Slurry Suspension

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What We Know about Mechanical Agitation

- Thoroughly studied for 40 years
- Characteristics
  - off-bottom suspension
  - on-bottom motion
  - uniform suspension
  - cloud height
- Visual observation
- Reliable means of measurement

What We Don’t Know about Pulse Jet Mixers

- We don’t know how a pulse will effect solids suspension
- Pulsed operation will not be better than continuous agitation
- We need to know about the effects of geometry on solids suspension
- We need to know how to scale-up

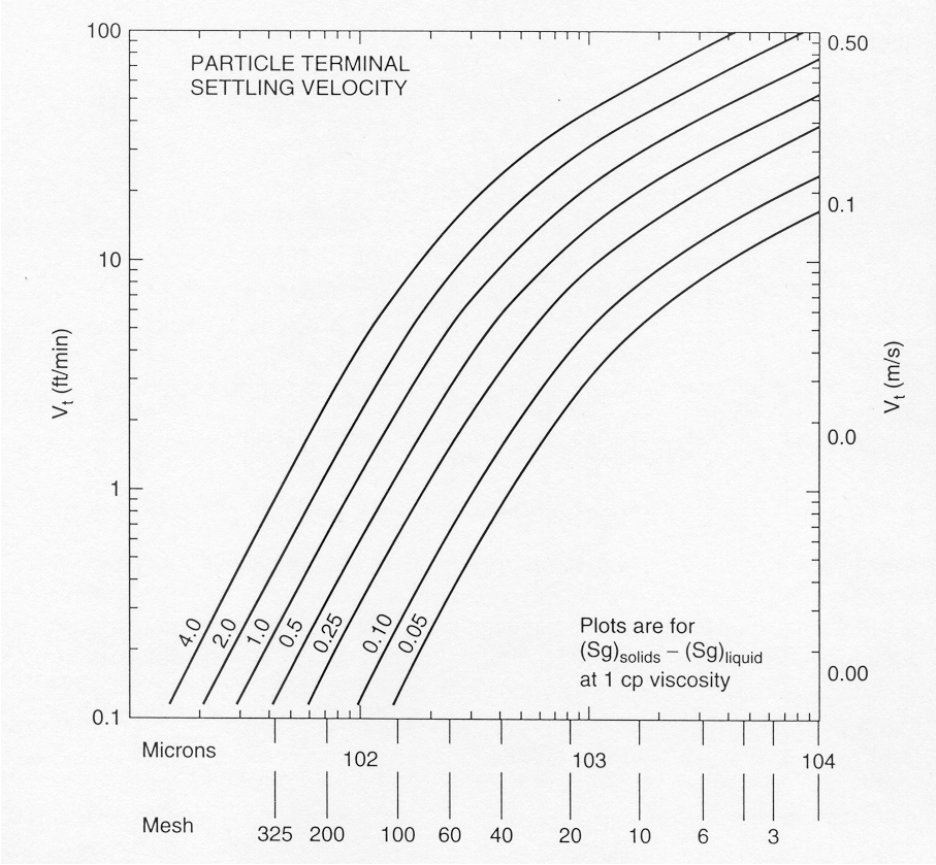
Everything We Know about Solids Suspension is Scale-up

- All of solids suspension is empirical
- Observation of suspension characteristics
- Testing in different scales
- Scale-up of small-scale tests

Difficulty

- **Primary factor – settling velocity**
  - **with density adjustment**
- **Many other factors involved**
  - **mixer geometry factors**
  - **particle property factors**
  - **fluid property factors**

Terminal Settling Velocity



Terminal Settling Velocity

- Settling due to density difference
- Slow settling
  - laminar
  - Stokes flow
- Rapid settling
  - turbulent
  - Newton flow
- Transition between laminar and turbulent

Agitated Suspension

- Not terminal settling velocity
- Agitated flow not vertical at all points
- Initial suspension by horizontal flow across bottom
- Suspension characteristics a stronger function of density than predicted by terminal settling velocity
- Density more important than diameter

Zwietering Correlation

$$N_{js} = S\,\nu^{0.1}\left[\frac{g_c\,(\rho_s - \rho_l)}{\rho_l}\right]^{0.45} X^{0.13}\,d_p{}^{0.2}\,D^{-0.85}$$

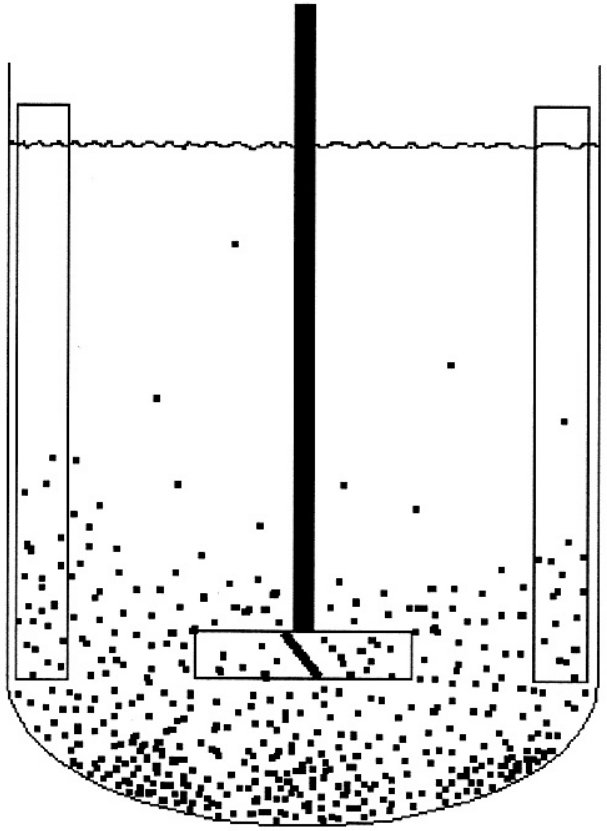
Density Effect on Terminal Settling Velocity

$$N_{js} = S' \left[\left(\frac{\rho_s - \rho_l}{\rho_l} \right) u_t \right]^{-0.28}$$

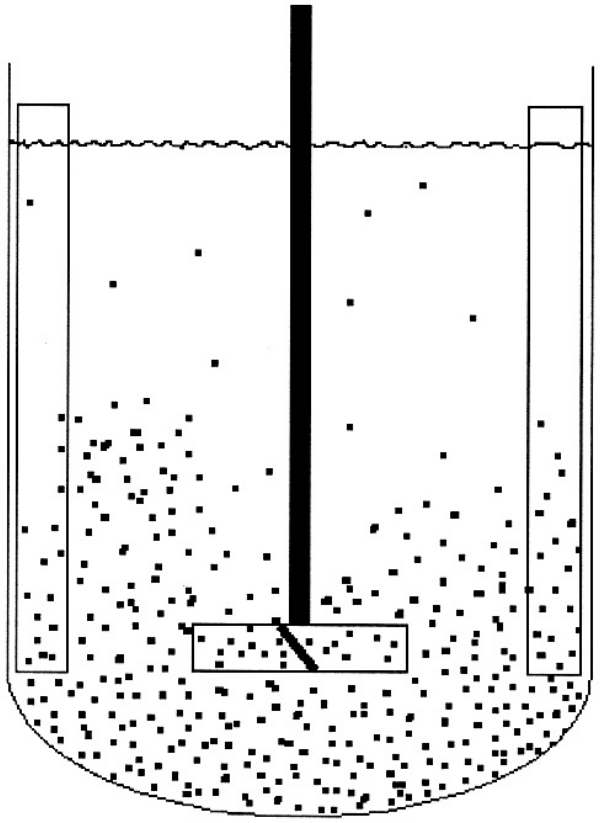
Mixing Intensity

- **On-bottom motion**
  - **all particles moving**
  - **not necessarily suspended**
- **Off-bottom suspension**
  - **all particles suspended**
  - **cloud height**
- **Uniform suspension**
  - **all particles well distributed**

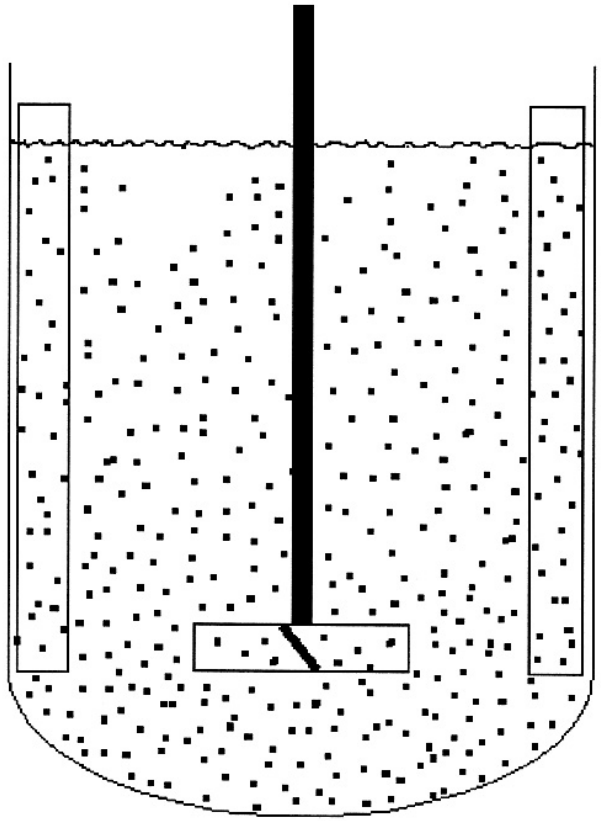
On-Bottom Motion



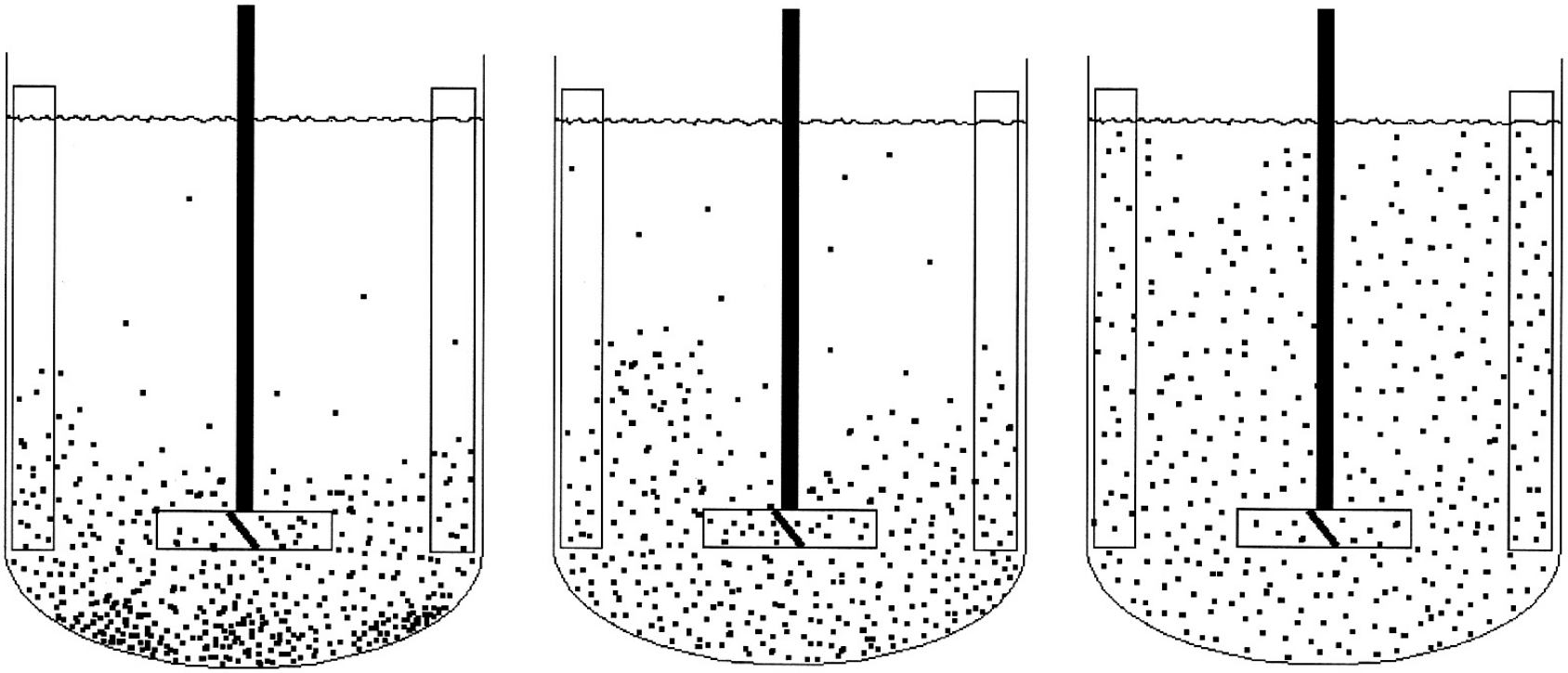
Off-Bottom Suspension



Uniform Suspension



Suspension Levels



On Bottom Motion

Off-Bottom Suspension

Complete Suspension

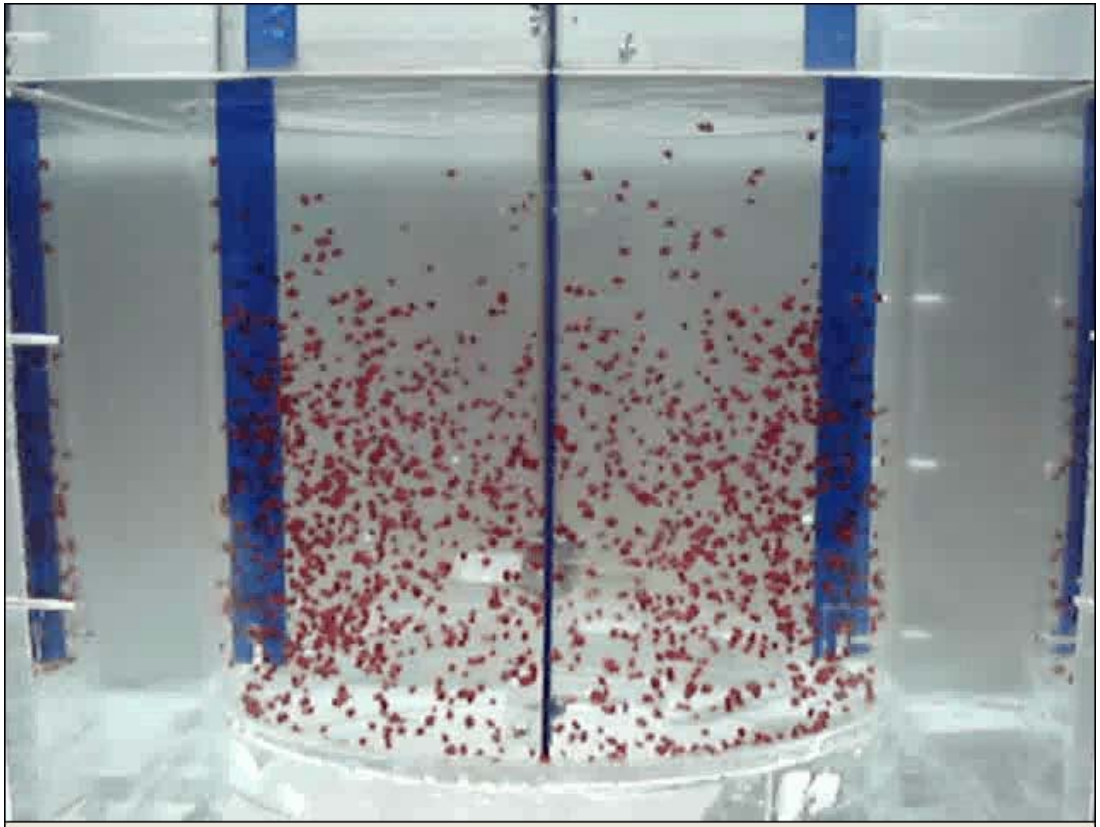
Mixer Design Factor

- **Just suspended speed – N_{JS}**
- **Classical correlation by Zwietering**
  - **adapted for practical use**
- **Other more complicated and more accurate correlations**
- **Testing and scale-up – best method**

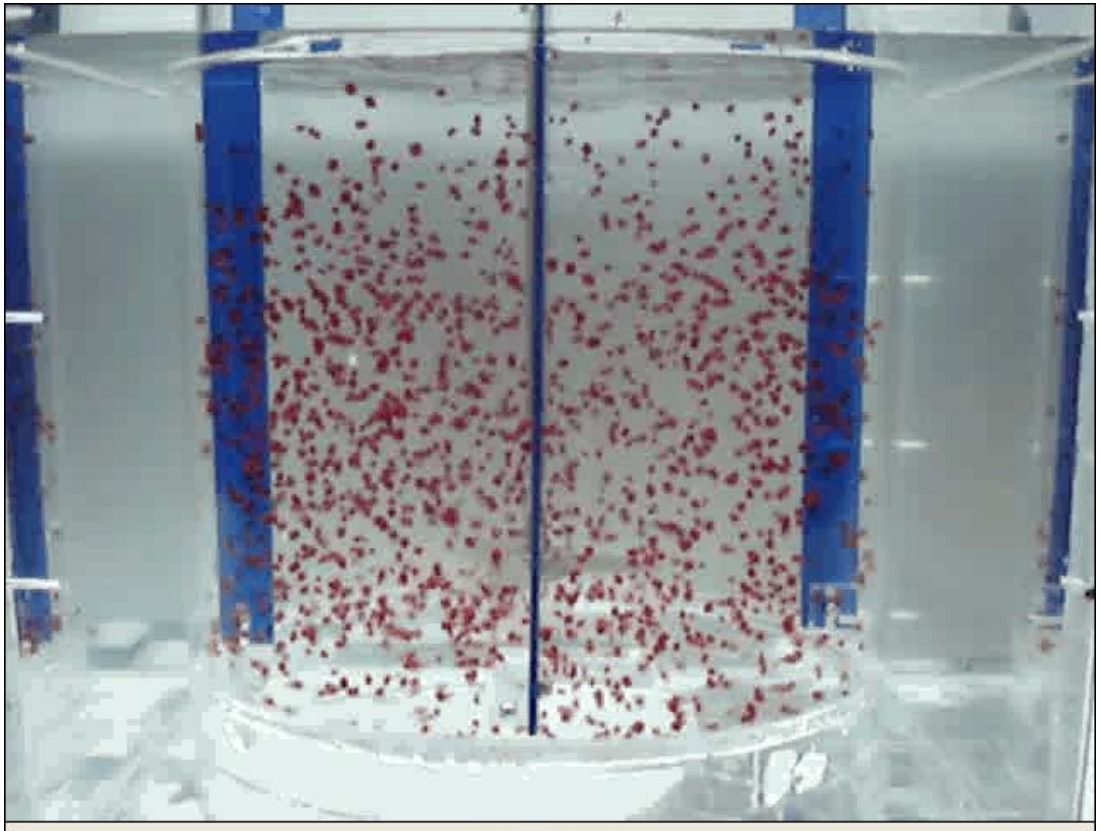
Mixer Geometry Factors

- **Impeller type – axial flow is best**
- **Impeller to tank diameter**
- **Off-bottom clearance**
- **Number of impellers**
- **Liquid level**
- **Baffle length – off-bottom clearance**

Pitched-Blade Turbine

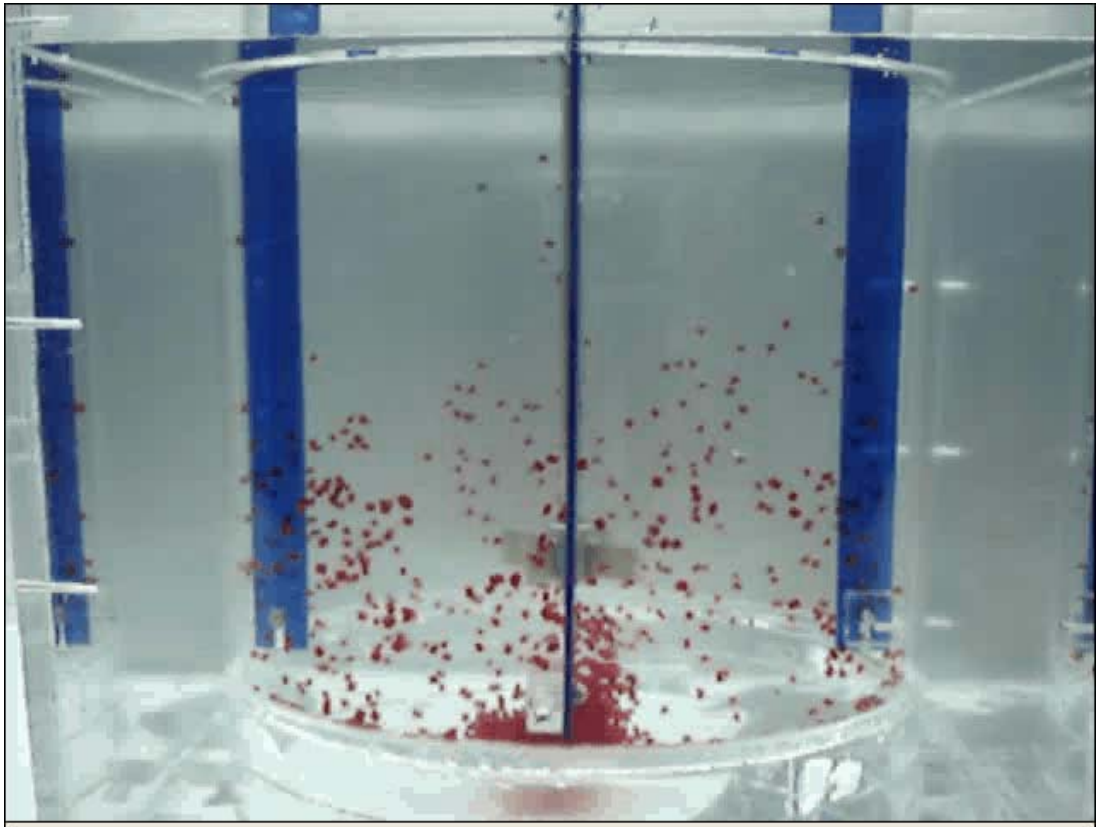


Hydrofoil Impeller



Hydrofoil 1-4.AVI

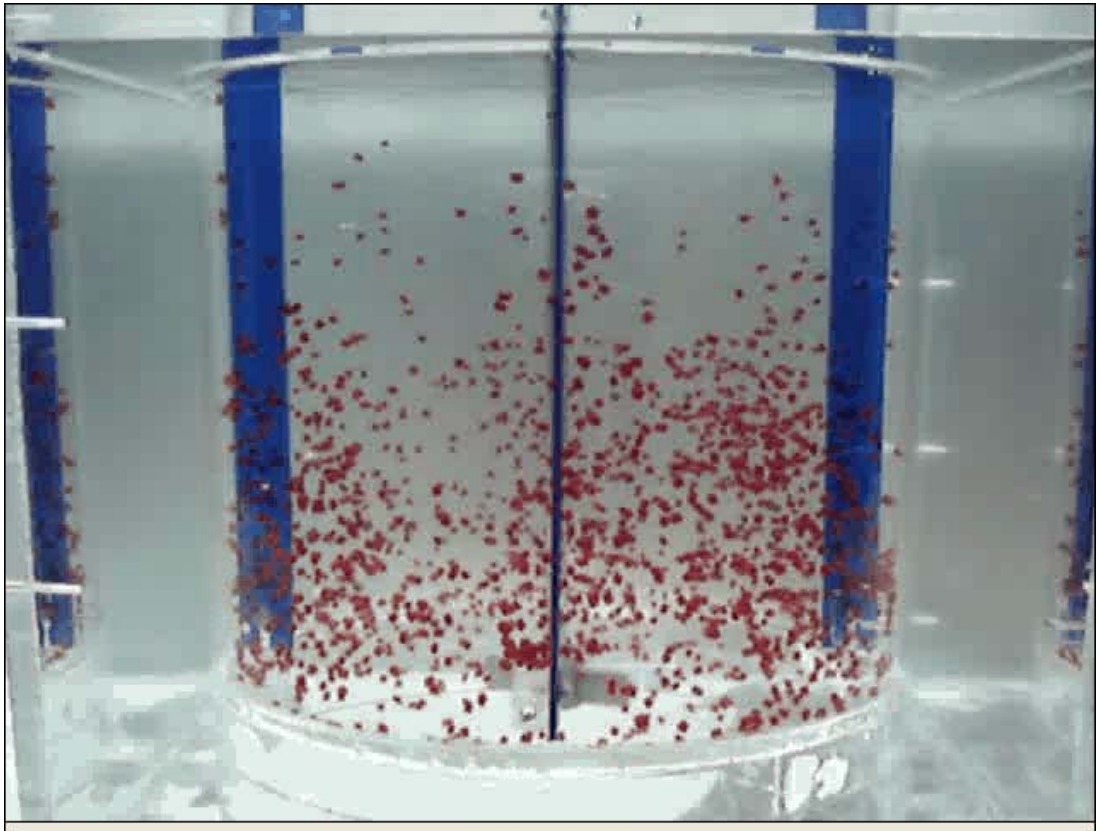
Straight-Blade Turbine



Suspension with Radial Flow

- **The straight-blade radial flow impeller did not work with typical off-bottom clearance**
- **Close clearance does work for solids suspension**
- **Impeller location can be a major factor in solids suspension**

Straight-Blade Turbine – Close Clearance

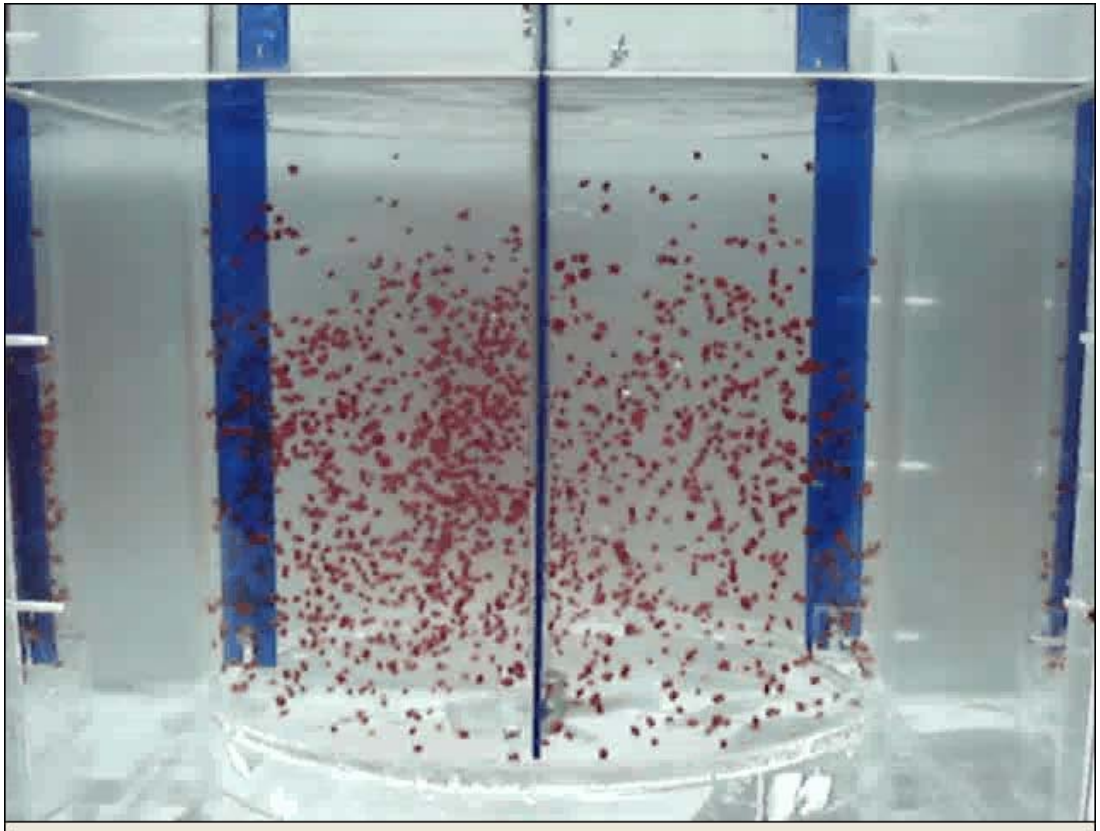


Straight Close.AVI

Suspension with Axial Flow

- **Axial flow impellers work at close clearance**
  - **pitched-blade turbine**
  - **hydrofoil impeller**
- **Pitched-blade turbine requires less power than straight-blade turbine for the same results**

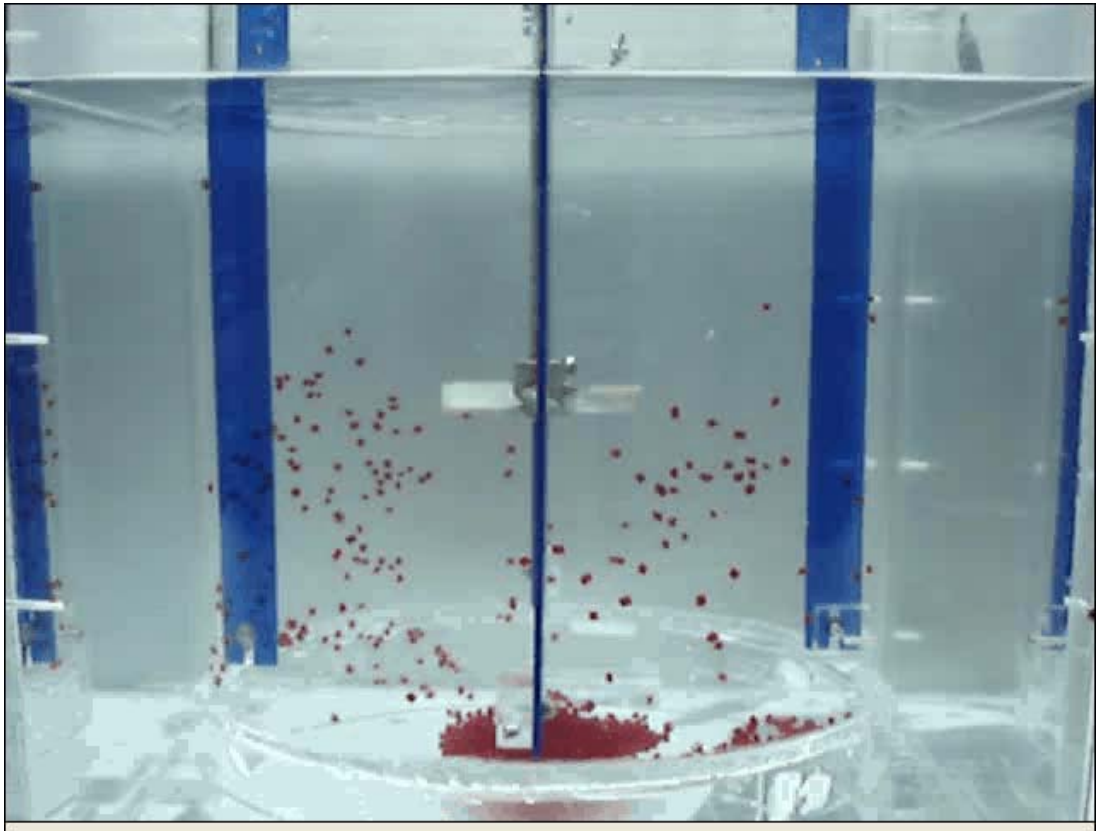
Pitched-Blade Turbine – Close Clearance



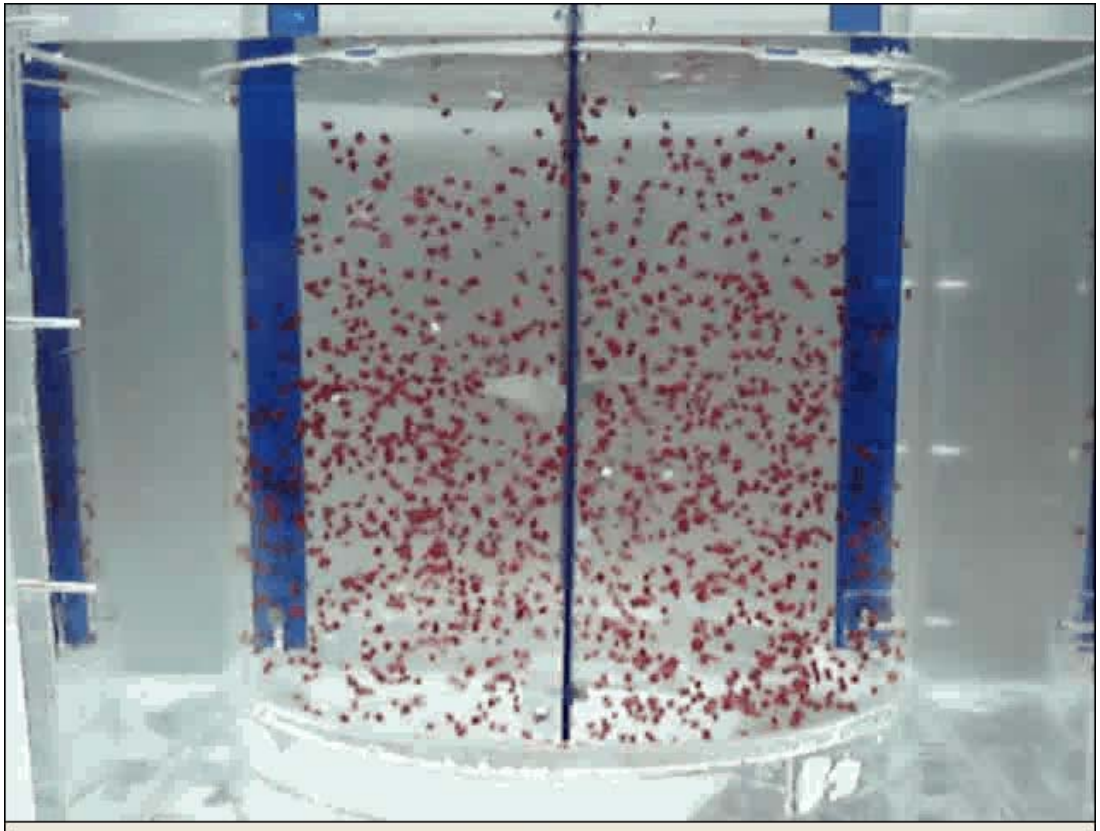
High Clearance Causes Problems

- **Pitched-blade turbine fails to suspend solids when too far off-bottom**
- **Hydrofoil impeller works better even at high clearance position**
- **Different degrees of axial flow are important for solids suspension**

Pitched-Blade Turbine – ½ Liquid Level Off-Bottom

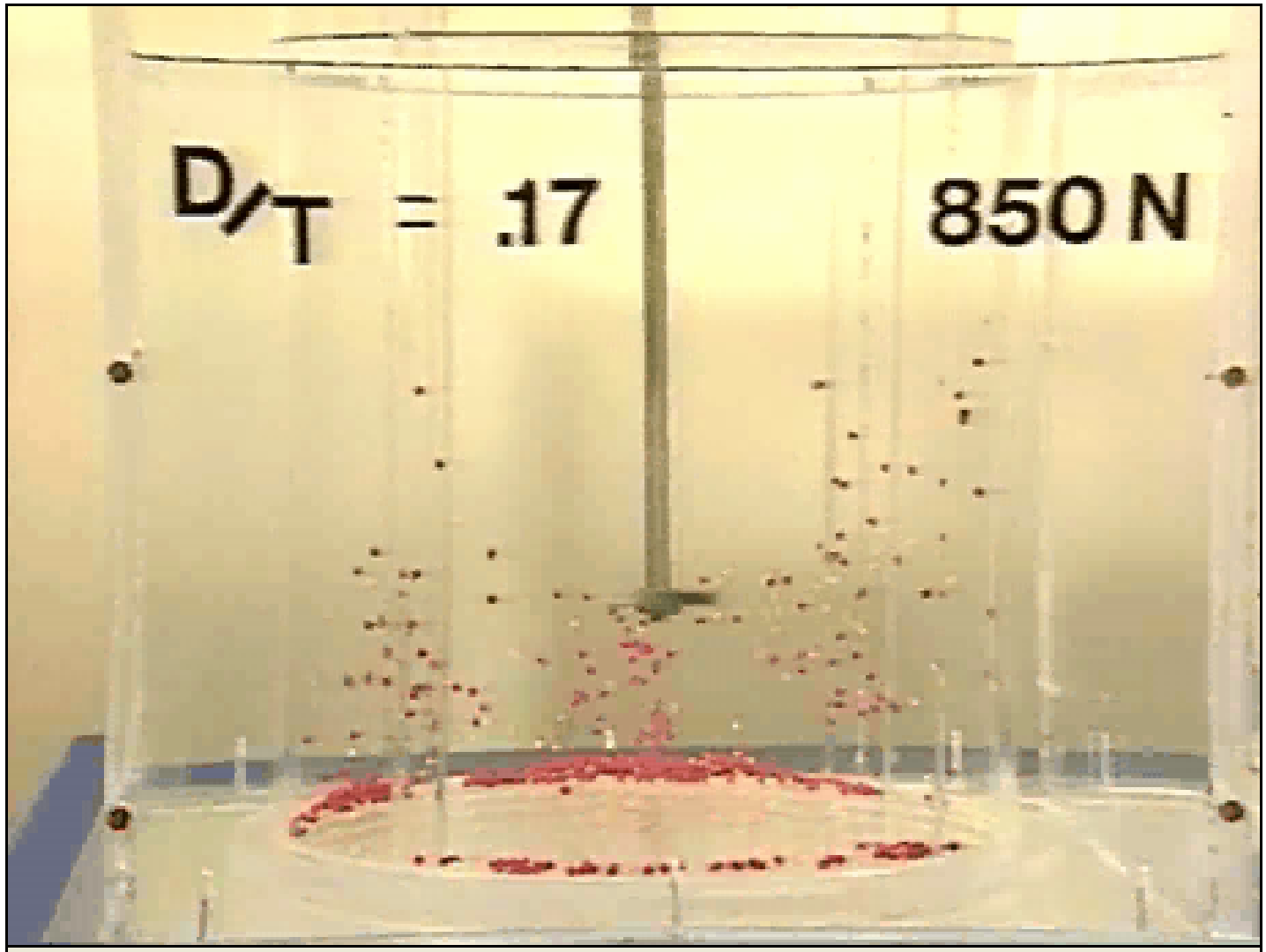


Hydrofoil Impeller – ½ Liquid Level Off-Bottom



Impeller-to-Tank Diameter Ratio

- **Small impellers require more power than larger ones**
- **Definite optimum impeller-to-tank diameter ratio – about 0.4**
- **Large impellers do not sweep the bottom**



DT17.avi

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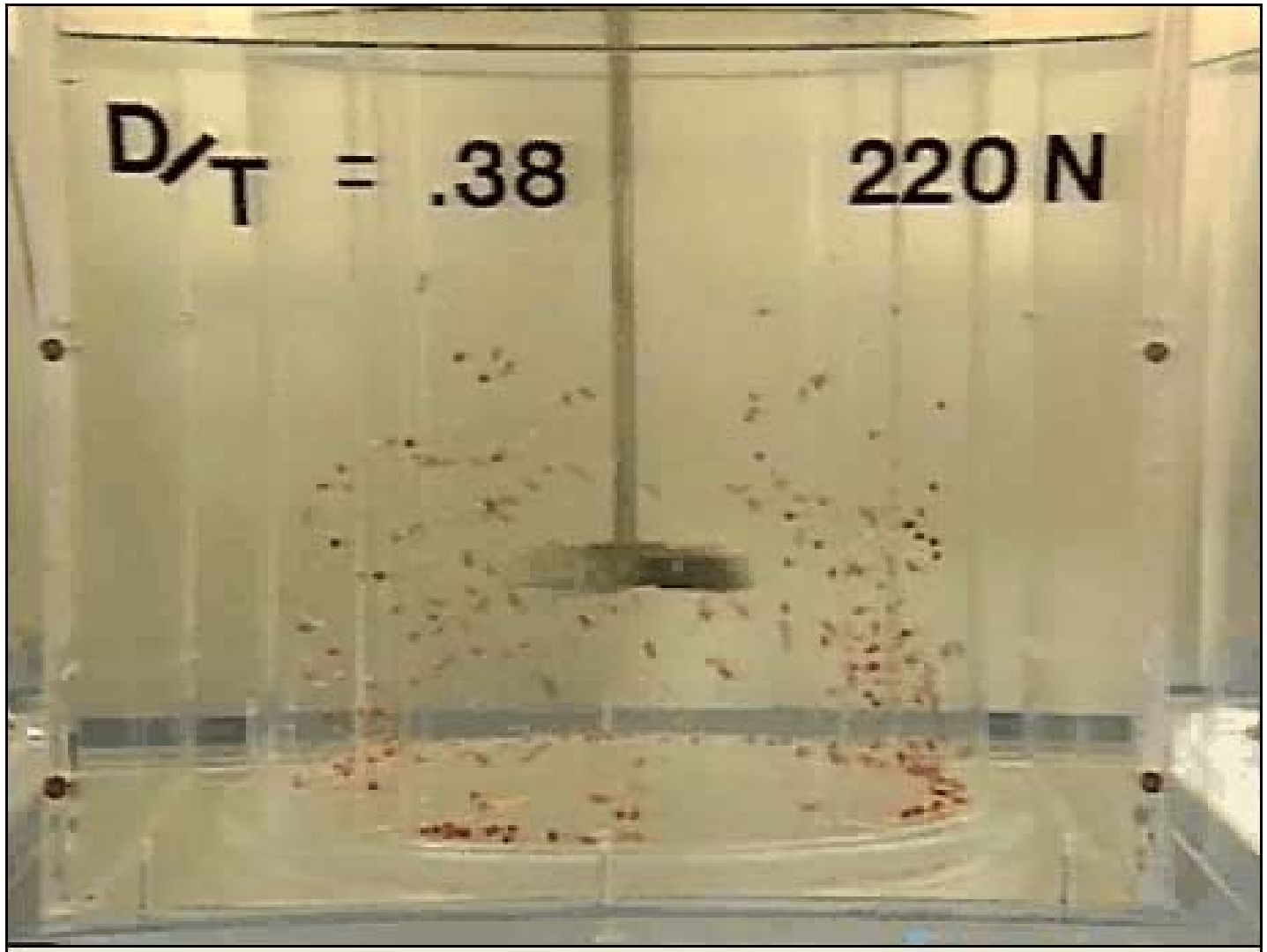

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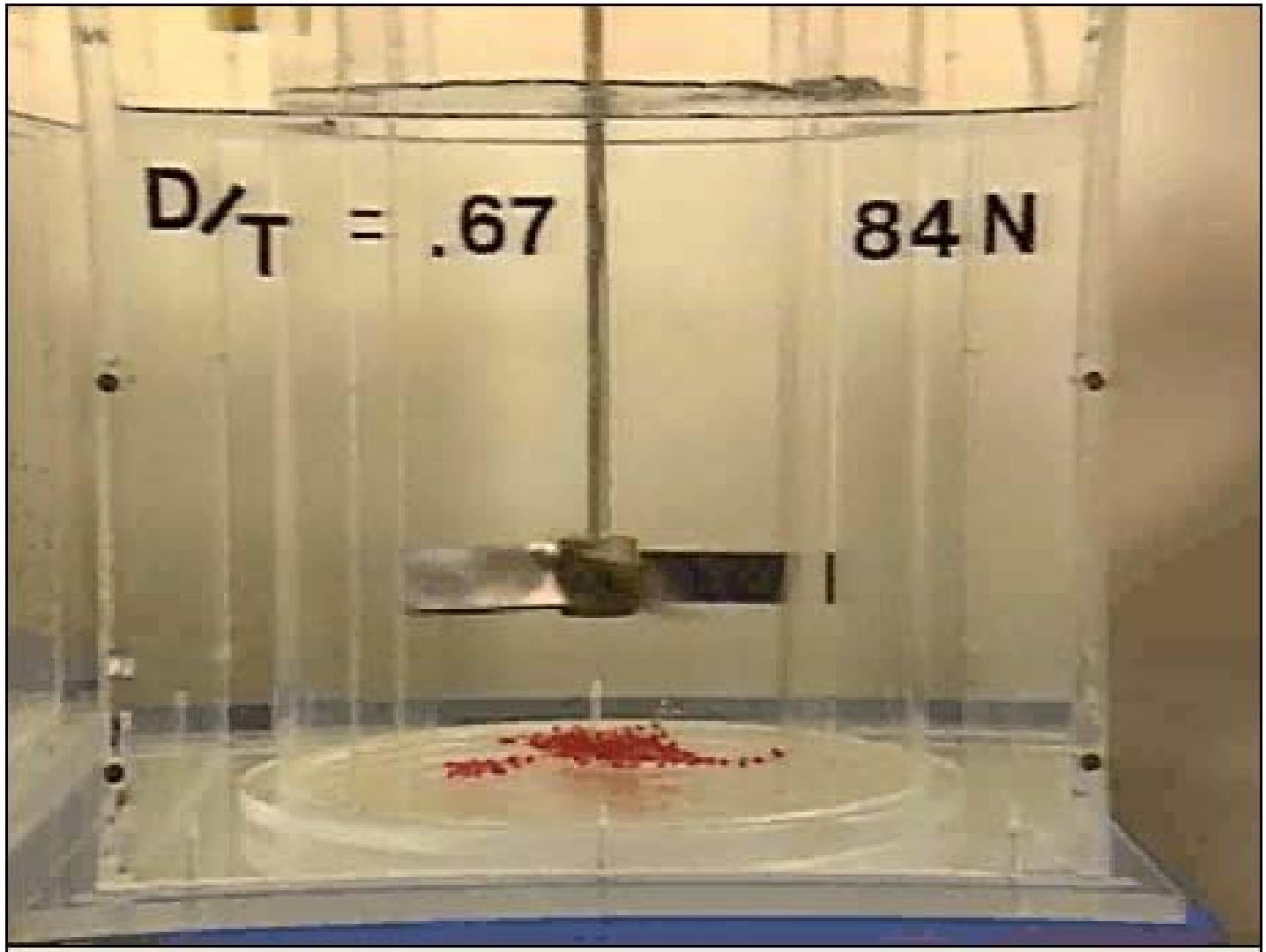

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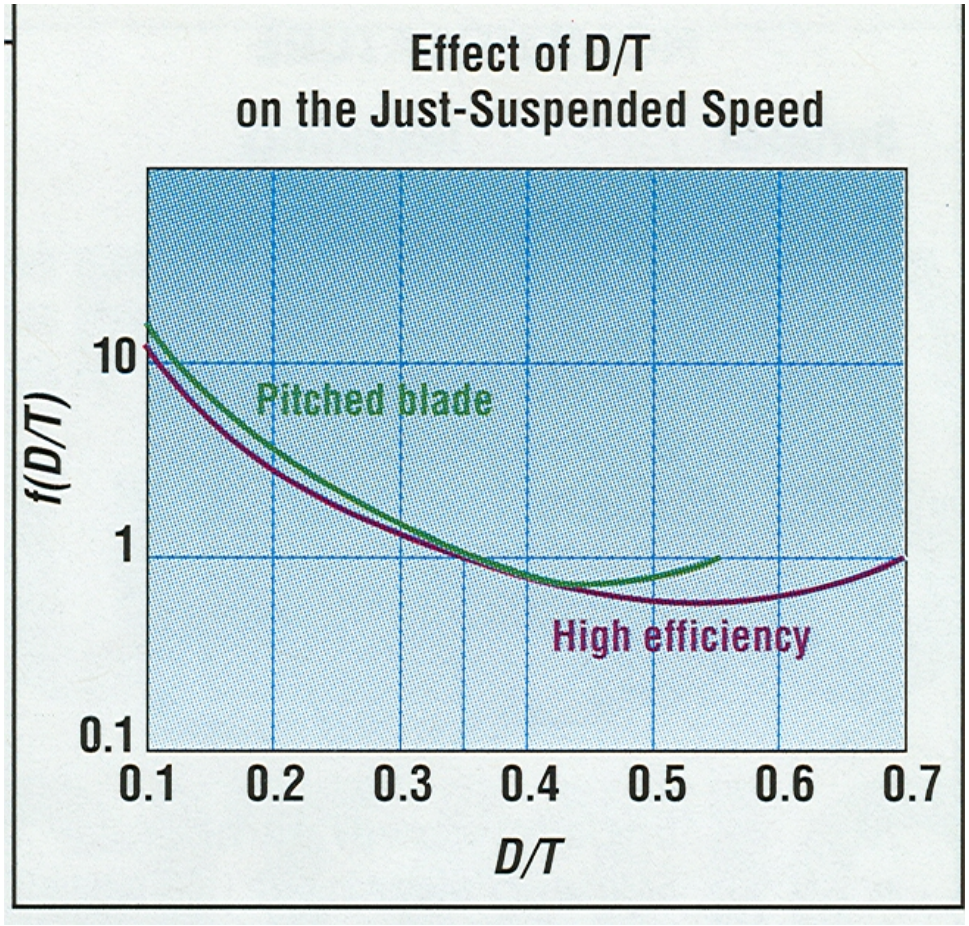
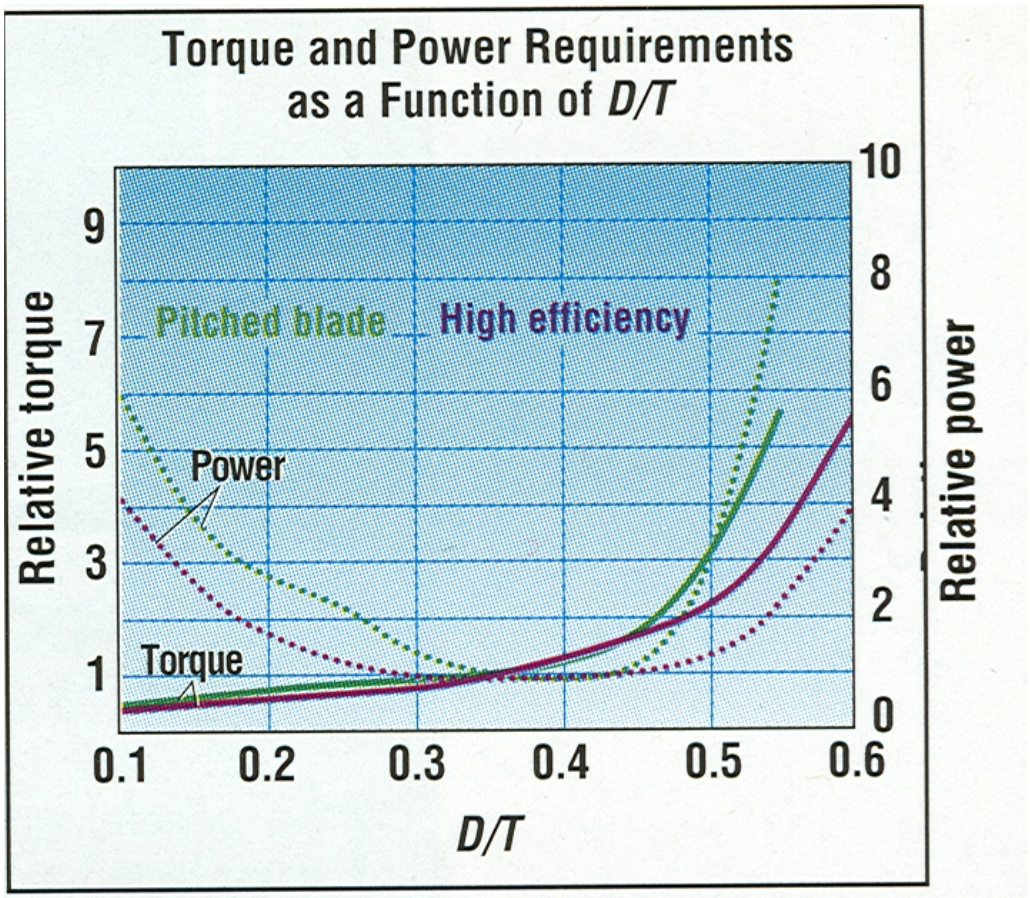
Just Suspended Speed



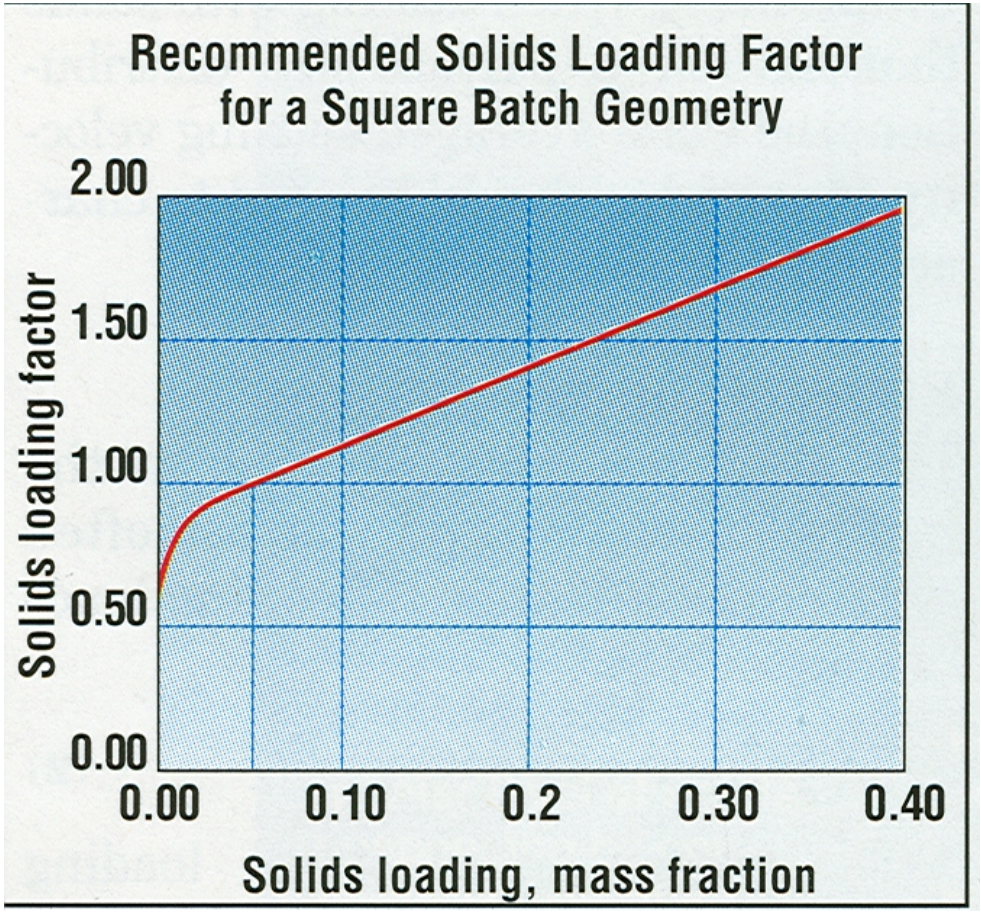
Power and Torque

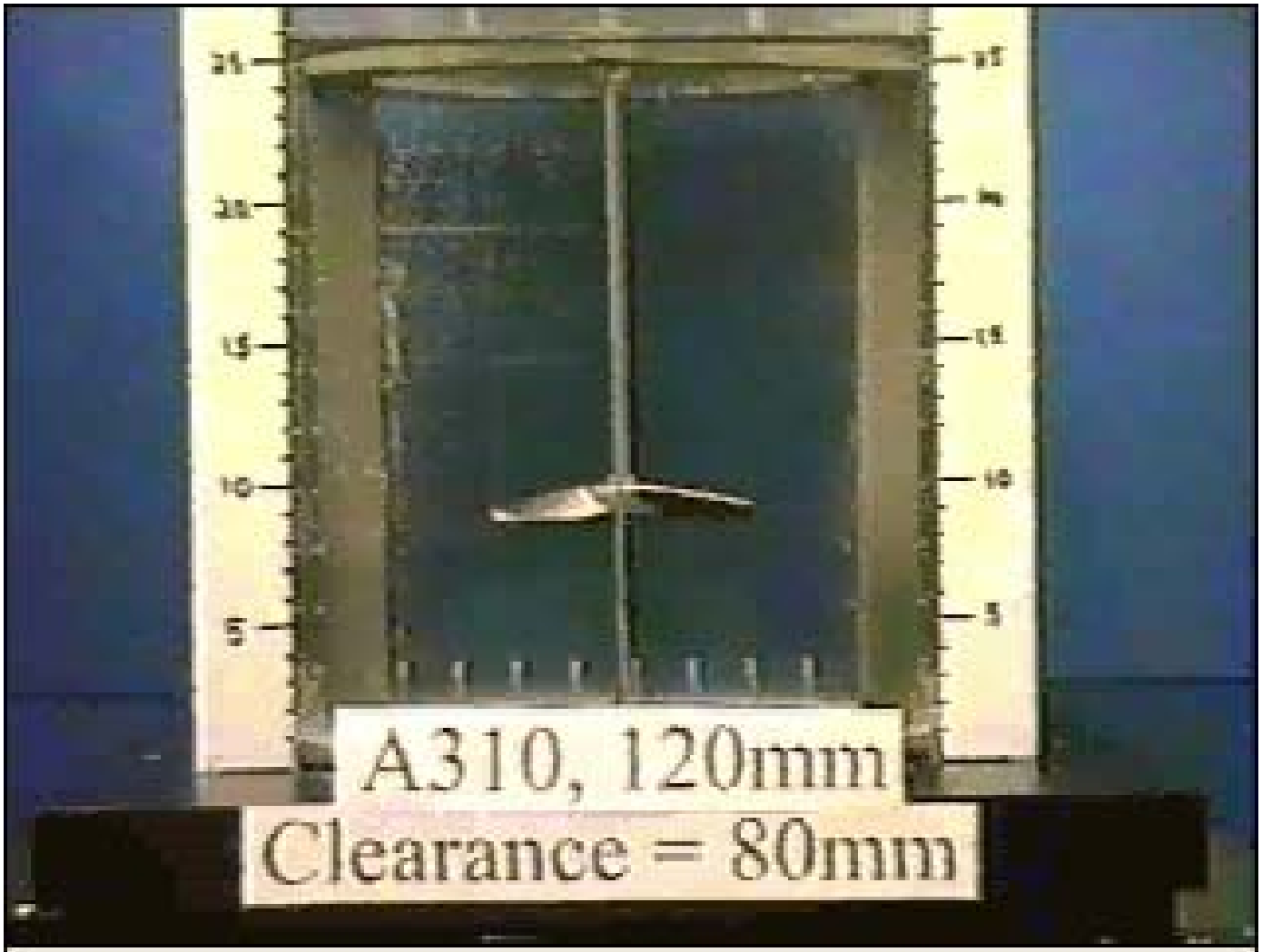


Solids Concentration

- **More solids – more difficult to suspend**
- **Increased concentration – higher speed for same suspension**

Effect of Concentration

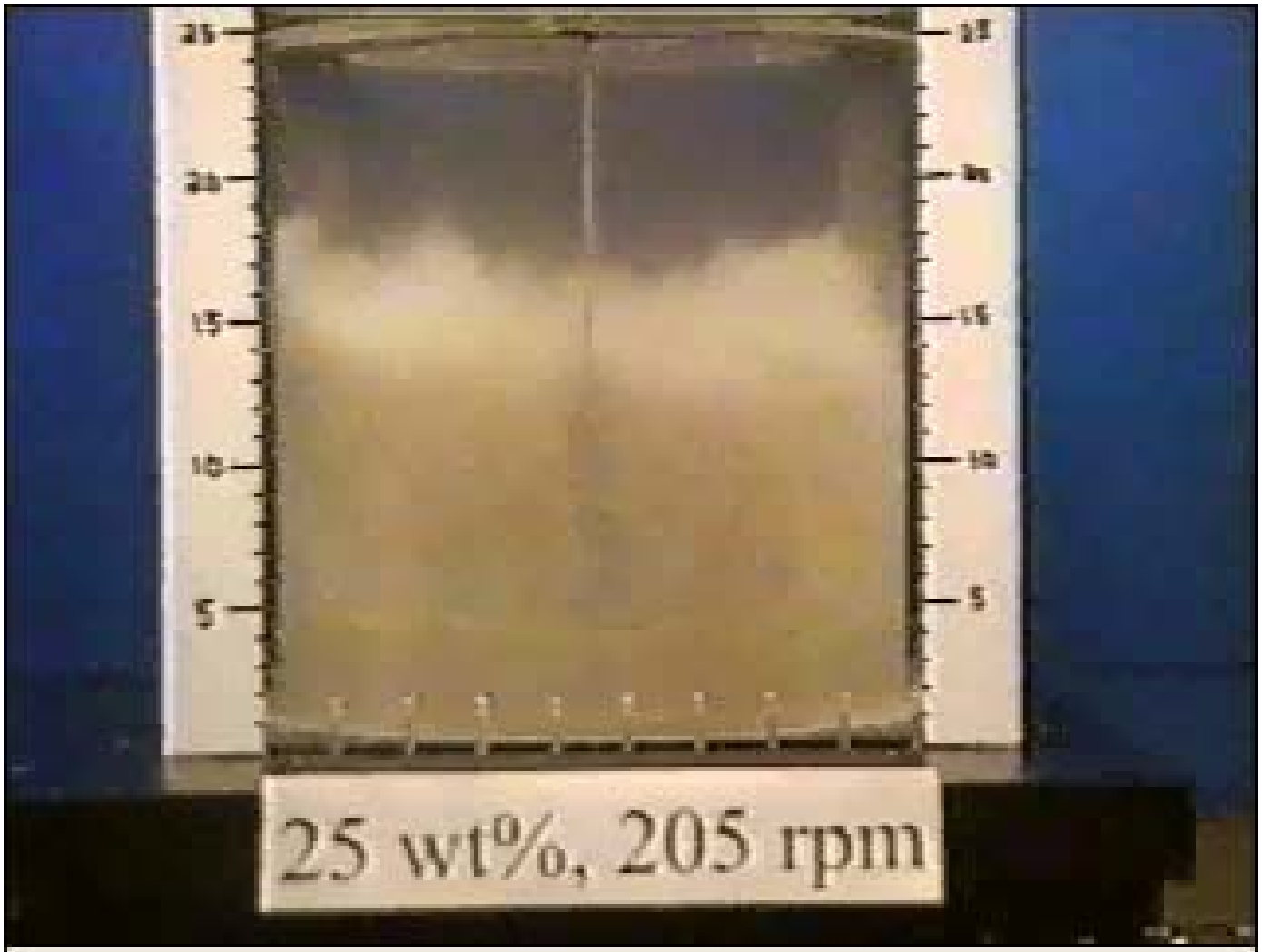




Njs.avi

Cloud Height

- Degree of uniformity
- Rapidly settling particles – uniform size distribution
- Distinctive cloud appearance
- More agitation – higher cloud height
- Suspension is never quite uniform



PBTSSN.avi

Similarity and Scale-up

- **Geometric similarity – essential**
- **Kinematic and dynamic similarity – limited benefit**
- **Scale-up by empirical relationships**

Scale-up by Geometric Similarity

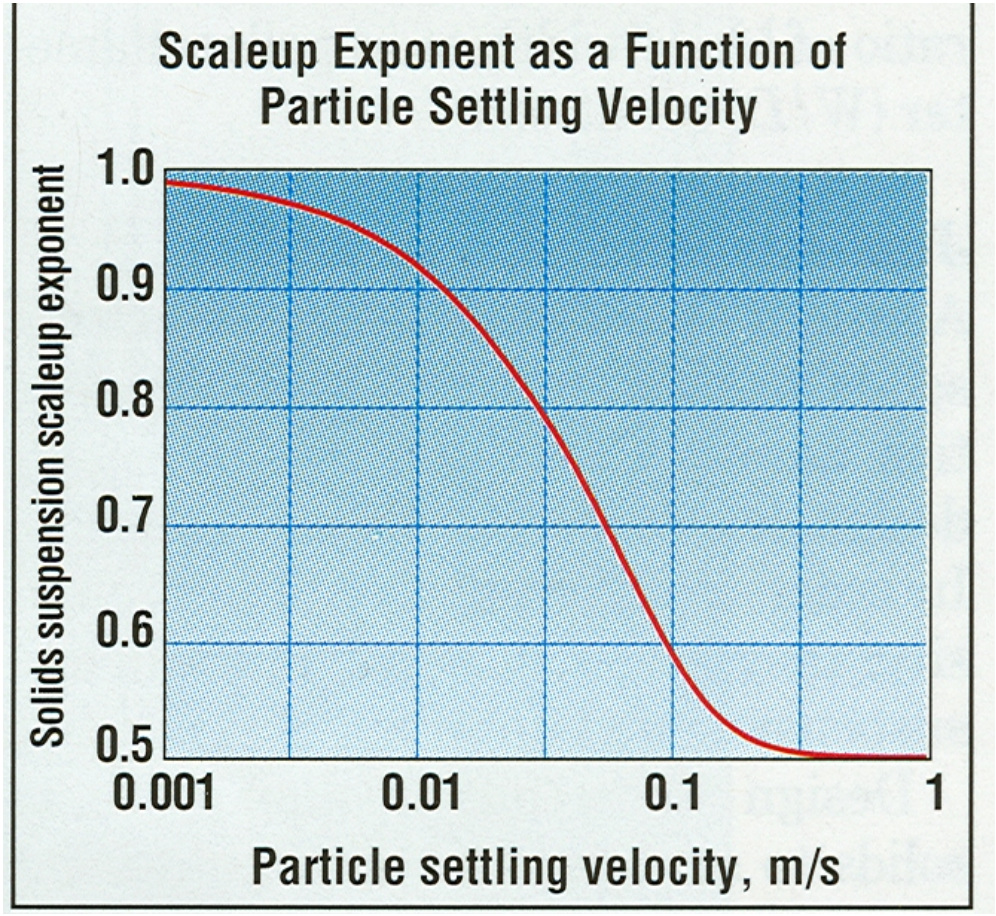
- **Speed adjustment only**
- **Large scale speed – less than small scale speed**
- **Exponent maintains one constant characteristic**

$$N_2 = N_1 \left(\frac{D_1}{D_2} \right)^n$$

Scale-up Exponent

- **Equal tip speed (fluid velocity)**
  - **n=1**
- **Equal power per volume**
  - **n=2/3**
- **Equal blend time**
  - **n=0**
- **Zwietering suspension**
  - **n=0.85**

Scale-up Solids Suspension



Scale-up

- Depends on settling velocity
  - slow settling follows flow
  - rapid settling difficult
- Scale-up may also depend on size of test
- Larger tests less conservative scale-up

Other Factors

- **Fluid viscosity**
  - **10 to 20 cp more difficult**
  - **100 cp easier – no settling**
- **Particle shape**
- **Size distribution**

Conclusions

- **Good understanding of solids suspension with mechanical mixers**
- **Understanding of steady jet mixers**
- **Little understanding of the effects of pulse mixing**
  - **cycle duration**
  - **refill period**
- **Uncertain scale-up criteria**

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