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**Pickup velocity of nanoparticles**

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Introduction

Pneumatic transport reactor for coating nanoparticles

- Titanium oxide nanopowder (P25)
- 27 m long reactor
- 4 mm int. diameter
- 5 m/s gas velocity
- Injection of platinum precursor (MeCpPtMe3)
- Collection 1 g / min product

van Ommen et al. (2015)
J. Vac. Sci. Technol. A 33, 021513

Coming 6 months: scale up to 1kg/min via

Catalysts
Q-dots for PV
Self-healing mat.
Li-ion batteries
Controlled release
Nuclear medicine

delftIMP
INTENSIFIED MATERIALS PRODUCTION
Introduction

• Critical velocities for gas-solid pneumatic conveying

  – Minimum pickup velocity ($U_{pu}$): Minimum fluid velocity necessary to start the motion of a particle initially at rest (Halow 1973)

  – Minimum saltation velocity ($U_{salt}$): Maximum fluid velocity at which the suspended particles commence to sediment (Cabrejos and Klinzing 1992)

• Why $U_{pu}$ is important
  – Start-up; re-suspension
  – Provides operational rule-of-thumb

First systematic study of pneumatic conveying of nanoparticles

Our six “standard” powders

<table>
<thead>
<tr>
<th>Commercial name (Evonik)</th>
<th>Material</th>
<th>Surf. type</th>
<th>Particle diam. (nm)</th>
<th>Particle density (kg/m³)</th>
<th>Hamaker coeff. (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerosil 130</td>
<td>SiO₂</td>
<td>Polar</td>
<td>16</td>
<td>2200</td>
<td>6.6⋅10⁻²⁰</td>
</tr>
<tr>
<td>Aerosil R972</td>
<td></td>
<td>Apolar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aeroxide Alu C</td>
<td>Al₂O₃</td>
<td>Polar</td>
<td>13</td>
<td>3600</td>
<td>1.45⋅10⁻¹⁹</td>
</tr>
<tr>
<td>Aeroxide Alu C805</td>
<td></td>
<td>Apolar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aeroxide P25</td>
<td>TiO₂</td>
<td>Polar</td>
<td>21</td>
<td>4000</td>
<td>1.54⋅10⁻¹⁹</td>
</tr>
<tr>
<td>Aeroxide T805</td>
<td></td>
<td>Apolar</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Earlier studies with these powders

**Fluidized bed:** Tahmasebpoor et al. Phys. Chem. Chem. Phys. 15(2013) 5788

**Powder flow shear tester:** Xanthakis et al., *Powder Technol.* 286 (2015) 156
Procedure to Measure $U_{pu}$

1. Fill nanoparticle sample in chamber
2. Weigh bottom part of Section B and assemble apparatus
3. Air supply 120s
4. Disassemble and weigh bottom part of section B again to note mass loss
Determining $U_{pu}$

Mass loss curve for Polar SiO$_2$

$U_{pu} = 0.459$ m/s
$U_{pu}$ Values

![Graph showing $U_{pu}$ values for different materials. The x-axis represents Silicon dioxide, Aluminum oxide, and Titanium dioxide, while the y-axis represents $U_{pu}$ in m/s. The graph distinguishes between Apolar (diamonds) and Polar (diamonds) materials.]
Apolar vs Polar

Polar nanoparticles: Hydroxyl groups on surface,
Apolar nanoparticles: Hydroxyl groups absent, replaced by organic groups during hydrophobization

Tahmasebpoor et al. (2013) Physical Chemistry Chemical Physics, 15, 5788
Three-zone model of Kalman et al. (2005)

- **Zone I**: \( Re_p^* = 5 Ar^{3/7} \) for \( Ar \geq 16.5 \)
- **Zone II**: \( Re_p^* = 16.7 \) for \( 0.45 < Ar < 16.5 \)
- **Zone III**: \( Re_p^* = 21.8 Ar^{1/3} \) for \( Ar \leq 0.45 \)

Geldart Group A

\[ Re_p^* = \frac{\rho_p d_p u_{pu}}{\mu_f \left[ 1.4 - 0.8 \exp \left( -\frac{D}{D_{ref}} \right) \right]} \]

\[ Ar = \frac{g \rho_f (\rho_p - \rho_f) d_p^3}{\mu_f^2} \]

• $U_{pu}$ an order-of-magnitude lower than predicted.
  – $Re_p^*$ order-of-magnitude smaller than Zone III prediction.
• $U_{pu}$ values agree well with extrapolated Zone I (Geldart Group B) correlation
Unsurprisingly, nanoparticles are entrained in agglomerates.
Zones in Pneumatic Conveying

Primary and complex agglomerates agree well with Zone I (Geldart Group B)
Conclusions

• Nanoparticles can be pneumatically transported!
• Polar nanoparticles have greater $U_{pu}$ than apolar nanoparticles.
• Difference between $U_{pu}$ polar and apolar species decrease in the order:
  \[ \text{SiO}_2 > \text{Al}_2\text{O}_3 > \text{TiO}_2 \]
• $U_{pu}$ of nanoparticles lower than predicted
  \( \rightarrow \) Nanoparticles are entrained as porous micron sized agglomerates.
• Behavior of nanoparticles corresponds more with pickup Zone I (Geldart Group B) than Zone III (Geldart Group C).

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