SbmFoam

A 2D OpenFOAM® solver for the flows of concentrated rigid particles
(a continuum approach)

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T. DBOUK, L. LOBRY, E. LEMAIRE, and F. MOUKALLED, ‘Shear-induced Particles Migration.
‘Predictions from Experimental Determination of The Particle Stress Tensor’,
Journal of Non-Newtonian fluid Mechanics, 198, pp. 78-95, August (**2013**).

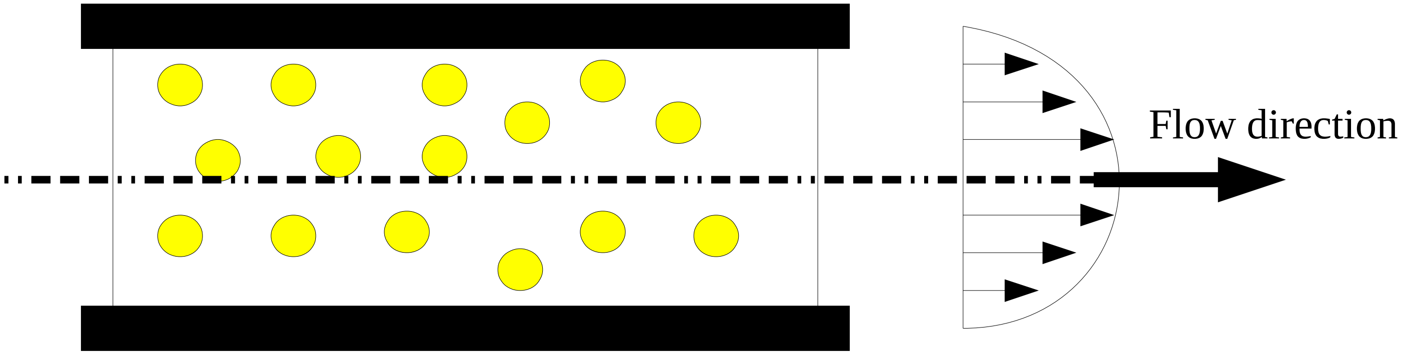
T. DBOUK, L. LOBRY, E. LEMAIRE,
‘Normal stresses in concentrated non-Brownian suspensions’,
Journal of Fluid Mechanics, Volume 715, pp 239-272, January (**2013**).

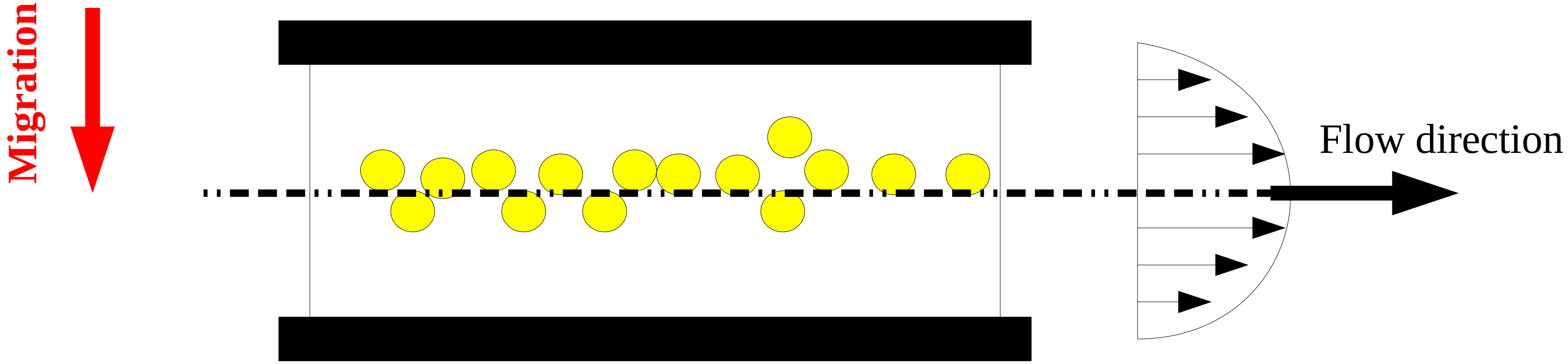
Particles Migration Phenomenon

Rigid particles - Suspension flow in a Channel

The Flow

Incompressible and viscous





Migration from higher to lower shear rate zones
(Towards the centerline)

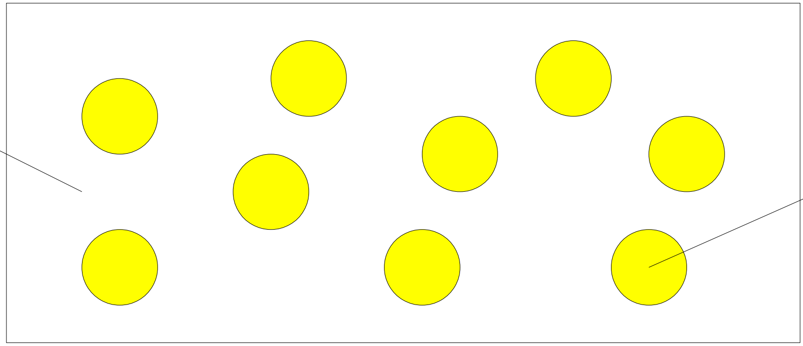
Suspension Model

Non-Brownian Suspensions of hard spheres

Newtonian Liquid

(density = ρ_f)

(viscosity = η_0 = cst.)



Monodispersed Spheres

(diameter = 2a $\geq$ 1 µm)

(density = ρ_p)

Isodense : ($\rho_f = \rho_p$)

Suspension Concentration $[\phi]$

$$\varphi = \frac{V_{solid}}{V_{total}}$$

Suspension Viscosity $[\eta(\phi)]$

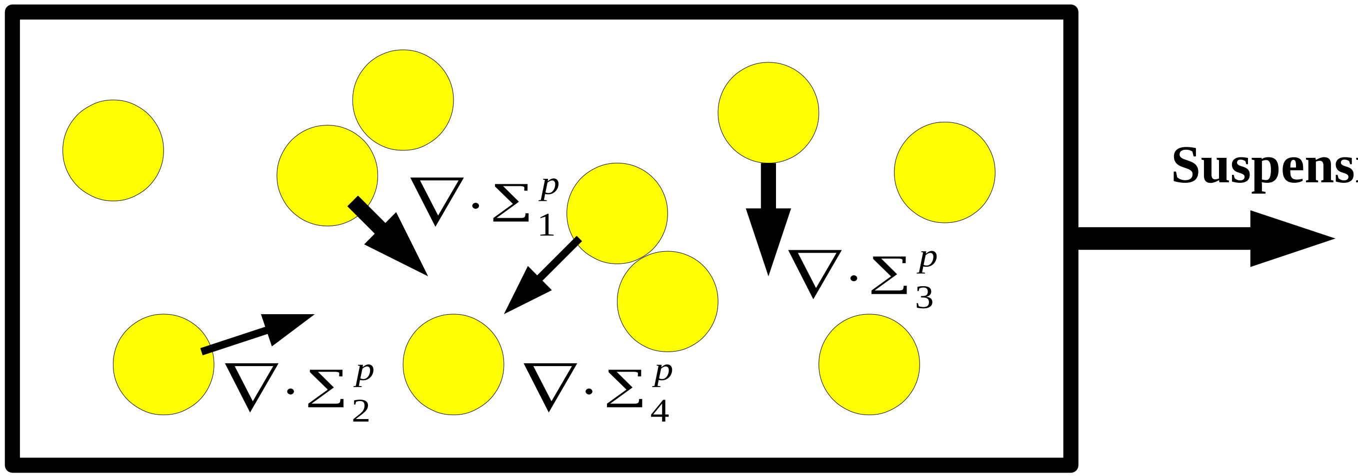
$$\eta(\phi) = \eta_0 \eta_s(\phi)$$

$$\eta_s(\phi) = \left(1 - \frac{\phi}{\phi_m}\right)^{-2}$$ *(can be measured)*

$0 \leqslant \phi < \phi_m$ $\quad$ $0{,}58 \leqslant \phi_m \leqslant 0{,}68$ (*for spheres*)

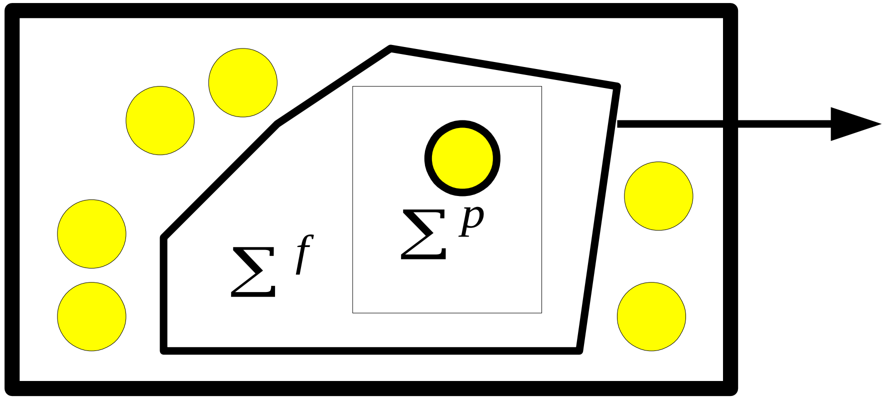
The Suspension Balance Model (SBM)

(A Continuum Approach)



Migration phenomenon is due to a flux vector $J \sim \nabla\cdot\Sigma^p$

The Suspension Balance Model (SBM)



Suspension stress
$\Sigma = \Sigma^f + \Sigma^p$

Conservation Laws

Continuity : $\nabla \cdot \boldsymbol{U} = 0 \quad (1)$

Momentum: $\nabla \cdot \boldsymbol{\Sigma} = 0 \quad (2)$

Transport: $\frac{\partial \varphi}{\partial t} + \boldsymbol{U} \cdot \nabla \varphi = -\nabla \cdot \boldsymbol{J} \quad (3)$

The Flow

Incompressible and viscous

The Suspension Balance Model (SBM)

$$\boxed{\boldsymbol{J} = ?}$$

$$\boldsymbol{J} = \frac{2a^2}{9\eta_0} f(\phi) \nabla \cdot \boldsymbol{\Sigma}^{\boldsymbol{p}}$$

Hindrance Function: $f(\phi) = (1 - \frac{\phi}{\phi_m})(1 - \phi)^{\alpha - 1} \quad (\alpha \in [2,4])$

The Suspension Balance Model (SBM)

$$\boldsymbol{\Sigma} = \boldsymbol{\Sigma}^{f} + \boldsymbol{\Sigma}^{p}$$

Suspension Stress **Fluid Stress** **Particle Stress**

$$\boldsymbol{\Sigma}^{f} = -P_f \boldsymbol{I} + 2\eta_0 \boldsymbol{E}$$

- Fluid Pressure
- Identity Tensor
- Local rate of strain Tensor

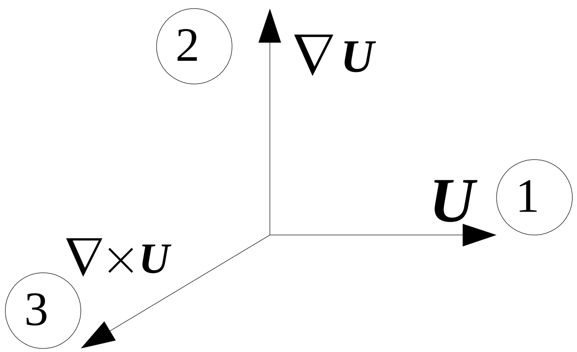
Particle phase Shear viscosity : $\eta_p(\phi) = \eta_s(\phi) - 1$

$$\boldsymbol{\Sigma}^{p} = -\boldsymbol{\Sigma}_{n}^{p} + 2\eta_0 \eta_p(\phi) \boldsymbol{E}$$

$$\boldsymbol{\Sigma}_{n}^{p} = \begin{array}{c}\begin{bmatrix} \Sigma_{11}^{p} & 0 & 0 \\ 0 & \Sigma_{22}^{p} & 0 \\ 0 & 0 & \Sigma_{33}^{p} \end{bmatrix} \\ \begin{array}{ccc} 1 & 2 & 3 \end{array}\end{array}$$

Normal Particle Stress Tensor

Measured



Directions :
- 1- Flow
- 2- Velocity-gradient
- 3- Vorticity

An OpenFOAM® Solver (2D)

The Suspension Balance Model → OpenFOAM®

$$\nabla \cdot \boldsymbol{U} = 0 \quad (1)$$

$$\nabla \cdot \boldsymbol{\Sigma} = 0 \quad (2)$$

$$\frac{\partial \varphi}{\partial t} + \boldsymbol{U} \cdot \nabla \varphi = - \nabla \cdot \boldsymbol{J} \quad (3)$$

Coupled

SbmFoam