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SIMULATION STUDY OF FENE-CR FLOWS IN TWO-DIMENSIONAL SUDDEN EXPANSIONS AT LOW-TO-MODERATE REYNOLDS NUMBERS

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OBJECTIVES

- Numerical analysis of viscoelastic fluid flow in a planar expansion ($E = D/d = 4$).

- Comparison between Newtonian and Non-Newtonian (viscoelastic) fluids.
  - Effect of elasticity;
  - Effect of inertia;
  - Effect of polymer concentration.

- Application the **FENE-CR* model** in the analysis of the viscoelastic flow (no shear-thinning).

- Utilization the **Finite Volume Method (FVM)** for the discretization equations, using the High Resolution Schemes (*HRS).*

*** FENE-CR – Finitely Extensible Nonlinear Elastic – Chilcott and Rallison (1988)**

EQUATIONS

- **Mass:**

$$\nabla \bullet \boldsymbol{u} = 0 \qquad (1)$$

- **Momentum:**

$$\rho \frac{D\boldsymbol{u}}{Dt} = -\nabla p + \nabla \bullet \boldsymbol{\tau}_{\mathrm{tot}} \qquad (2)$$

Newtonian solvent Polimeric solution

$$\boldsymbol{\tau}_{\mathrm{tot}} = \boldsymbol{\tau}_{\mathrm{s}} + \boldsymbol{\tau} \qquad (3)$$

- **Constitutive: Modified FENE-CR Model (FENE-MCR)**

$$\tau + \frac{\lambda}{f(\tau)} \overset{\nabla}{\tau} = 2\eta_P \boldsymbol{D} \qquad (4)$$

$$f(\tau) = \frac{L^2 + (\lambda/\eta_P)\, tr(\tau)}{L^2 - 3} \qquad (5)$$

DIMENSIONLESS GROUPS

The relevant dimensionless groups to be varied in a parametric way are:

- **The extensibility parameter of the FENE-CR model:**

$$L^2 = 100 \tag{6}$$

- **The Reynolds number:**

$$Re = \frac{\rho U d}{\eta_0} \tag{7}$$

- **The Weissenberg number:**

$$We = \frac{\lambda U}{d} \tag{8}$$

- **and the solvent viscosity ratio:**

$$\beta = \frac{\eta_s}{\eta_0} \tag{9}$$

GEOMETRY

DIMENSIONS

$d = 1$

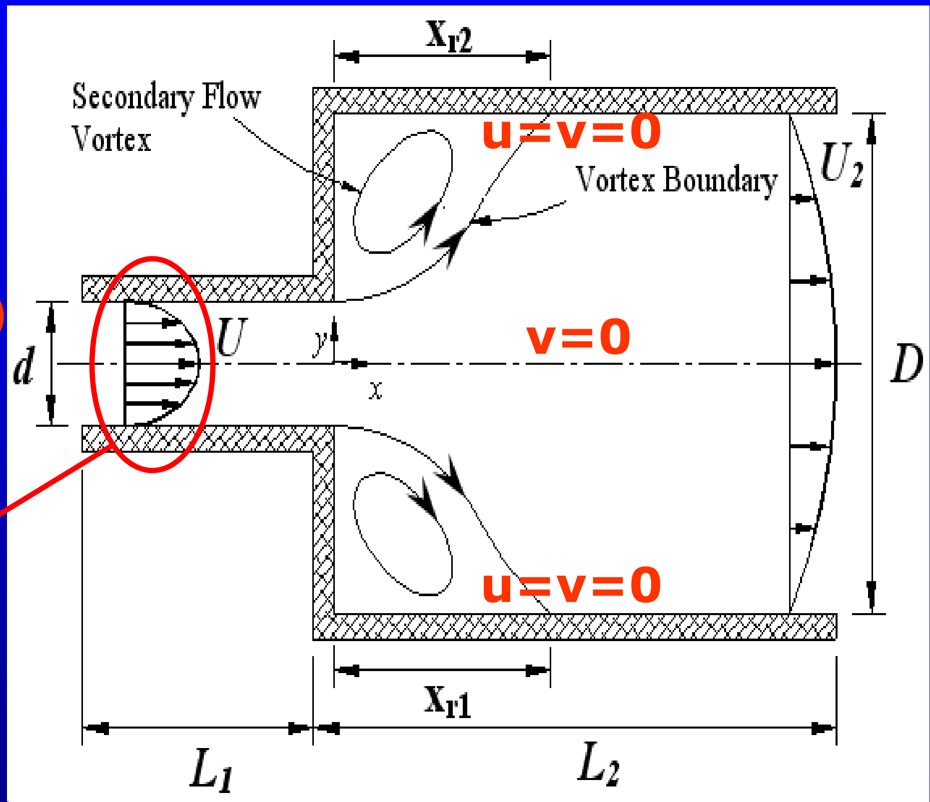
$D = 4$

$L_1 = 20d$

$L_2 = 50d$

u(y)

v=0



Inlet Conditions:

Fully developed Profile

Wall Conditions:

No slip conditions: u=v=0

Outlet Conditions:

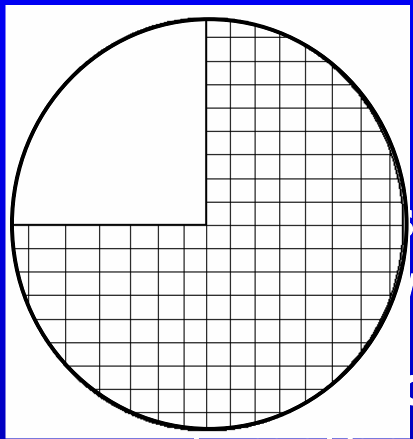
Vanishing axial variation for all quantities

$$\frac{\partial}{\partial x} \equiv 0$$

Except pressure which was linearly extrapolated from the inside

NUMERICAL METHOD

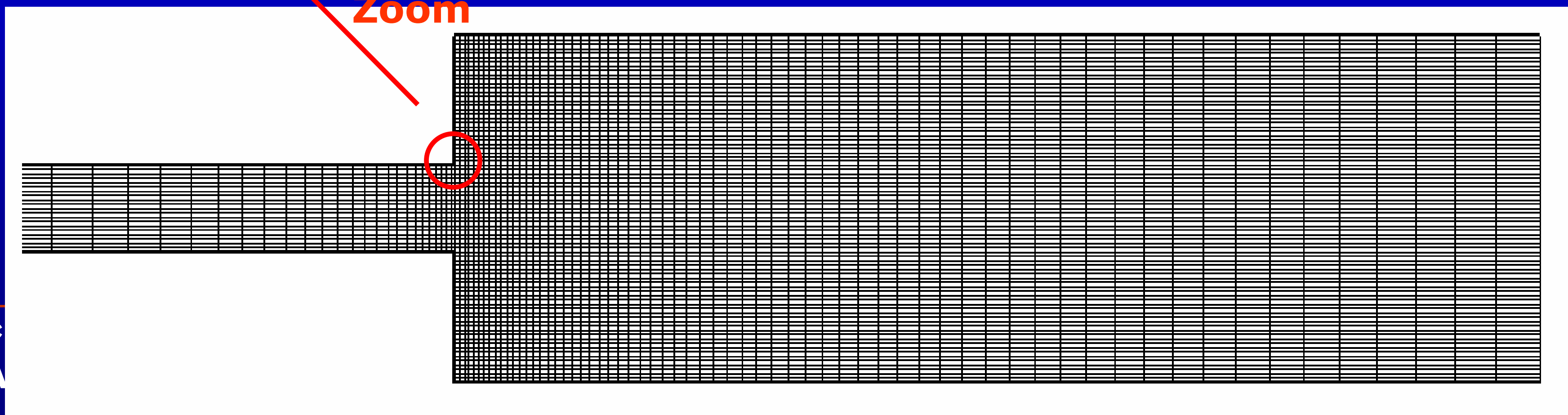
- **FINITE VOLUME METHOD (FVM).**
  - For discretization equations.
  - Non uniform orthogonal mesh.



$$\delta x_{\min} = \delta y_{\min} = 0.05$$

...ssure/velocity coupling is followed by Rhie ... method (1983)

...city/stress coupling is followed by Oliveira *et al.* method (1998).



Zoomed view of Mesh ($-5 \leq x \leq 12.5$; $-2 \leq y \leq 2$)

$L_1 = 20d$ e $L_2 = 50d$

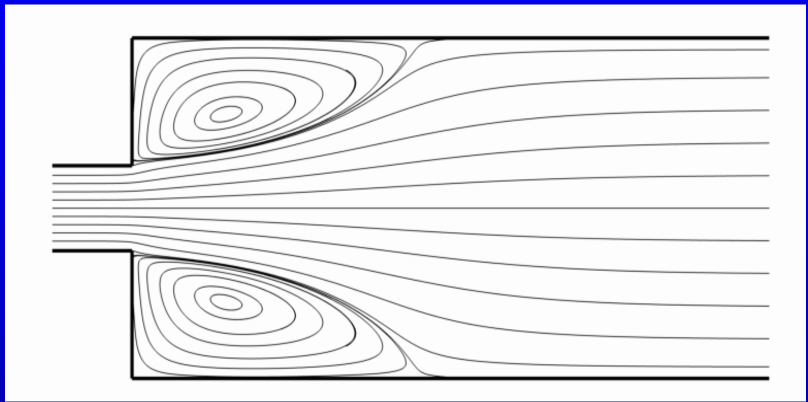
*** ... of A...**

**** Semi-Implicit Method for Pressure-Linked Equations – Consistent. (Van Doormaal and Raithby (1984)).**

RESULTS *Effect of elasticity (We)*

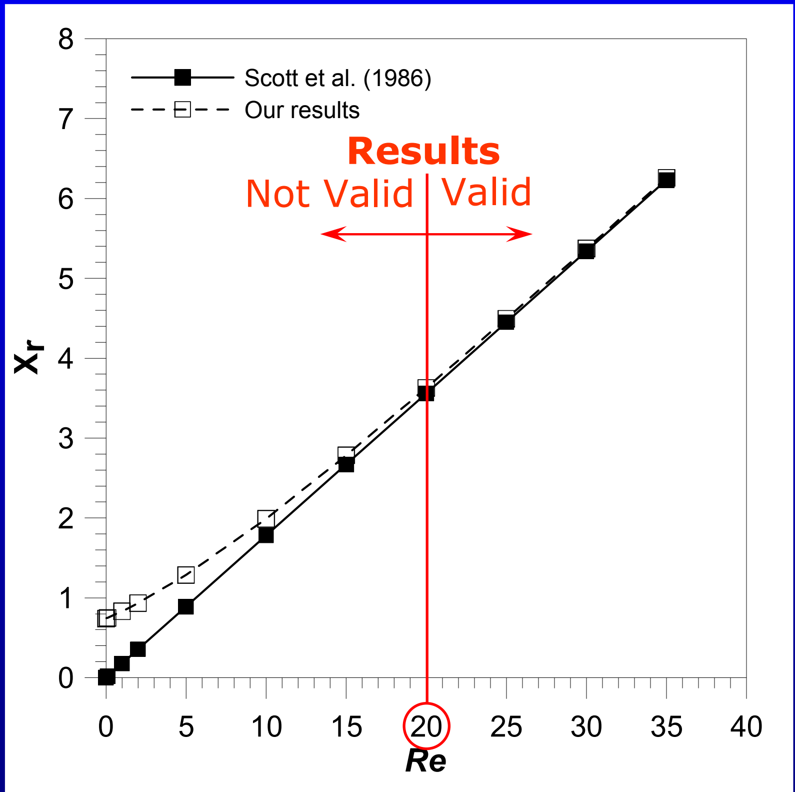
***Re* = 20; *L*^{2} = 100; β = 0.5**

Newtonian: *We* = 0

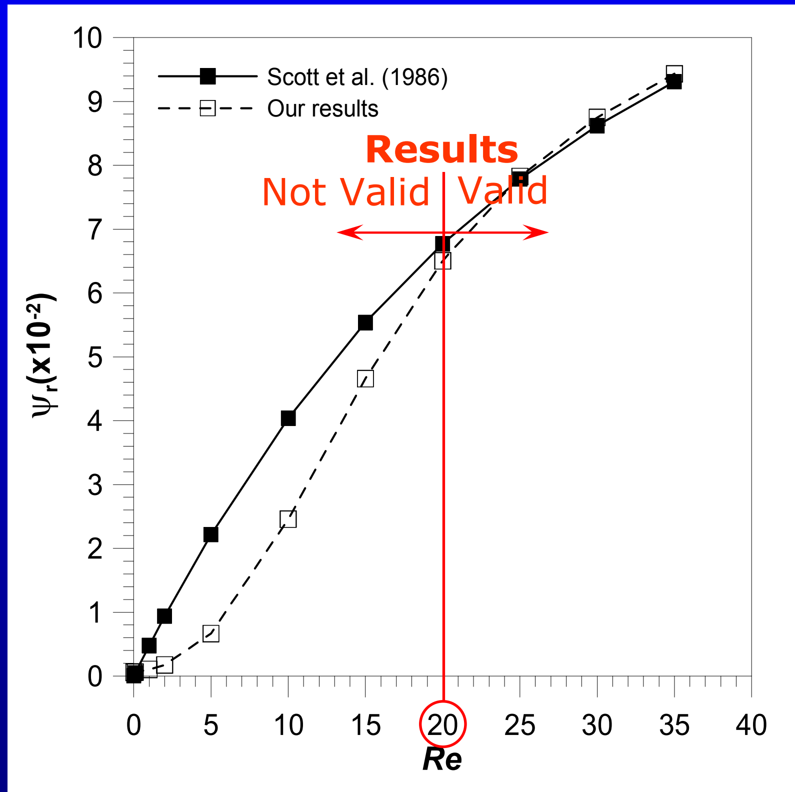


Comparation our numerical data with the correlations proposed by Scott *et al.* (1986).

VALIDATION



Vortex lenght (X_r) versus *Re* number.

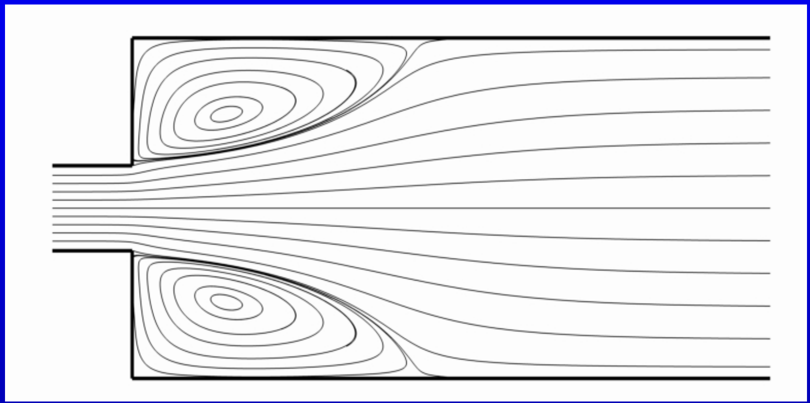


Vortex Intensity (ψ_r) versus *Re* number.

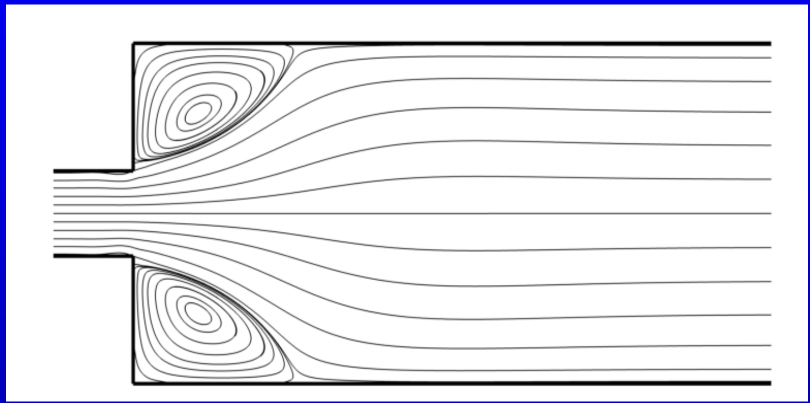
RESULTS *Effect of elasticity (We)*

***Re* = 20; *L*^{2} = 100; β = 0.5**

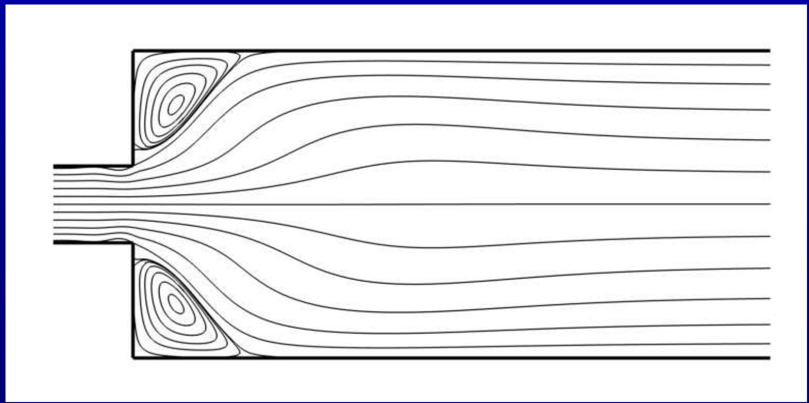
Newtonian: *We* = 0



Viscoelastic: *We* = 2



Viscoelastic: *We* = 5

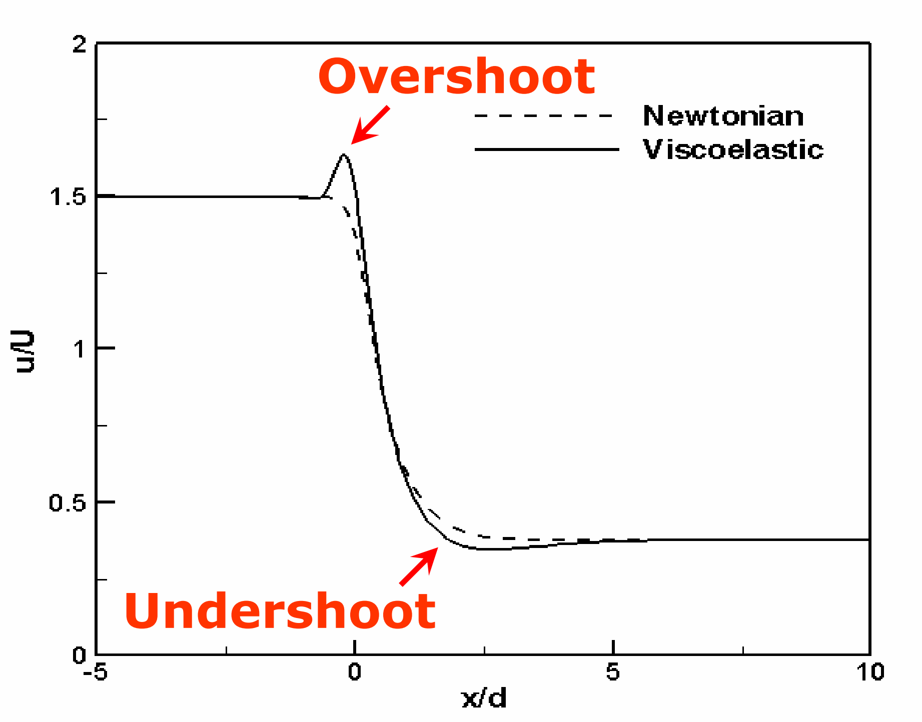


Bulging of Streamlines

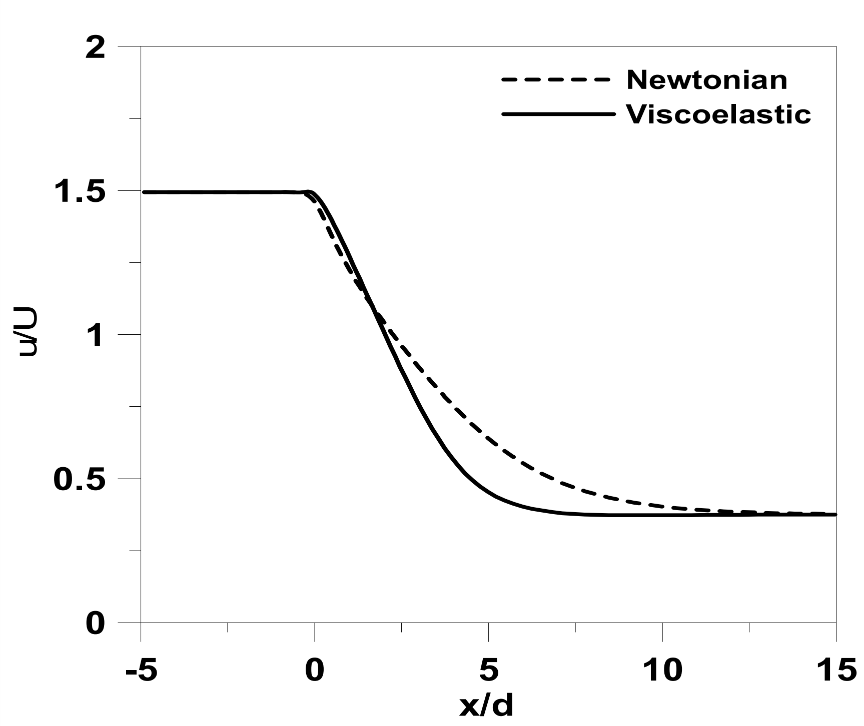
Variation of streamwise velocity component along the central plane (y=0).

$L^2 = 100$, $We = 2$, $\beta = 0.5$

$Re = 0.01$



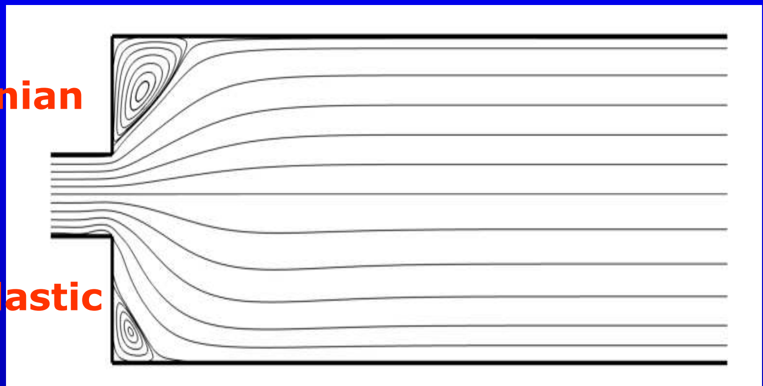
$Re = 35$



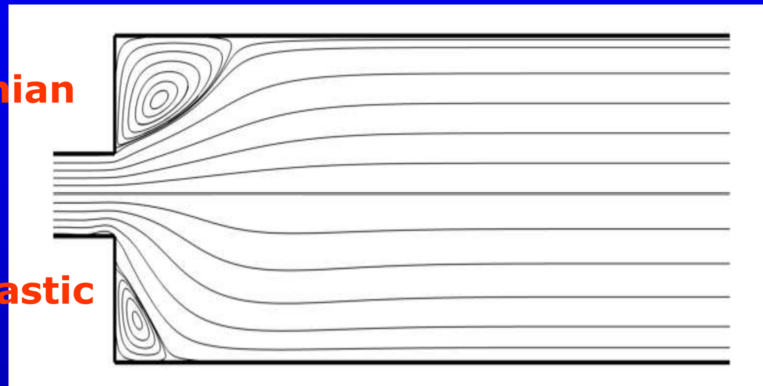
RESULTS *Effect of inertia (Re)*

Newtonian/Viscoelastic case We = 2; L^2 = 100 ; β = 0.5

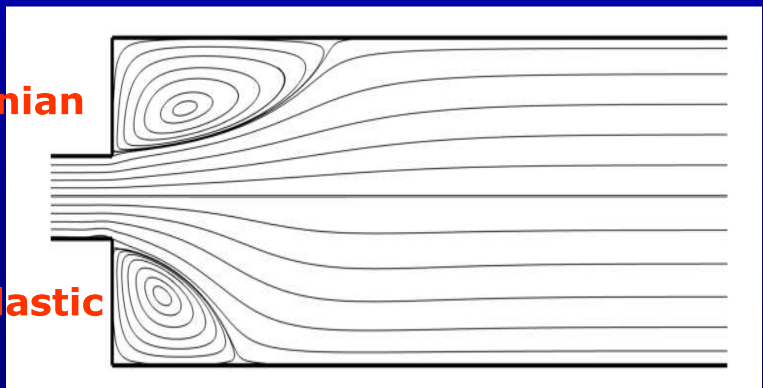
Newtonian *Re* = 5



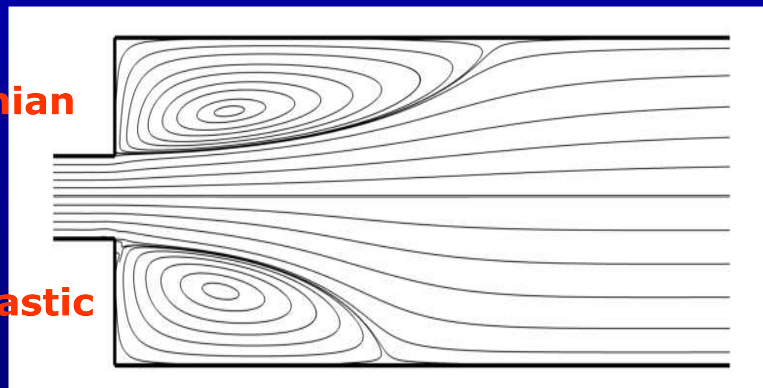
Newtonian *Re* = 10



Newtonian *Re* = 20

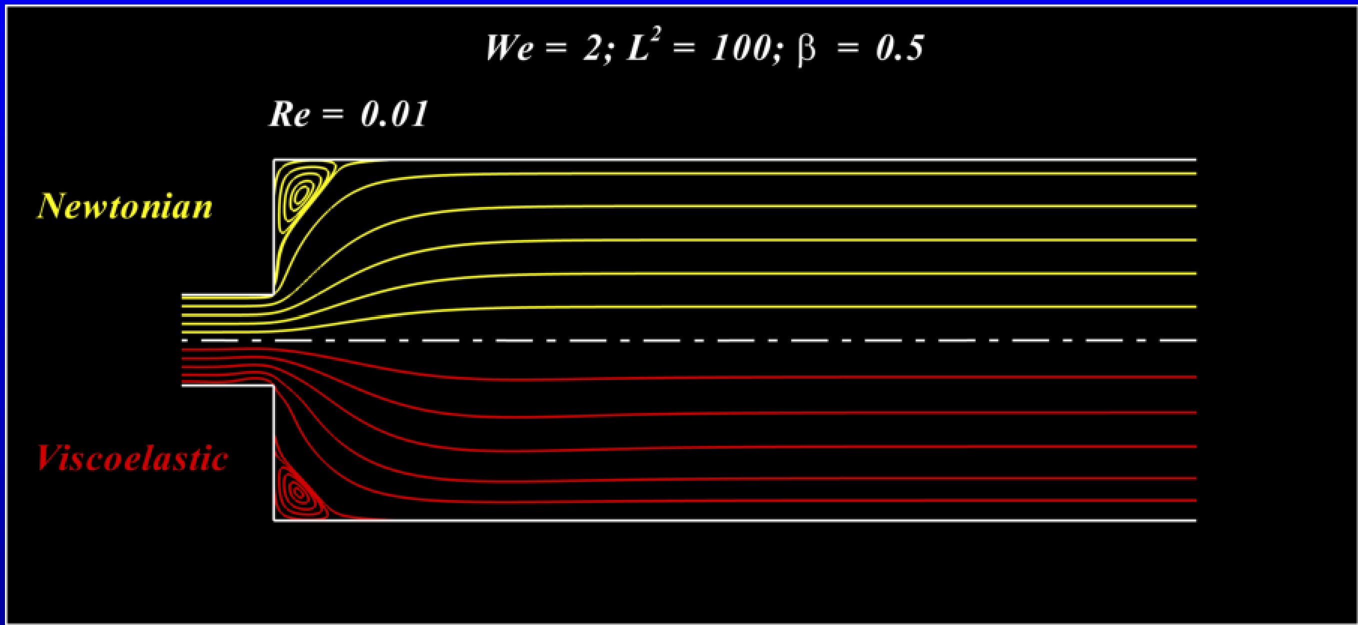


Newtonian *Re* = 35



RESULTS *Effect of inertia (Re)*

Newtonian/Viscoelastic case



RESULTS *Effect of concentration (β)*

Newtonian Case

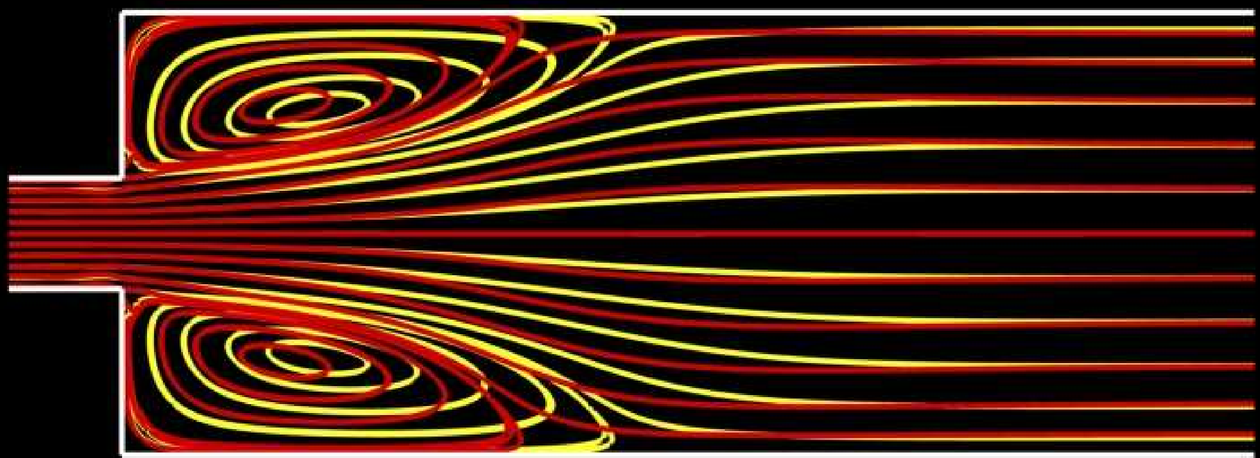
***Re* = 35**

Viscoelastic Case

***Re* = 35**

***We* = 2; L^2 = 100**

β = 0.9



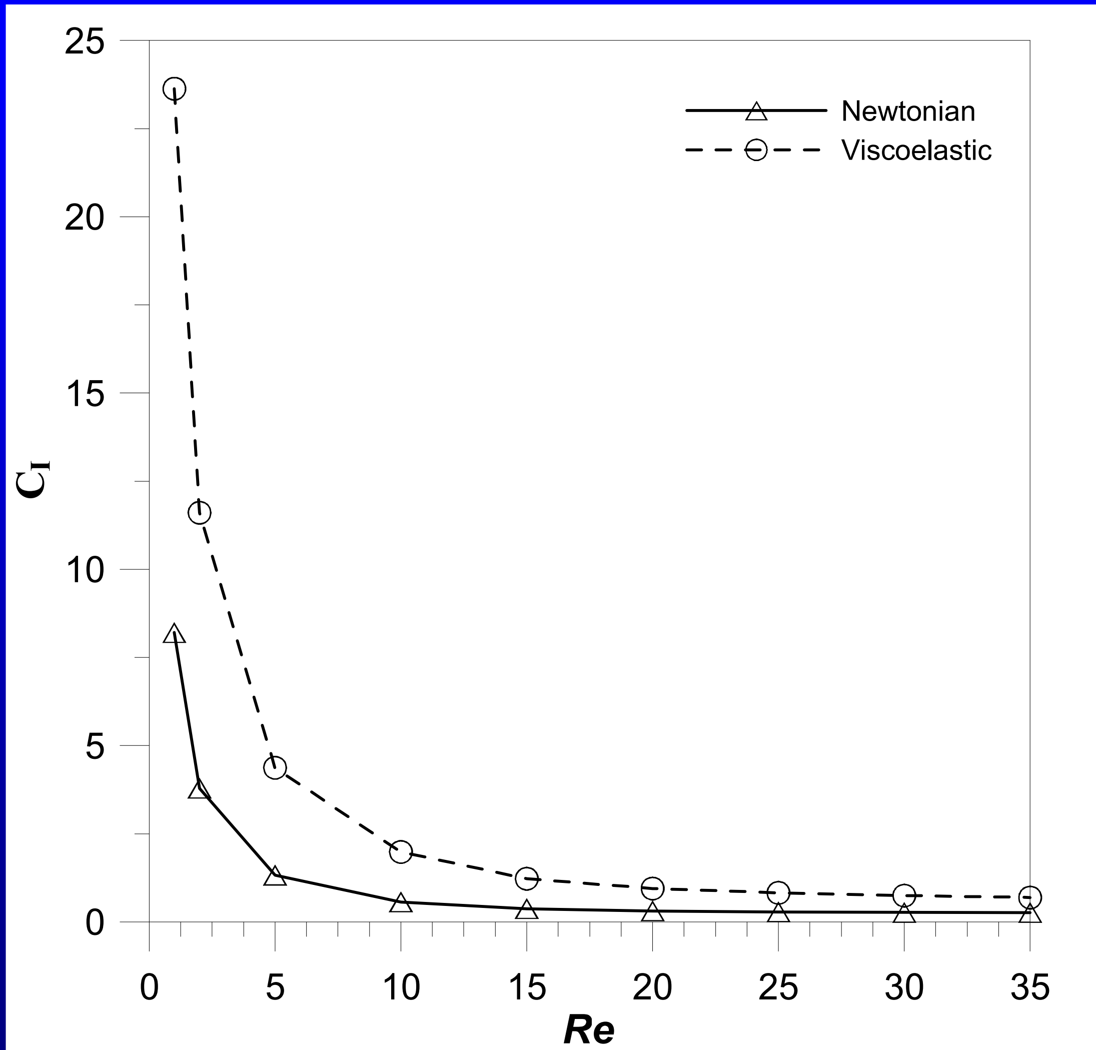
***Re* = 35**

Viscoelastic Case
***We* = 2; *L*2 = 100**

β = 0.5
Viscoelastic Case
***We* = 2; L^2 = 100**
β = 0.3

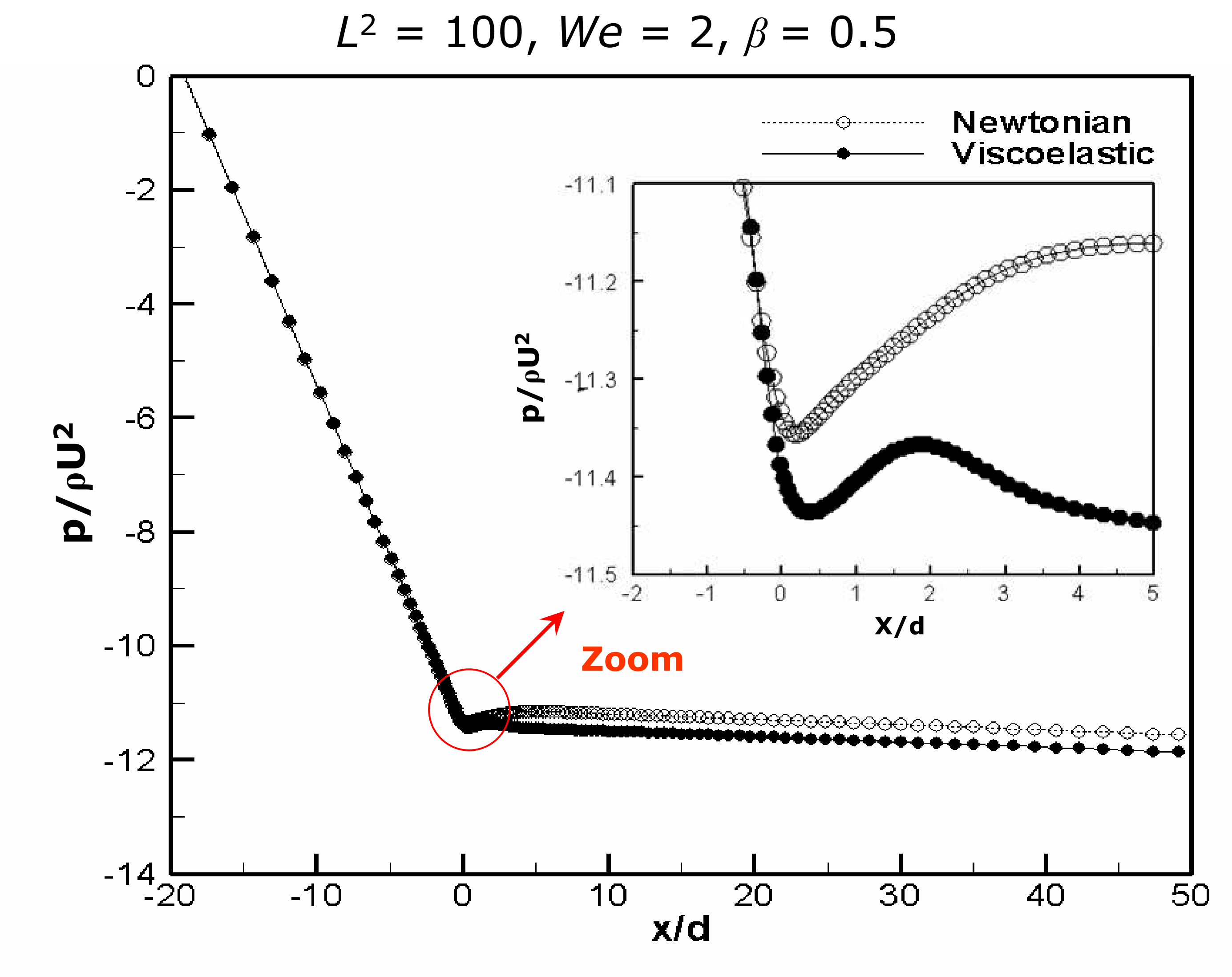
Variation of the localized loss coefficients with Reynolds number.

$$C_I = \frac{\Delta p - \Delta p_F - \Delta p_R}{\frac{1}{2}\rho U^2}$$



Comparation of Newtonian against viscoelastic flow case (L^2 = 100, We = 2, β = 0.5)

Pressure profile
along central plane (*y*=0).
***Re* = 20**



CONCLUSIONS

- At low-to-moderate Reynolds numbers (0.01-35) the flow is almost symmetric in respect to the center plane.
- For the Newtonian fluid: for *Re* larger than 1 inertial forces prevail in the flow, while for Reynolds numbers significantly less than 1 the viscous forces dominate.
- The effect of elasticity is to delay the onset of the bifurcation.
- Vortex sizes and intensities are smaller for the viscoelastic liquid, compared with the Newtonian fluid.
- The present results showing a significant reduction in vortex size and intensity with viscoelasticity could not have been obtained with generalized Newtonian fluid because here the shear viscosity was kept constant.
- The pressure recovery, after the expansion zone, is lower for the viscoelastic fluid.

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