $u_3 \sim$ film thickness



Objectives :

- h (Film thickness)
  → Wear & lifetime prediction
- Ft (Friction force)
  → Energy loss prediction

At least 2 Physics

Isothermal Newtonian Model

complexity level:

- Equivalent elasticity deformations

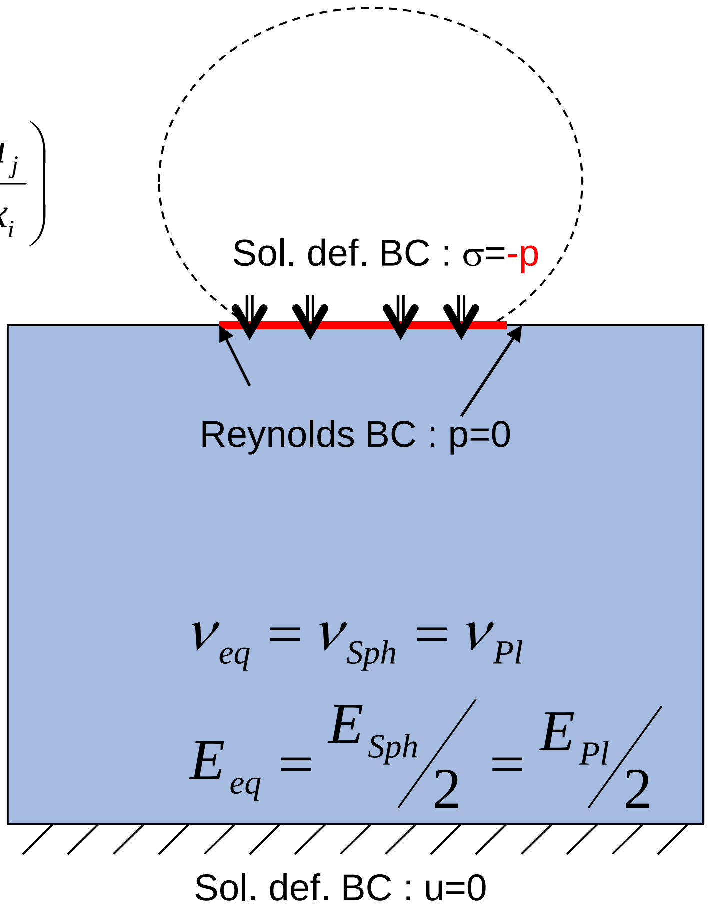
$$\sigma_{ij} = \frac{E_{eq}}{1+\nu_{eq}}\left(\varepsilon_{ij} + \frac{\nu_{eq}}{1-2\nu_{eq}}\varepsilon_{kk}\delta_{ij}\right) \qquad \varepsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$$

- Navier Stokes → Reynolds

$$\nabla\left(\frac{\rho h^3}{12u_e\eta}\nabla p\right) = \frac{\partial(\rho h)}{\partial x}$$

$$\text{with}: \rho = \rho(p,\ldots),\ \eta = \eta(p,\ldots) \quad \text{and}$$

$$h(x,y) = h_0 + \frac{x^2}{2R} + \frac{y^2}{2R} - u_3(x,y)$$

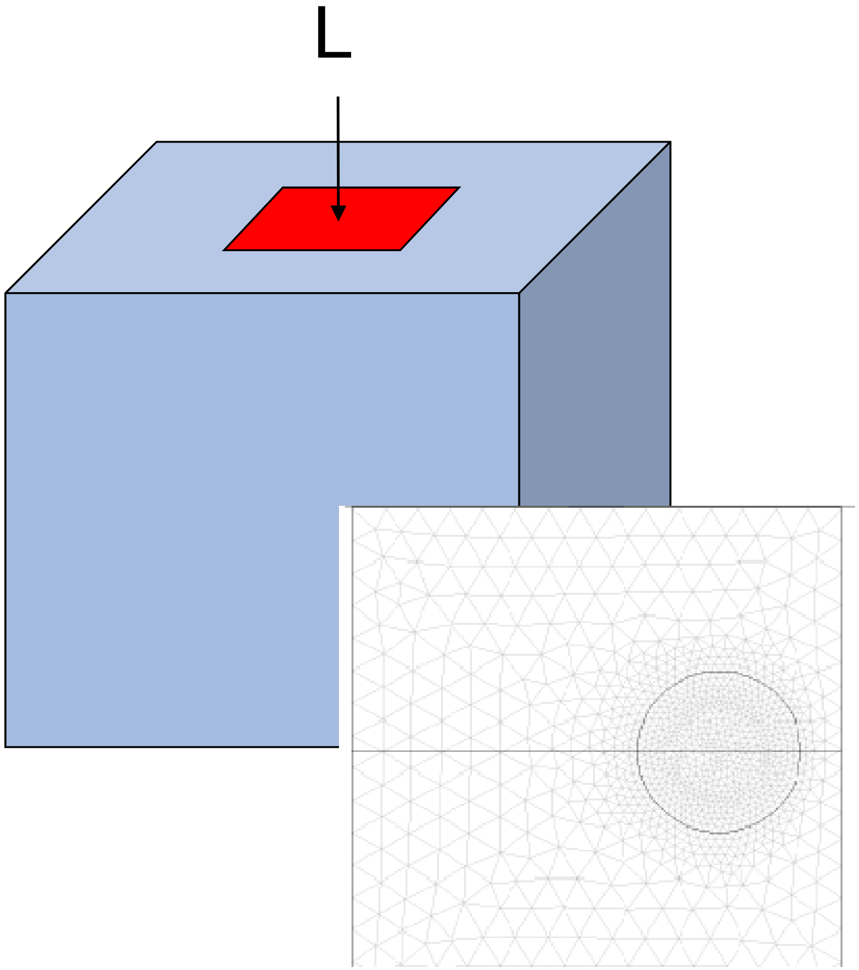


Building the model

complexity level:

- 1 geometry
- 2 physics
  - Solid, stress-strain module
  - PDE,
    Weak form on Boundary module
- 1 global equation
  + 1 integration coupling variable

$$\iint_S p(x,y)dS = L$$

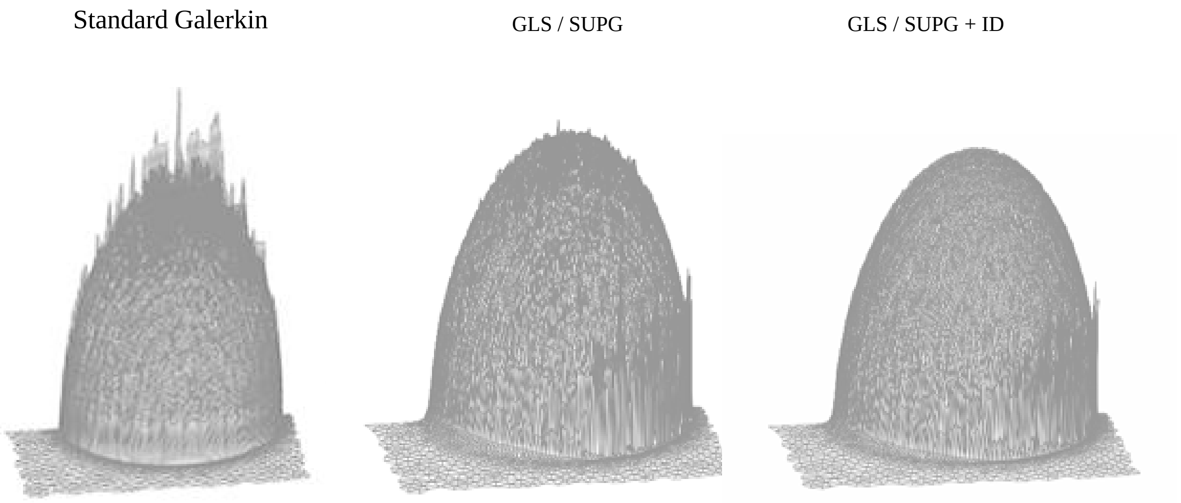


Difficulties

complexity level:

- Stabilization techniques

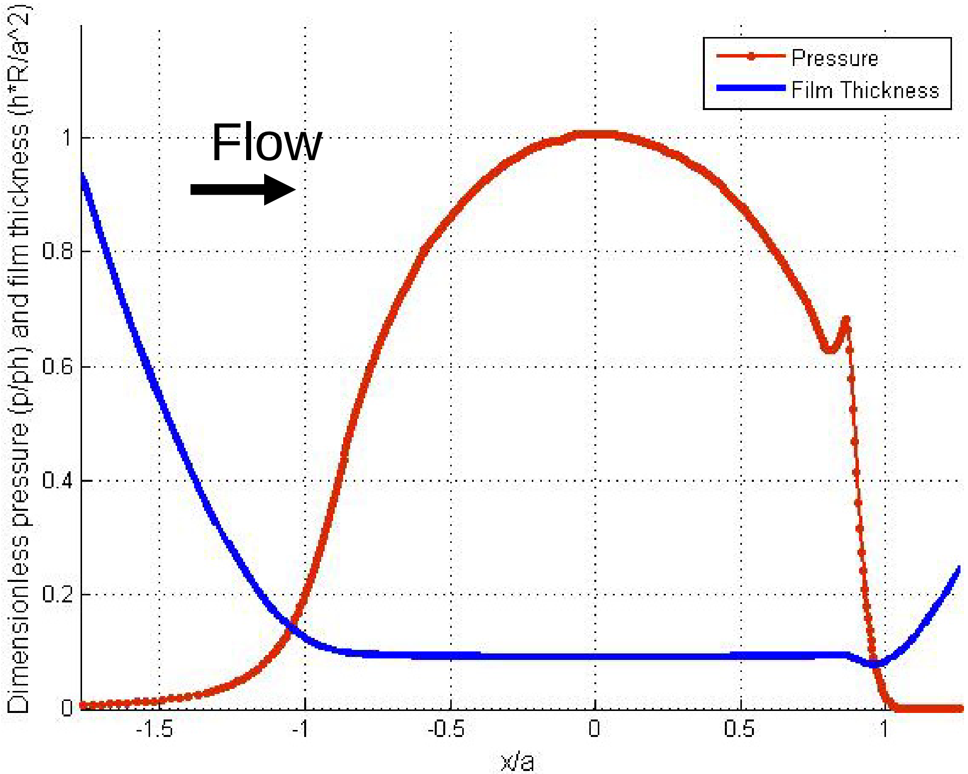
p ↑→ η ↑↑ → Diffusion << Convection → Galerkin fails → SUPG, GLS and/or ID

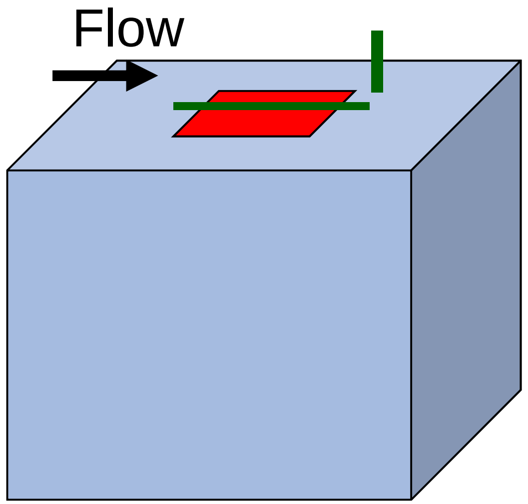


<u>See :</u> A.C. Galeão et al. App. num. math., vol. **48**, pp. 205 – 222, 2004

Classical results

complexity level:





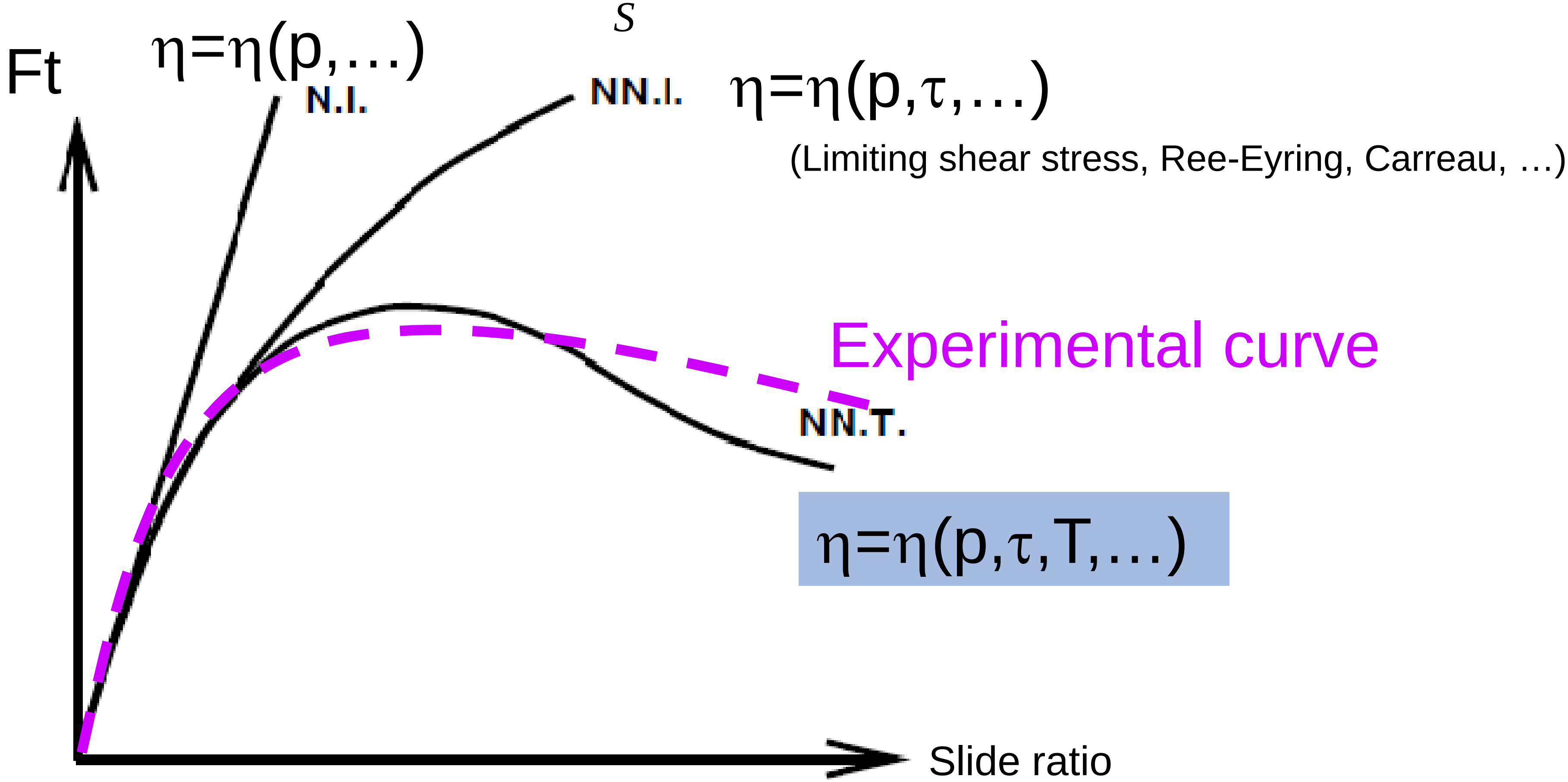
Qualitative validation

Pressure distribution in the fluid and film thickness distribution along the line

Friction

$$Ft = \int_S \tau_{xy} \, dS$$

complexity level:



Thermal non-Newtonian Model

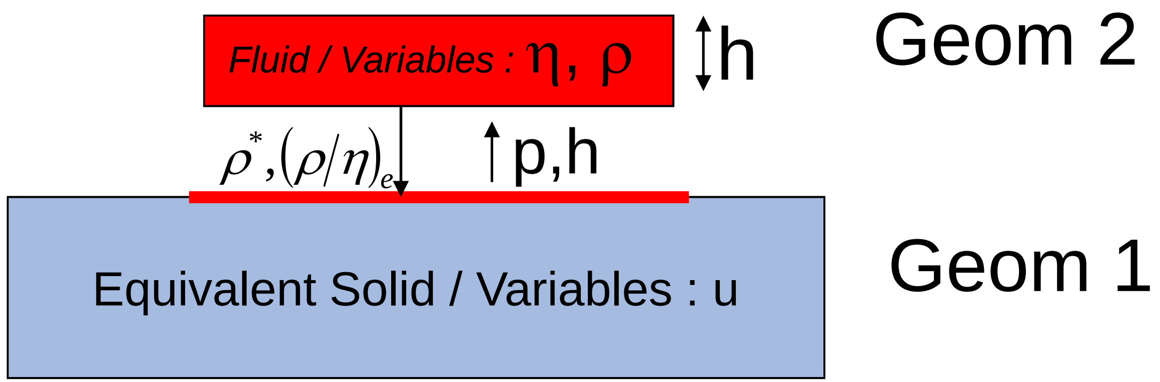
complexity level:

- $\eta=\eta(p, \tau, T,\ldots)$ & $\rho=\rho(T, \ldots)$
- A thermal generalized Reynolds equation

$$\frac{\partial}{\partial x}\left[\left(\frac{\rho}{\eta}\right)_e h^3 \frac{\partial p}{\partial x}\right]+\frac{\partial}{\partial y}\left[\left(\frac{\rho}{\eta}\right)_e h^3 \frac{\partial p}{\partial y}\right]=12\frac{\partial}{\partial x}\left(\rho^* U_m h\right)$$

$$\rho^* = \int_0^h f_1(\rho,\eta)dz$$

$$\left(\frac{\rho}{\eta}\right)_e = \int_0^h f_2(\rho,\eta)dz$$



See : B. Najji et al. ASME J. of Tribology, vol. 111, pp. 29 – 33, 1989

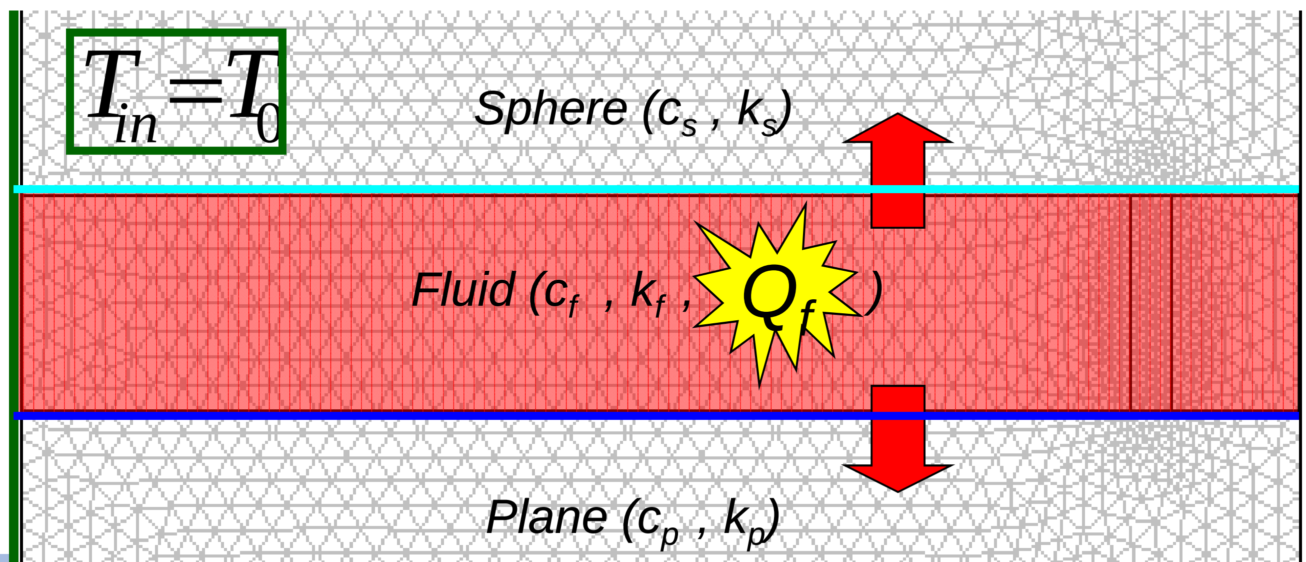
Thermal non-Newtonian Model

complexity level:

- The 3 energy equations (convection/conduction)

$$-\nabla(k\nabla T)+\rho c\vec{U}\nabla T = Q \qquad Q_{fluid} = Q_{compression} + Q_{shear}$$

- In Comsol: A new physic added to Geom. 2 :
  `Convection and Conduction Module`



$$k_f \left.\frac{\partial T}{\partial z}\right|_{z=h^-} = k_s \left.\frac{\partial T}{\partial z}\right|_{z=h^+}$$

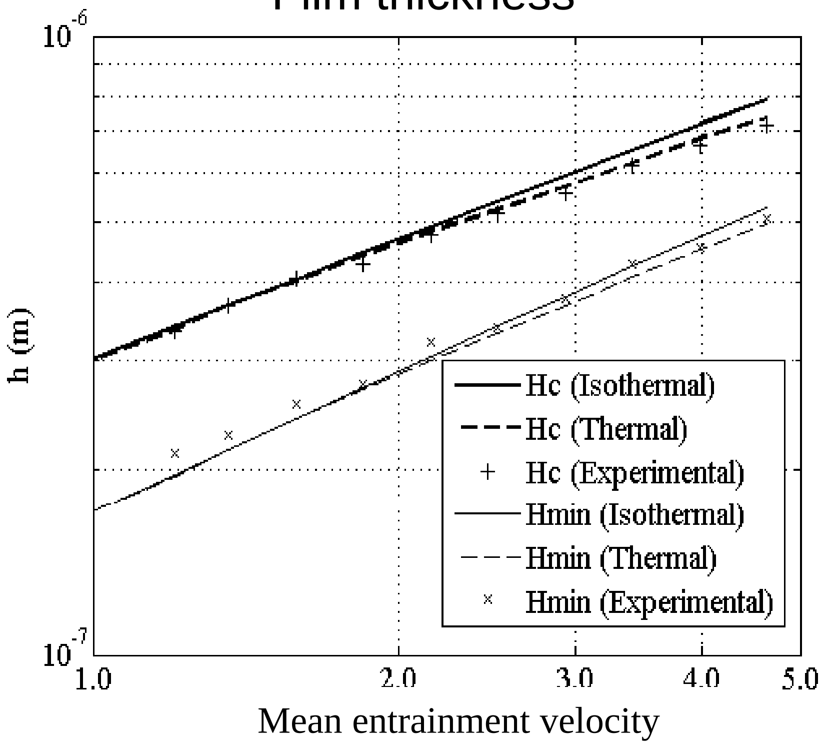
$$k_f \left.\frac{\partial T}{\partial z}\right|_{z=0^+} = k_p \left.\frac{\partial T}{\partial z}\right|_{z=0^-}$$

Thermal non-Newtonian Model

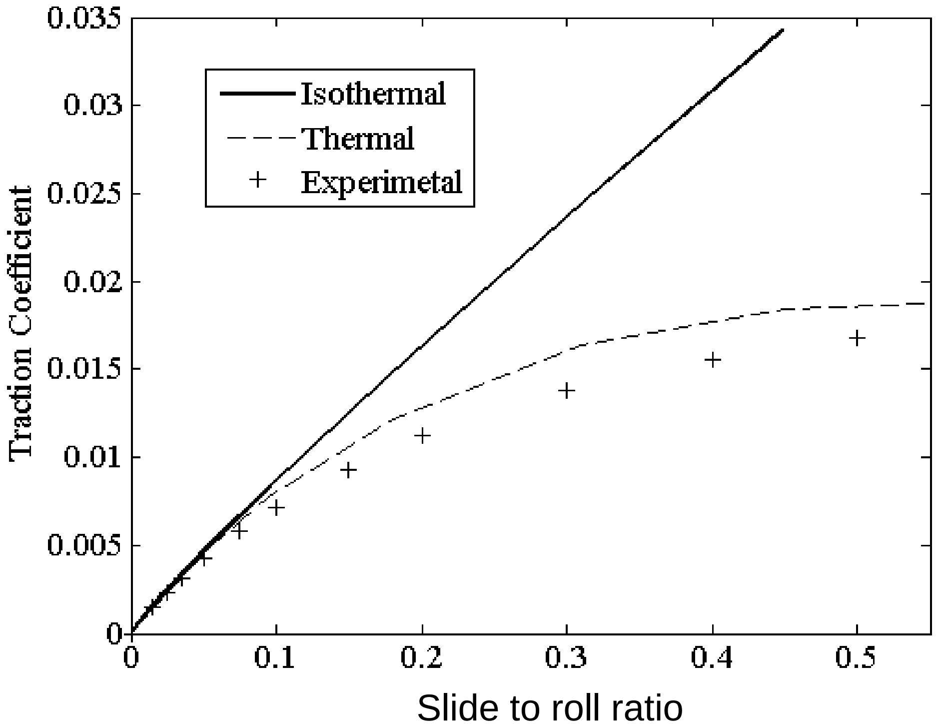
complexity level:

- Results

Film thickness



Friction



See : W. Habchi et al. Tribology Letters, vol. 30, n° 1, pp. 41 – 52, 2008

Thank you for your attention

Questions ?

For more information :
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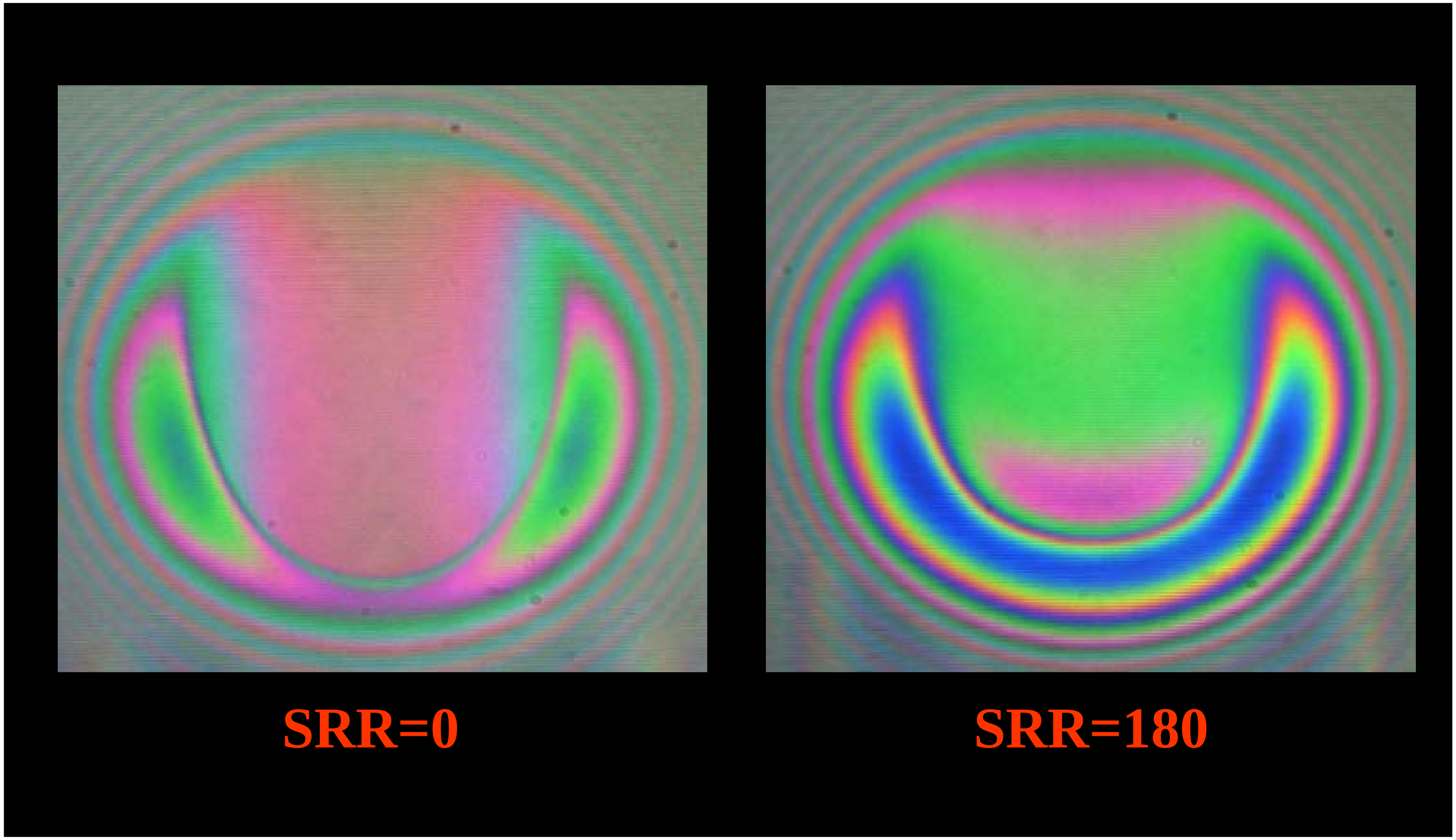
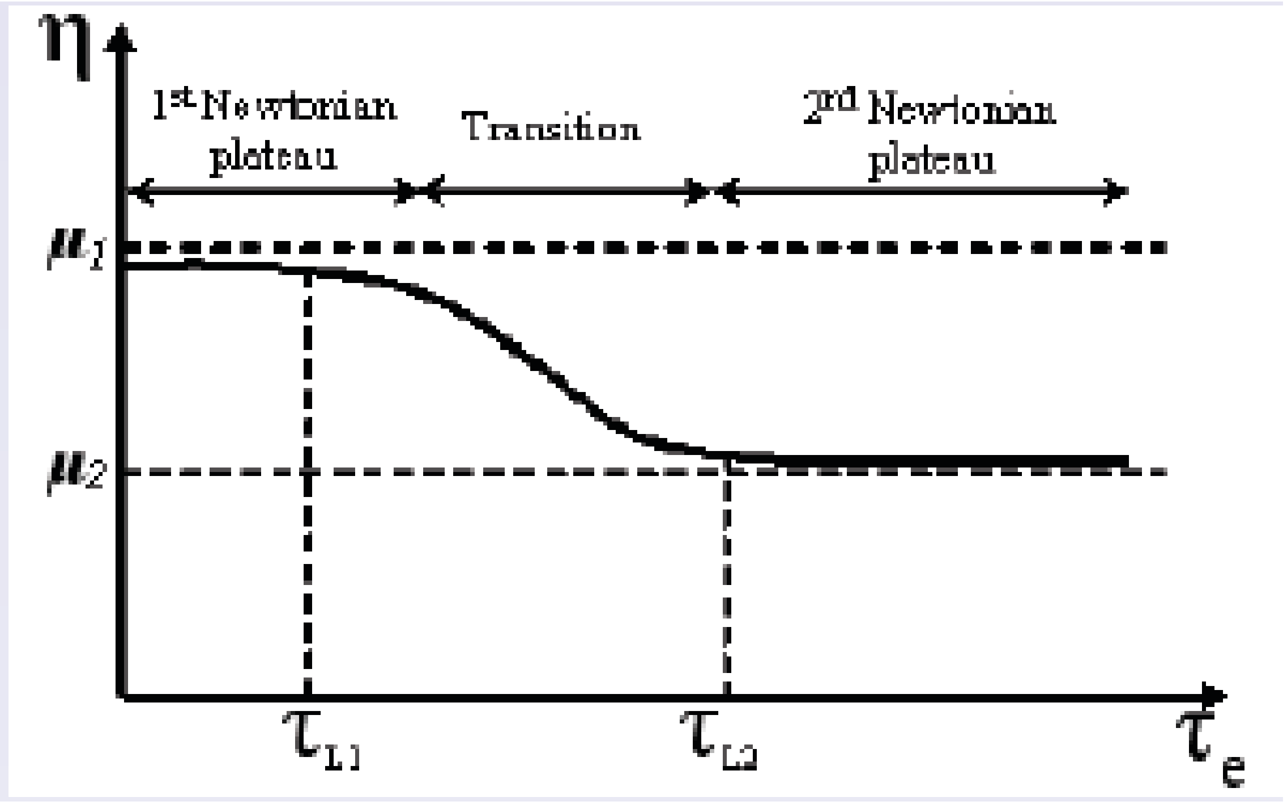
(our comsol model file will be on the proceeding cd)

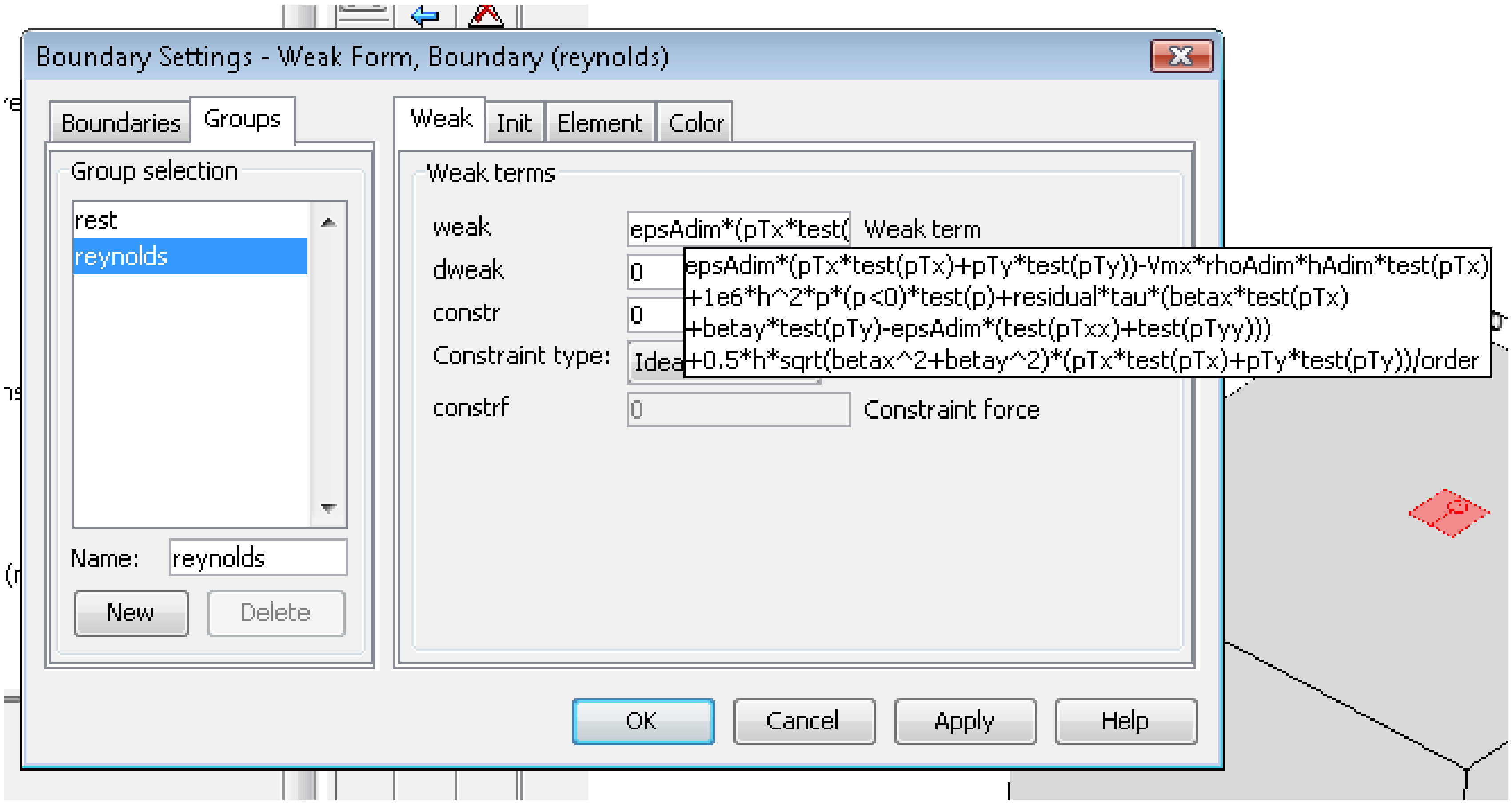
Experimental measurements



Carreau law

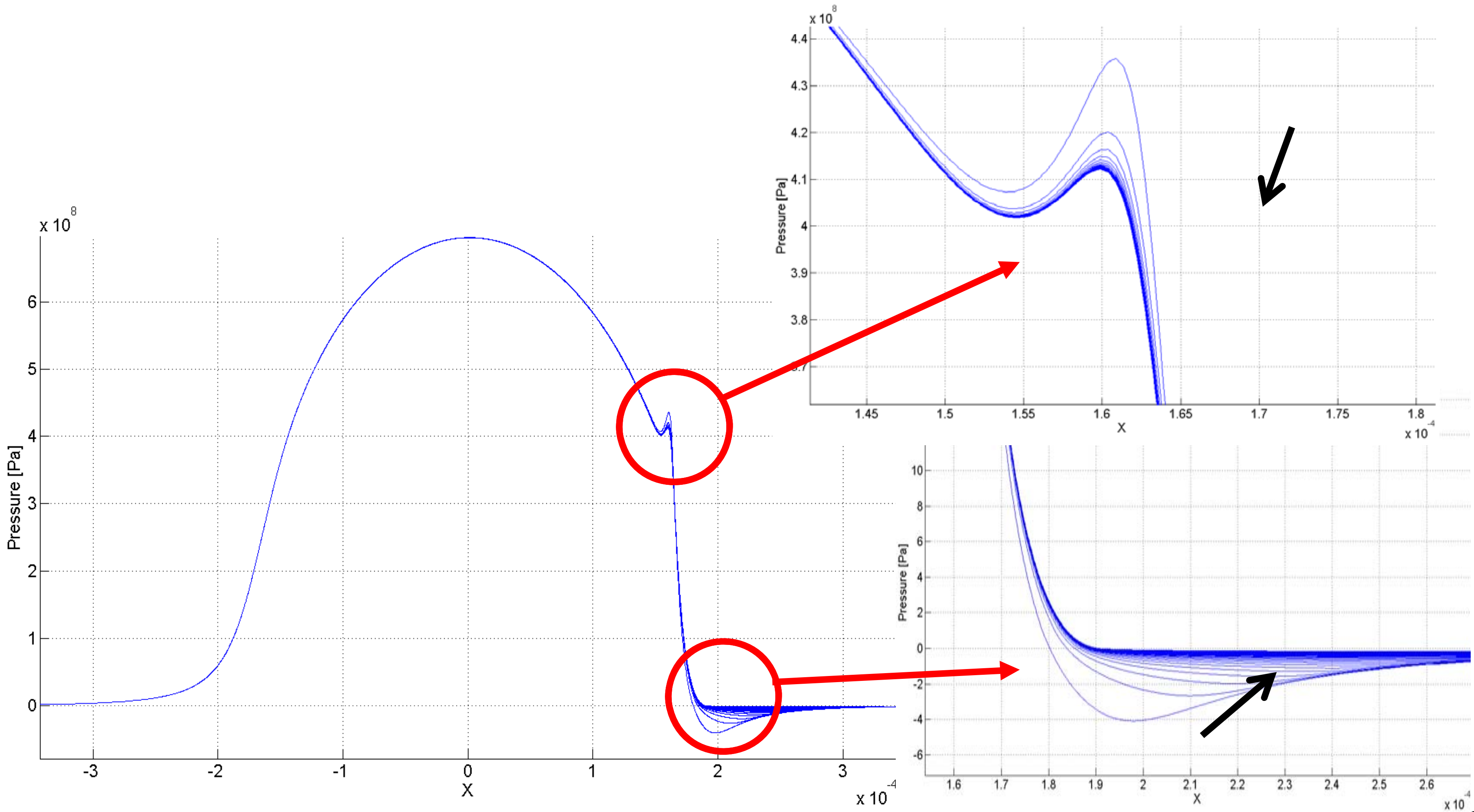

η
1st Newtonian plateau
Transition
2nd Newtonian plateau
μ1
μ2
τL1
τL2
τe

Weak Form


Boundary Settings - Weak Form, Boundary (reynolds)
Boundaries
Groups
Group selection
rest
reynolds
Name:
reynolds
New
Delete
Weak
Init
Element
Color
Weak terms
weak
epsAdim*(pTx*test(
Weak term
dweak
0
constr
0
Constraint type:
Idea
constrf
0
Constraint force
epsAdim*(pTx*test(pTx)+pTy*test(pTy))-Vmx*rhoAdim*hAdim*test(pTx)
+1e6*h^2*p*(p<0)*test(p)+residual*tau*(betax*test(pTx)
+betay*test(pTy)-epsAdim*(test(pTxx)+test(pTyy)))
+0.5*h*sqrt(betax^2+betay^2)*(pTx*test(pTx)+pTy*test(pTy))/order
OK
Cancel
Apply
Help

Penalty term for cavitation

complexity level:



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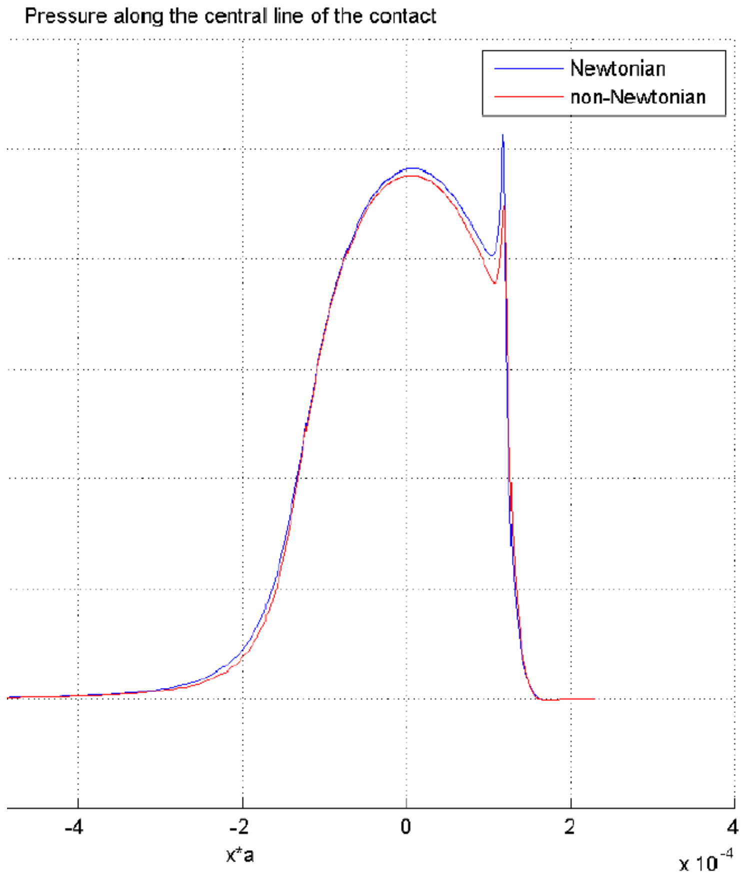
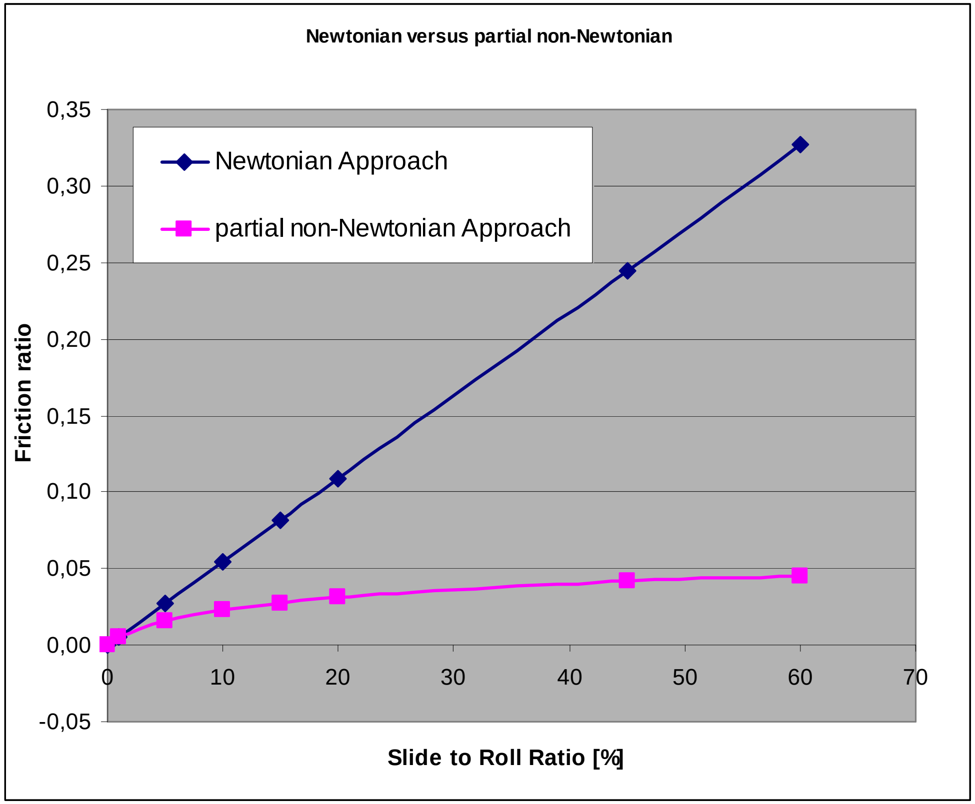
Isothermal non-Newtonian Model

complexity level:

- More results





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