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Development of a mechanistic pressure drop model for Taylor flow in narrow channels

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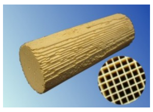
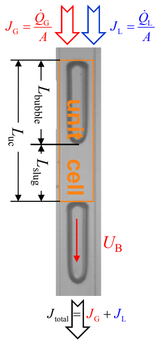
1. Introduction

- Monolithic reactors offer potential benefits for **heterogeneously catalyzed multiphase reactions** (e.g. Fischer-Tropsch synthesis).
- **Taylor flow** has advantageous mass transfer characteristics due to large specific interfacial area, thin liquid films, and good mixing in the liquid slug by recirculation.
- Here a new model for the dynamic **pressure drop** (PD) along a Taylor flow unit cell is developed from DNS results





2. Pressure drop models in literature

- Lockhart-Martinelli-Chisholm (LMC) model (does not account for σ)

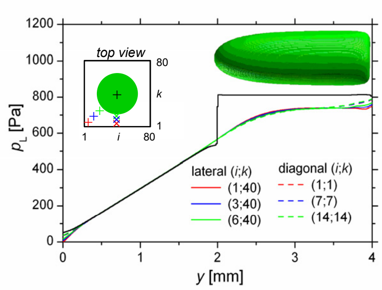
$$\frac{\Delta P_{uc}^{LMC}}{L_{uc}} = \underbrace{\frac{C_f}{2}\frac{\mu_L J_L}{D_h^2}}_{=\left(\frac{dP}{dy}\right)_L} \underbrace{\left(1+5\sqrt{\frac{\mu_G}{\mu_L}\frac{\beta}{1-\beta}}+\frac{\mu_G}{\mu_L}\frac{\beta}{1-\beta}\right)}_{=\phi_L^2 = 1+\frac{C_{Chisholm}}{\chi}+\frac{1}{\chi^2}} \qquad \chi^2 \equiv \frac{\left(\frac{dP}{dy}\right)_L}{\left(\frac{dP}{dy}\right)_G} = \frac{\mu_L}{\mu_G}\frac{J_L}{J_G}$$

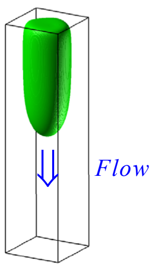
- Kreutzer [1]: $a_{exp}=0.17$, $a_{num}=0.07$, $\delta=0$; Warnier [2]: $a_{exp}=0.1$, $\delta=D_B/3$

$$\frac{\Delta P_{uc}^{K/W}}{L_{uc}} = \frac{C_f}{2}\frac{\mu_L J_{total}}{D_h^2}\left(\frac{L_{slug}+\delta}{L_{uc}}\right)\left(1+a\frac{D_h}{L_{slug}+\delta}La^{0.33}\right) \qquad La \equiv \frac{Re_B}{Ca_B} = \frac{\sigma\rho_L D_h}{\mu_L^2}$$

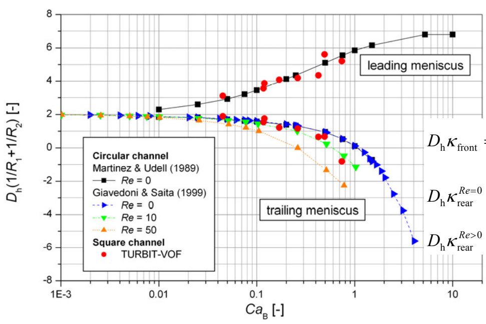
3. Pressure profiles from DNS

- Co-current downward Taylor flow in a square mini-channel [3]





- Pressure drop along the bubble / liquid film $\Delta P_{bubble}^{BW} = (\kappa_{rear} - \kappa_{front})\sigma$



$$\kappa_{rear} = \kappa_{rear}^{Re=0}(Ca_B) + \kappa_{rear}^{Re>0}(We_B)$$

$$D_h\kappa_{front} = 7.07 - \frac{7.07-2.121}{1+2.961 Ca_B^{0.916}}$$

$$D_h\kappa_{rear}^{Re=0} = \begin{cases} 2-1.354 Ca_B & (Ca_B \le 0.15) \\ 1.75(1-Ca_B) & (Ca_B > 0.15) \end{cases}$$

$$D_h\kappa_{rear}^{Re>0} = (0.0013 We_B - 0.1185) We_B$$

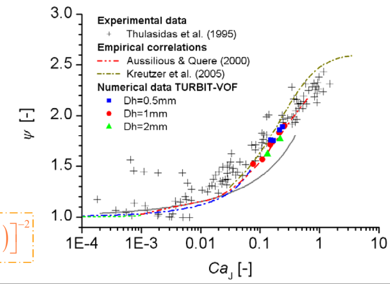
- Relating the unknown bubble velocity to the given total superficial velocity

$$Ca_B = \frac{U_B}{J_{total}}\frac{\mu_L J_{total}}{\sigma} \equiv \psi Ca_J$$

$$We_B \equiv \frac{\rho_L D_h U_B^2}{\sigma} = \psi^2 La Ca_J^2$$

$$\psi = \left(\frac{1+3.33\psi^{2/3}Ca_J^{2/3}}{1+2\psi^{2/3}Ca_J^{2/3}}\right)^2$$

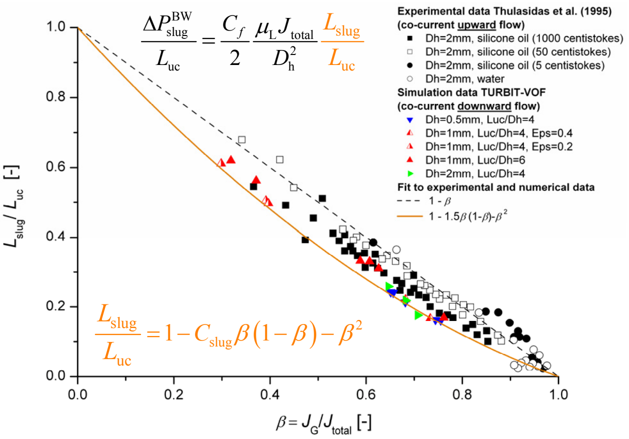
$$\psi = \frac{4}{\pi}\left[0.7+0.5\exp\left(-2.25\psi^{0.445}Ca_J^{0.445}\right)\right]^{-2}$$



4. New pressure drop model

- Dynamic pressure drop consists of 2 parts: $\frac{\Delta P_{uc}^{BW}}{L_{uc}} = \frac{\Delta P_{slug}^{BW}}{L_{uc}} + \frac{\Delta P_{bubble}^{BW}}{L_{uc}}$
- Pressure drop in the liquid slug

$$\frac{\Delta P_{slug}^{BW}}{L_{uc}} = \frac{C_f}{2}\frac{\mu_L J_{total}}{D_h^2}\frac{L_{slug}}{L_{uc}}$$



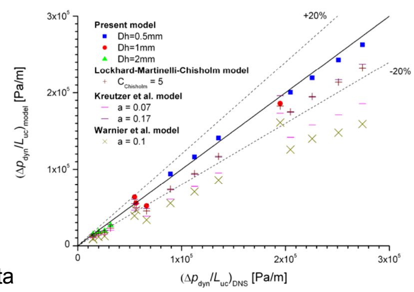
$$\frac{L_{slug}}{L_{uc}} = 1 - C_{slug}\beta(1-\beta) - \beta^2$$

5. Conclusions

- The new model is in very good agreement with the DNS data
- It allows to estimate the unit cell pressure drop from the following six parameters:

$$\rho_L, \mu_L, \sigma, J_L, J_G, D_h$$

- Outlook: comparison with experimental pressure drop data



References

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