A Revised Multi-Dimensional Particle Bed Model for Fluidised Beds

Luca Mazzei[1], Paola Lettieri[1], Tim Elson[1], Derek Colman[2]

[1] Department of Chemical Engineering, University College London, UK

[2] BP Chemical Ltd., Sunbury on Thames, UK

Contents

“Revised Particle Bed Model”

Equations of Change

An Eulerian-Eulerian modelling approach based on the Foscolo & Gibilaro Particle Bed Model (1987).

Mass conservation – Fluid phase

$$\frac{\partial}{\partial t}\left(\varepsilon \cdot \rho_f\right) + \vec{\nabla} \bullet \left(\varepsilon \cdot \rho_f \cdot \vec{U}_f\right) = 0$$

Mass conservation – Solid phase

$$\frac{\partial}{\partial t}\left(\alpha \cdot \rho_p\right) + \vec{\nabla} \bullet \left(\alpha \cdot \rho_p \cdot \vec{U}_p\right) = 0$$

Equations of Change

Linear momentum conservation – Fluid phase

$$\frac{\partial}{\partial t}\left(\varepsilon \cdot \rho_f \cdot \vec{U}_f\right) + \vec{\nabla} \bullet \left[\varepsilon \cdot \rho_f \cdot \left(\vec{U}_f \otimes \vec{U}_f\right)\right] =$$

$$= +\vec{\nabla} \bullet \underline{\underline{\tau}}_f - \vec{\nabla} P + \varepsilon \cdot \rho_f \cdot \vec{g} - \left(\vec{F}_{S,V} + \vec{F}_{K,V} + \vec{F}_{E,V}\right)$$

Linear momentum conservation – Solid phase

$$\frac{\partial}{\partial t}\left(\alpha \cdot \rho_p \cdot \vec{U}_p\right) + \vec{\nabla} \bullet \left[\alpha \cdot \rho_p \cdot \left(\vec{U}_p \otimes \vec{U}_p\right)\right] =$$

$$= +\alpha \cdot \rho_p \cdot \vec{g} + \left(\vec{F}_{S,V} + \vec{F}_{K,V} + \vec{F}_{E,V}\right)$$

Closure Relationships
Buoyancy

- Original PBM: buoyancy proportional to the pressure gradient present in the bed.

$$\vec{F}_{S,V} = -(1-\varepsilon)\cdot\vec{\nabla}P$$

- Revised PBM: buoyancy equal to the weight of the fluidizing fluid displaced by the solid particles.

$$\vec{F}_{S,V} = -(1-\varepsilon)\cdot\rho_f\cdot\vec{g}$$

Closure Relationships
Drag Force

- The relevant constitutive equation has been modified introducing a revised "corrective" function which accounts for the presence of the dispersed solid phase.

- Drag Force: $\vec{F}_{K,V} = +\beta \cdot \left(\vec{U}_f - \vec{U}_p \right)$

- Original PBM: $\beta = +\frac{3}{4} \cdot C_D\left(\mathrm{Re}\right) \cdot \frac{\left| \vec{U}_f - \vec{U}_p \right| \cdot \rho_f \cdot \left(1 - \varepsilon\right)}{D_p} \cdot \varepsilon^{-1.8}$

- Revised PBM: $\beta = +\frac{3}{4} \cdot C_D\left(\mathrm{Re}\right) \cdot \frac{\left| \vec{U}_f - \vec{U}_p \right| \cdot \rho_f \cdot \left(1 - \varepsilon\right)}{D_p} \cdot \varepsilon^{-\phi(\varepsilon, \mathrm{Re})}$

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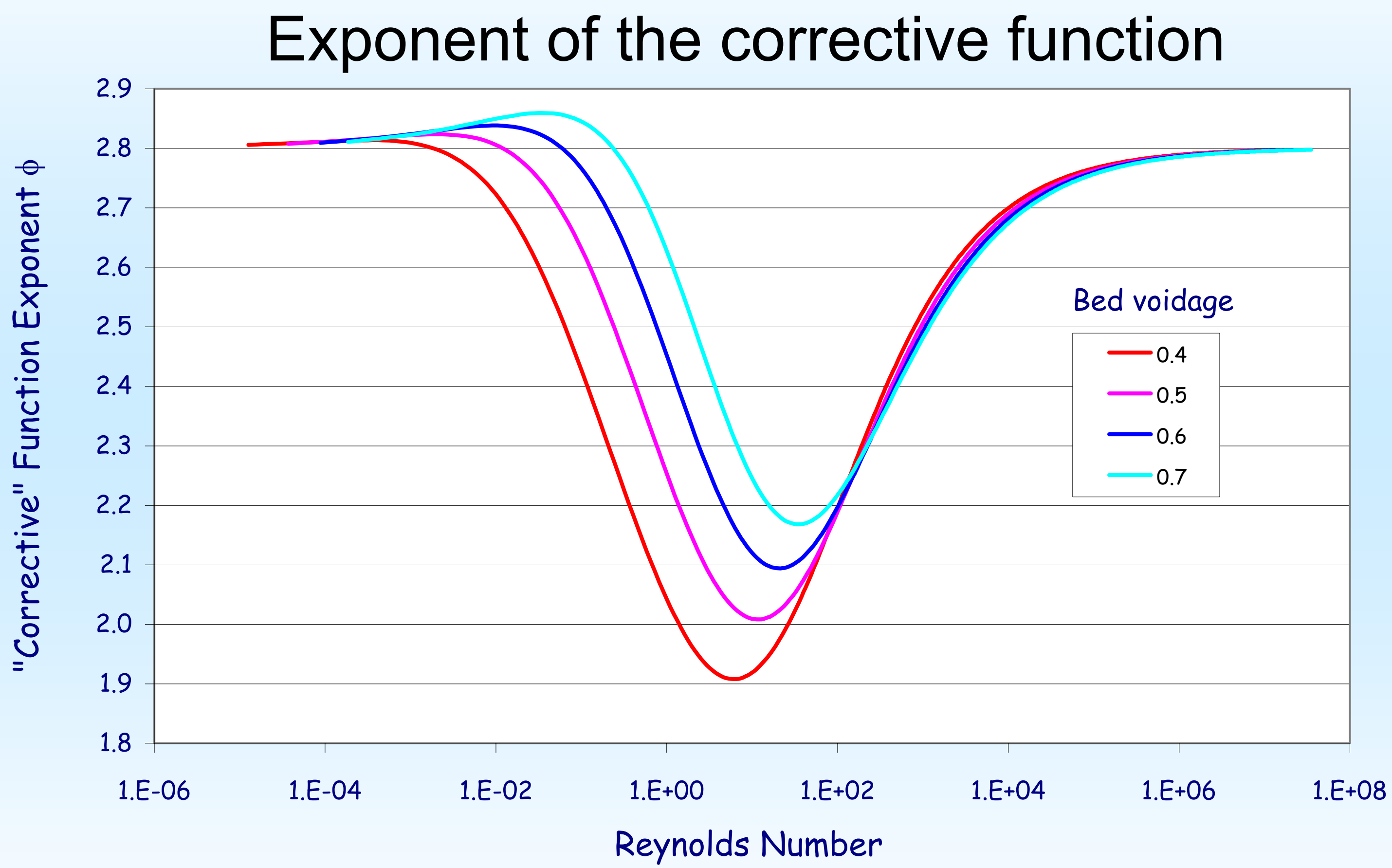
Closure Relationships
Drag Force



Closure Relationships
Elastic Force

- The relevant constitutive equation has been derived without using any equilibrium-based relations. The force is no longer constant in direction and parallel to the gravitational field, but is proportional to the drag force.

- Original PBM: $$\vec{F}_{E,V} = +E \cdot \frac{\partial \varepsilon}{\partial z} \cdot \hat{k} \quad ; \quad \hat{k} = +\frac{1}{g} \cdot \vec{g}$$

- Revised PBM: $$\vec{F}_{E,V} = +E \cdot \left(\vec{\nabla} \varepsilon \bullet \hat{n}_{K,V} \right) \cdot \hat{n}_{K,V}$$

$$\hat{n}_{K,V} = +\frac{1}{\left\| \vec{F}_{K,V} \right\|} \cdot \vec{F}_{K,V}$$

Closure Relationships
Elastic Modulus

- Original PBM: $E = +3.2 \cdot D_p \cdot (1-\varepsilon) \cdot (\rho_p - \rho_f) \cdot g$

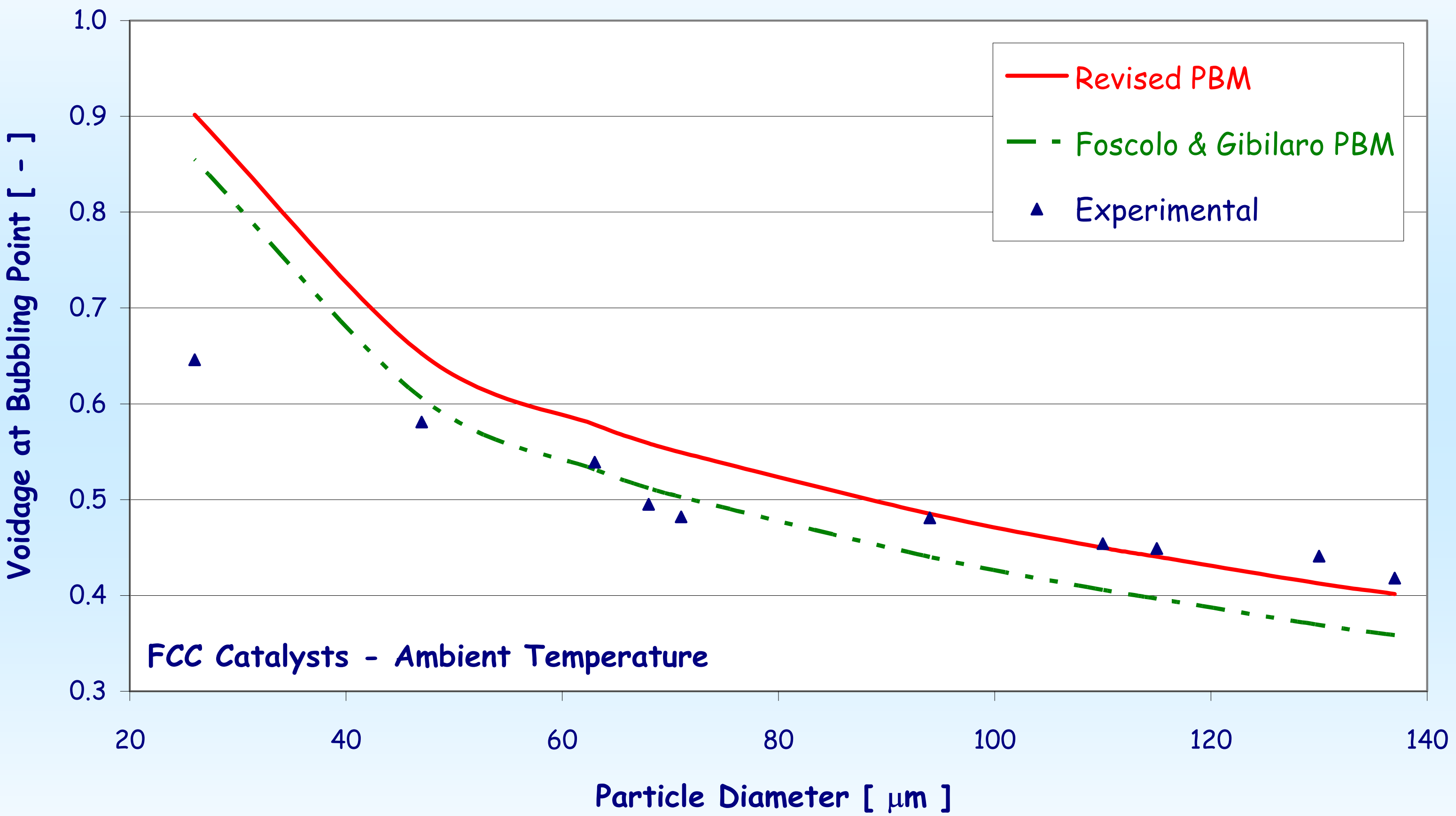
- Revised PBM: $E = -\frac{2}{3} \cdot D_p \cdot \Omega(\varepsilon, \mathrm{Re}) \cdot \| \vec{F}_{K,V} \|$

Stability Analysis

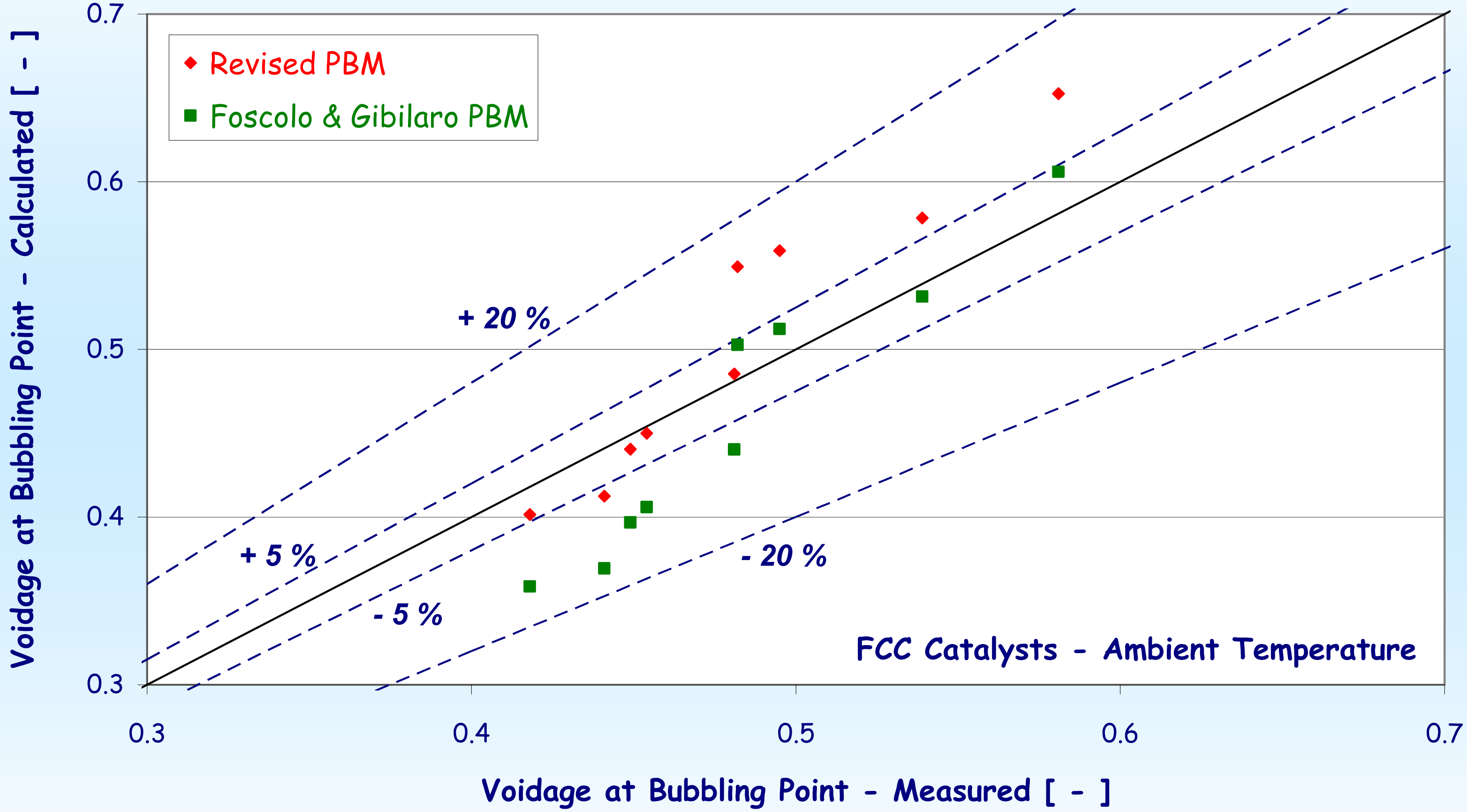
- A stability analysis has been performed to predict the minimum bubbling voidage for homogeneous fluidized beds.

- The theoretical results have been compared to experimental data obtained at different operating temperatures.

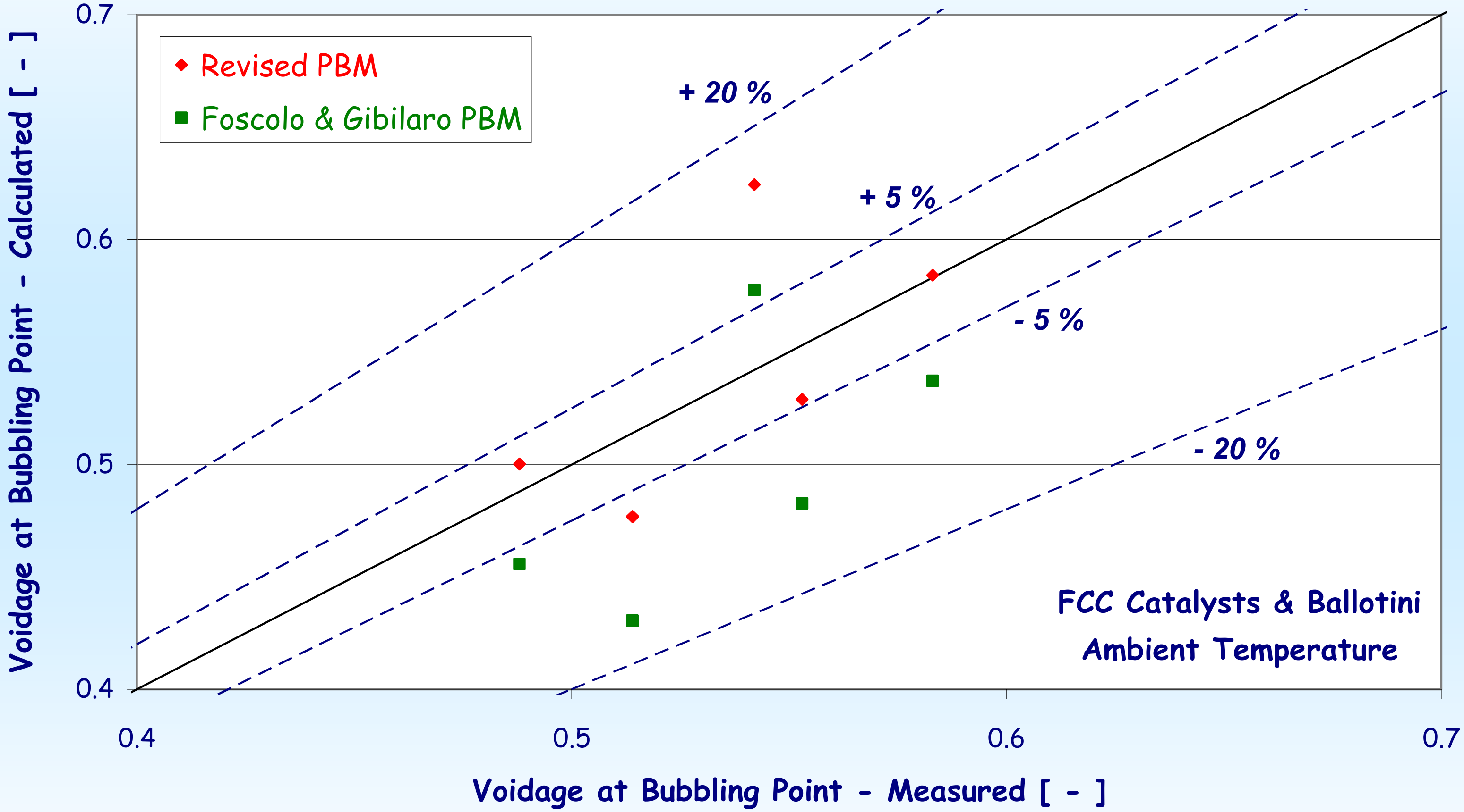
Stability Analysis



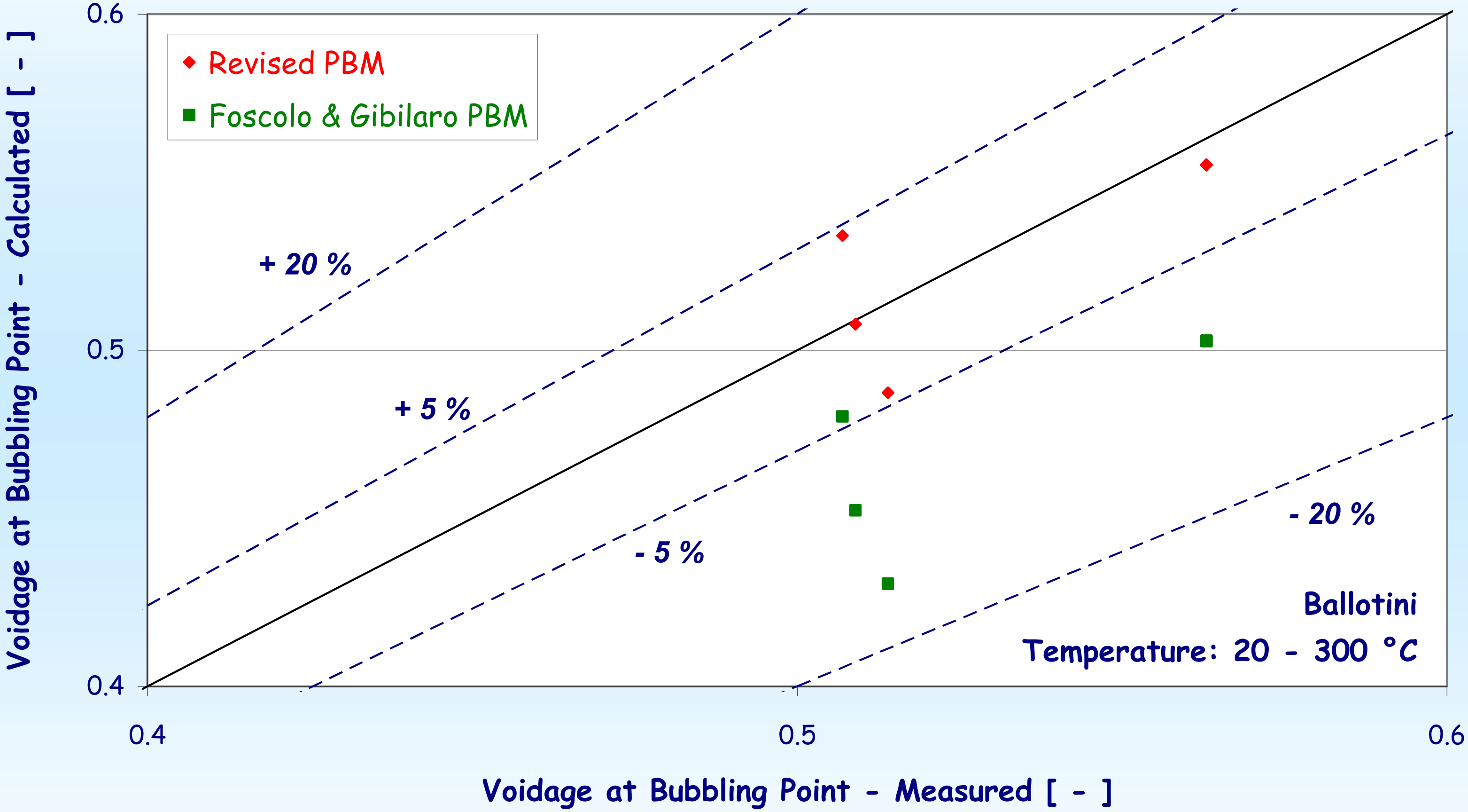
Stability Analysis



Stability Analysis



Stability Analysis



CFD modelling of a bubbling fluidized bed

based on the

“Revised Particle Bed Model”

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Fluidization Dynamics

- The fluidization dynamics of a Geldart Group B powder has been simulated using the revised Particle Bed Model.

- Ballotini : $D_p = 350\ \mu m$ - $\rho_p = 2500\ kg/m^3$

- Air : $U_o = 0.25\ m/s$

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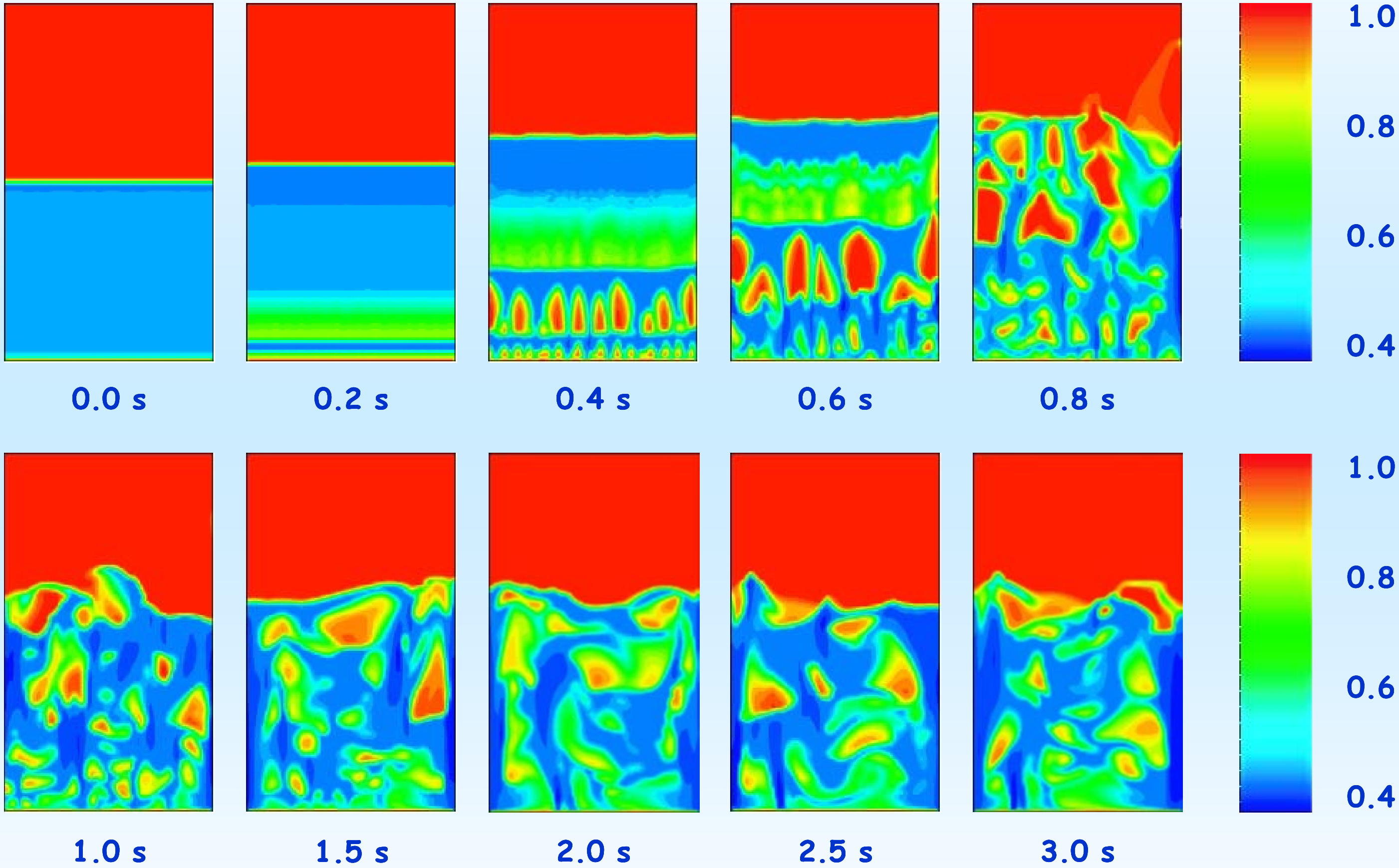
Voidage Profiles



On-going Work

- Model validation by means of experiments.
- Investigation of the dynamics of different fluidizing regimes.
- Development of solid-viscosity models for turbulent fluidization.