4.6: Hindered Settling

The above equations calculate the settling velocities for individual grains. The grain moves downwards and the same volume of water has to move upwards. In a mixture, this means that, when many grains are settling, an average upwards velocity of the water exists. This results in a decrease of the settling velocity, which is often referred to as hindered settling. However, at very low concentrations the settling velocity will increase because the grains settle in each other’s shadow. Richardson and Zaki (1954) determined an equation to calculate the influence of hindered settling for volume concentrations $C_v$ between 0 and 0.3. The coefficient in this equation is dependent on the Reynolds number. The general equation yields:

$$\frac{v_{th}}{v_t} = \left(1 - C_v\right)^{\beta}$$

The following values for $\beta$ should be used according to Richardson and Zaki (1954):

- $R_e < 0.2$, $\beta = 4.65$
- $0.2 < R_e < 1.0$, $\beta = 4.35 \cdot R_e^{-0.03}$
- $1.0 < R_e < 200$, $\beta = 4.45 \cdot R_e^{-0.1}$
- $R_e > 200$, $\beta = 2.39$

However this does not give a smooth continuous curve. Using the following definition does give a continuous curve:

$$\begin{array}{ll}
R_e < 0.1 & \beta = 4.65 \\
0.1 < R_e < 1.0 & \beta = 4.35 \cdot R_e^{-0.03} \\
1.0 < R_e < 400 & \beta = 4.45 \cdot R_e^{-0.1} \\
R_e > 400 & \beta = 2.39
\end{array}$$

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Other researchers found the same trend but sometimes somewhat different values for the power $\beta$. These equations are summarized below and shown in Figure 4.6-1.

According to Rowe (1987) this can be approximated by:

$$\beta=\frac{4.7+0.41 \cdot \text{Re}_p^{0.75}}{1+0.175 \cdot \text{Re}_p^{0.75}}$$

Wallis (1969) found an equation which matches Rowe (1987) for small Reynolds numbers and Garside & Al-Dibouni (1977) for the large Reynolds numbers:

$$\beta=\frac{4.7 \cdot (1+0.15 \cdot \text{Re}_p^{0.687})}{1+0.253 \cdot \text{Re}_p^{0.687}}$$

Garside & Al-Dibouni (1977) give the same trend but somewhat higher values for the exponent $\beta$.

$$\beta=\frac{5.1+0.27 \cdot \text{Re}_p^{0.9}}{1+0.1 \cdot \text{Re}_p^{0.9}}$$

Di Felici (1999) finds very high values for $\beta$ but this relation is only valid for dilute mixtures (very low concentration, less than 5%).

$$\beta=\frac{6.5+0.3 \cdot \text{Re}_p^{0.74}}{1+0.1 \cdot \text{Re}_p^{0.74}}$$

Figure 4.6-1: The hindered settling power according to several researchers.