Dense Phase Pneumatic Conveying of Powders:
Design Aspects and Phenomena

A thesis submitted for the fulfilment of the requirements for the award of the degree of

Doctor of Philosophy

from

The University of Newcastle

by

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July, 2008
DECLARATION

I hereby certify that the work embodied in this thesis is the result of original research and has not been submitted for a higher degree to any other University or Institution

________________________________________

Kenneth Charles Williams
AKNOWLEDGEMENTS

There are specific individuals, departments and organisations that thanks must be given as they have been instrumental to me in either helping to nurture a seed of an idea, guiding an avenue of thought or providing much needed foundations for developing my research. Understandably, I give thanks to the following:

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### NOMENCLATURE

**Upper Case Letters**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A$</td>
<td>area</td>
<td>$[m^2]$</td>
</tr>
<tr>
<td>$A_F$</td>
<td>Mainwaring and Reed de-aeration constant [24]</td>
<td>$[Pa \cdot s \cdot m^{-1}]$</td>
</tr>
<tr>
<td>$A_i$</td>
<td>$i = 1, 2, 3$ or $4$ are constants in chapter 4</td>
<td>[-]</td>
</tr>
<tr>
<td>$A_P$</td>
<td>amplitude of the gas pulse</td>
<td>$[Pa]$</td>
</tr>
<tr>
<td>$B$</td>
<td>bend factor</td>
<td>[-]</td>
</tr>
<tr>
<td>$B_i$</td>
<td>$i = 1, 2, 3$ or $4$ are constants in chapter 4</td>
<td>[-]</td>
</tr>
<tr>
<td>$C$</td>
<td>solids friction power law constant in equation 5.3</td>
<td>[-]</td>
</tr>
<tr>
<td>$C_i$</td>
<td>$i = 1, 2, 3$ or $4$ are constants in chapter 4</td>
<td>[-]</td>
</tr>
<tr>
<td>$D$</td>
<td>diameter (pipe)</td>
<td>$[m]$</td>
</tr>
<tr>
<td>$DL$</td>
<td>abbreviation for Dilute phase only flow</td>
<td>[-]</td>
</tr>
<tr>
<td>$FD$</td>
<td>abbreviation for fluidised dense phase flow</td>
<td>[-]</td>
</tr>
<tr>
<td>$F_{Fr}$</td>
<td>Molerus defined adhesion factor [28]</td>
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</tr>
<tr>
<td>$Fr$</td>
<td>Froude number</td>
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<td>Sanchez de-aeration based parameter [45]</td>
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<td>Hausner ratio</td>
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<td>Dixon’s single plug constant in Equation 2.12 [8]</td>
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<td>$K_v$</td>
<td>Jones vibrated de-aeration factor [18]</td>
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<td>$N_B$</td>
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<td>$N_C$</td>
<td>Chambers air-particle parameter [6]</td>
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<td>$P$</td>
<td>pressure</td>
<td>$[Pa]$</td>
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<td>Description</td>
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<td>------</td>
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<tr>
<td>PL</td>
<td>abbreviation for plug flow</td>
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<tr>
<td>P*</td>
<td>Sanchez permeability based parameter [45]</td>
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<tr>
<td>Q</td>
<td>volumetric flow rate</td>
<td>[m³ s⁻¹]</td>
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<tr>
<td>S</td>
<td>displacement (Chapter 6)</td>
<td>[m]</td>
</tr>
<tr>
<td>Ti</td>
<td>pressure transducer number, i=1, 2, 3,….</td>
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</tr>
<tr>
<td>Tp</td>
<td>time period of the pressure pulse</td>
<td>[s]</td>
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<tr>
<td>X</td>
<td>conversion factor in Equation 2.17</td>
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<tr>
<td>Y</td>
<td>constant in Equation 2.18</td>
<td>[Pa m kg⁻¹ s⁻¹]</td>
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### Lower Case Letters

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<thead>
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<th>Unit</th>
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<td>[-]</td>
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<tr>
<td>c</td>
<td>exponent in equation 2.18</td>
<td>[-]</td>
</tr>
<tr>
<td>d</td>
<td>diameter (particle)</td>
<td>[m]</td>
</tr>
<tr>
<td>g</td>
<td>acceleration due to gravity</td>
<td>[m s⁻²]</td>
</tr>
<tr>
<td>k</td>
<td>parameter in Equation 2.6</td>
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<tr>
<td>k₁</td>
<td>defined Equation 2.11</td>
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<tr>
<td>m</td>
<td>mass flow rate</td>
<td>[kg s⁻¹]</td>
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<tr>
<td>m*</td>
<td>solids loading ratio</td>
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<tr>
<td>r</td>
<td>radius</td>
<td>[m]</td>
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<tr>
<td>t</td>
<td>time</td>
<td>[s]</td>
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<tr>
<td>tₖ</td>
<td>calculated de-aeration time</td>
<td>[s]</td>
</tr>
<tr>
<td>tᵥₐ</td>
<td>Chambers de-aeration rate [6]</td>
<td>[s]</td>
</tr>
<tr>
<td>v</td>
<td>velocity</td>
<td>[m s⁻¹]</td>
</tr>
<tr>
<td>w</td>
<td>parameter defined in Equation 2.6</td>
<td>[-]</td>
</tr>
</tbody>
</table>
w_i parameter defined in Equation 2.11 [-]
x_i i = 1, 2, 3, 4, correlation constants in Equation 5.5 [-]
z pressure drop per displacement (Chapter 6) [Pa/m]

**Greek Letters**

δ effective angle of internal friction [°]
ε voidage [-]
λ friction factor [-]
Ω Fargette air-particle parameter [11] [-]
ρ density [kg m⁻³]
ϕ friction angle [°]
ψ permeability factor [m³ s kg⁻¹]
μ viscosity [kg m s⁻¹]

**Subscripts**

a air
b bulk
bl bulk, loose poured
f fluid or friction
g gas
i integer
j integer
mb minimum bubbling
mf minimum fluidisation
mod modification or change to a parameter
o origin or reference condition
NOTE: Some symbols displayed above are the same symbols used in the cited article by the relevant authors. Using the same symbols avoided confusion when discussing similar parameters derived by different researchers.