Multiphase Flows – WS 2022/23
Problem Session 10: Process Engineering Applications

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Problem 1: Sedimentation of Single Particles (1)

We investigate the sedimentation of single particles at different conditions.

a) *Compute the steady-state sedimentation velocity of a single particle with diameter* $d_P = 0.02\ \mathrm{mm}$ *in water at* $20\ °\mathrm{C}$.

b) *Compute the steady-state sedimentation velocity of a single particle with diameter* $d_P = 0.2\ \mathrm{mm}$ *in air at* $1000\ °\mathrm{C}$.

c) *Compute the time after which an initially quiescent particle with diameter* $d_P = 0.02\ \mathrm{mm}$ *has reached* $99\ \%$ *of its steady-state sedimentation velocity in water at* $20\ °\mathrm{C}$. *The acceleration factor for the accelerated liquid is* $\alpha = 0.5$.

Particle density: $\rho_P = 5200\ \frac{\mathrm{kg}}{\mathrm{m}^3}$

Properties of water $(20\ °\mathrm{C})$*:* $\rho_{W,20} = 998.2\ \frac{\mathrm{kg}}{\mathrm{m}^3}, \eta_{W,20} = 1.004 \cdot 10^{-3}\ \frac{\mathrm{kg}}{\mathrm{m{\cdot}s}}$

Properties of air $(1000\ °\mathrm{C})$*:* $\rho_{A,1000} = 0.2733\ \frac{\mathrm{kg}}{\mathrm{m}^3}, \eta_{A,1000} = 47.93 \cdot 10^{-6}\ \frac{\mathrm{kg}}{\mathrm{m{\cdot}s}}$

Problem 1: Sedimentation of Single Particles (2)

Use the following drag laws:

$$\mathrm{Re} \leq 0.1:\ C_\mathrm{D} = \frac{24}{\mathrm{Re}}$$

$$0.1 < \mathrm{Re} < 2 \cdot 10^3:\ C_\mathrm{D} = \frac{24}{\mathrm{Re}} + \frac{4}{\sqrt{\mathrm{Re}}} + 0.4$$

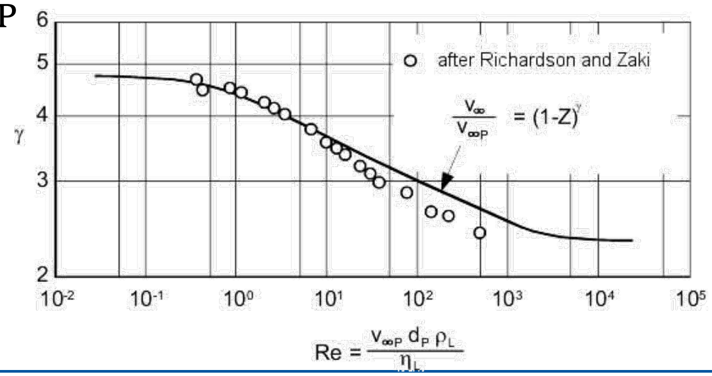
The acceleration factor α is defined as the ratio of the volume of accelerated water (around the particle) and the particle volume.

Particle Cloud Behavior

- In technical systems: particles often aggregate –> formation of particle clouds (PC)
  - → velocity smaller than velocity for single particle
  - → particles do not move any more in "pure" fluid, but in a medium with different properties due to the presence of a high particle number
- Particle volume concentration: $Z = \frac{\dot{V}_P}{\dot{V}_M} = \frac{\dot{V}_P}{\dot{V}_L + \dot{V}_P}$

➢ Cloud settling velocity [Richardson and Zaki]:

$$\frac{v_{\infty,\mathrm{PC}}}{v_{\infty,\mathrm{SP}}} = (1-Z)^{\gamma}\,, \qquad Z \geq 0.001; \qquad \frac{v_{\infty,\mathrm{PC}}}{v_{\infty,\mathrm{SP}}} = 1\,, \qquad Z < 0.001$$

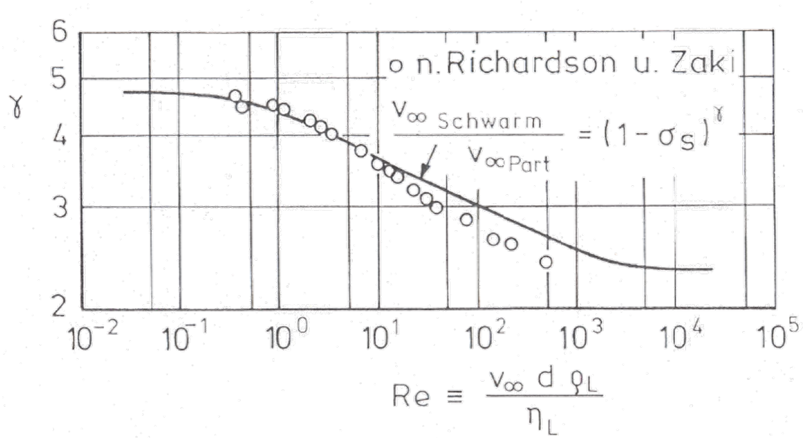


Problem 2: Sedimentation Velocity of Particle Cloud

We investigate the sedimentation of particles with diameter $d_P = 0.02\ \mathrm{mm}$. *The stationary sedimentation velocity of the single particles in water has been determined as* $v_{\infty,SP} = 9.123 \cdot 10^{-4}\ \frac{\mathrm{m}}{\mathrm{s}}$ *in Problem 1.*

Compute the particle cloud velocity of particles with this size assuming a particle mass concentration of $w_{\mathrm{P}} = 10\%$ *in the fluid.*

Properties: $\rho_{\mathrm{P}} = 5200\ \frac{\mathrm{kg}}{\mathrm{m}^3}$, $\rho_{\mathrm{W}} = 998.2\ \frac{\mathrm{kg}}{\mathrm{m}^3}$, $\eta_{\mathrm{W}} = 1.004 \cdot 10^{-3}\ \frac{\mathrm{kg}}{\mathrm{m \cdot s}}$



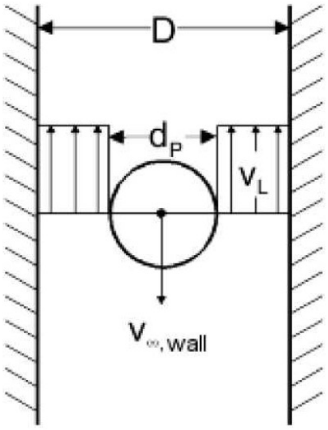
Problem 3: Sedimentation Velocity with Wall Impact

Determine the stationary sedimentation velocity $v_{\infty,\mathrm{P}}$ for a spherical particle with diameter d_P in water in a cylindric vessel with diameter D.

Note that the velocity $v_{\infty,\mathrm{P}}$ is influenced by the displaced fluid. Assume Stokes flow and a "piston profile" for the fluid velocity around the particle.

Properties: $\rho_P = 5200\ \frac{\mathrm{kg}}{\mathrm{m}^3},\ \rho_W = 998.2\ \frac{\mathrm{kg}}{\mathrm{m}^3},\ \eta_W = 1.004 \cdot 10^{-3}\ \frac{\mathrm{kg}}{\mathrm{m \cdot s}}$

Geometry: $d_P = 2\ \mathrm{mm},\quad D = 10\ \mathrm{mm}$



Thank you for your attention

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