Experimental investigation of a Rotating Fluidized Bed in a Static Geometry

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http://www.lct.ugent.be
• Introduction

• Concept of Rotating Fluidized Bed in a Static Geometry (RFB-SG)

• Experimental set-up and its operation

• Results and discussion
  - Overall pressure drop
  - Maximum solid particles capacity
  - Solid particles velocity
  - Void fraction

• Conclusions
Advantages of centrifugal fluidization in gas-solid operations
- Higher slip velocity, therefore, *high heat and mass transfer* at the particle scale
- *Uniform temperature* distribution at the reactor scale
- Ability to work at *high feed flow rates*

General applications of centrifugal reactors
- For short gas-solid contact time operations
- Drying, polymerization, fluidization of nano-particles, agglomeration, gas-solid separation, dust emission control
- A flexible cold-flow experimental set-up design
- Variation in:
  Feed inlet opening thickness \((I_O)\)
  Number of feed inlets \((n)\)
  Reactor diameter \((D_R)\)
  Exhaust diameter \((D_E)\)
  Mode of operation – Pressure or Suction
  Axis of rotation – Horizontal or Vertical
- Variation in:
  - Gas flow rate
  - Solids feed rate
  - Solids content
  - Solid particles size
  - Solid particles density

- Goal is to obtain a stable axisymmetric rotating bed of solid particles
Typical operation & conditions

<table>
<thead>
<tr>
<th>Independent geometrical variables</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor diameter</td>
<td>0.54 m</td>
</tr>
<tr>
<td>Feed inlet opening thickness</td>
<td>0.002 m</td>
</tr>
<tr>
<td>Number of inlets</td>
<td>36 (-)</td>
</tr>
<tr>
<td>Mode of operation</td>
<td>Pressure</td>
</tr>
<tr>
<td>Axis of rotation</td>
<td>Horizontal</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Independent operating variables</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air flow rate</td>
<td>0.4 kg/s to 1.2 kg/s</td>
</tr>
<tr>
<td>Solid particles size</td>
<td>0.9 mm to 3 mm</td>
</tr>
<tr>
<td>Solid particles density</td>
<td>950 kg/m³</td>
</tr>
<tr>
<td>Solids content</td>
<td>0.5 kg to 6 kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Measurement technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure drop</td>
<td>Pressure probe and sensors</td>
</tr>
<tr>
<td>Solid content</td>
<td>Real time weighing balance</td>
</tr>
<tr>
<td>Solid particles bed height</td>
<td>High speed camera</td>
</tr>
<tr>
<td>Solid particle velocity</td>
<td>High speed camera</td>
</tr>
</tbody>
</table>
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• **Results and discussion**
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  - Void fraction

• Conclusions
Total pressure drop behavior

- Contributions in the total pressure drop

$$\Delta P_{\text{total}} = \Delta P_{\text{packed bed (radial)}} + \Delta P_{\text{tangential}} + \Delta P_{\text{inlet slots}} + \Delta P_{\text{Free-board}}$$

Theoretical calculation (Ergun equation)

Experimentally measured

- Ergun equation for packed bed pressure drop (Radial pressure drop)

$$\Delta P_{\text{packed bed}} = \phi_1 U_0 r_0 \ln\left(\frac{r_0}{r_i}\right) + \phi_2 U_0^2 r_0^2 \left(\frac{1}{r_i} - \frac{1}{r_0}\right)$$

where,

$$\phi_1 = \frac{1650(1-\varepsilon)\mu}{d_p^2}, \quad \phi_2 = \frac{24.5(1-\varepsilon)\rho_g}{d_p}, \quad U_0 = \frac{G}{\pi D_R L_R}$$

Notations:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_p$</td>
<td>Mean particle diameter (m)</td>
</tr>
<tr>
<td>$D_R$</td>
<td>Diameter of the reactor (m)</td>
</tr>
<tr>
<td>$L_R$</td>
<td>Axial length of the reactor (m)</td>
</tr>
<tr>
<td>$G$</td>
<td>Volumetric gas flow rate (m$^3$/s)</td>
</tr>
<tr>
<td>$r_0$</td>
<td>Outer radius of packed bed (m)</td>
</tr>
<tr>
<td>$r_i$</td>
<td>Inner radius of packed bed (m)</td>
</tr>
<tr>
<td>$U_0$</td>
<td>Superficial gas velocity (m/s)</td>
</tr>
<tr>
<td>$\Delta P$</td>
<td>Pressure drop (Pa)</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>Void fraction (-)</td>
</tr>
<tr>
<td>$\rho_g$</td>
<td>Density of gas (kg/m$^3$)</td>
</tr>
<tr>
<td>$\mu$</td>
<td>Gas viscosity (kg/ms)</td>
</tr>
</tbody>
</table>
Overall pressure drop behavior

- Pressure drop behavior is the *signature* of the flow in the reactor
- As the solids content increases, overall *bed height increases*, leading to an increased pressure drop
Overall pressure drop behavior

Total pressure drop v/s superficial gas velocity at various solids content for solid particles with size: 1.6 mm

- Similar behavior of pressure increase observed for different particle size
Overall pressure drop behavior

Total pressure drop v/s superficial gas velocity at various solid particles size, and constant solids content of 3kg

- Decrease in solid particle size, increases the specific surface area, this is leads to increase in radial drag forces, resulting into higher pressure drop across the solid particles bed
- Maximum solids content gives an idea about average solids residence time (for drying operations), and space velocity (WHSV)
- Increasing gas flow rate *increases* the maximum solids capacity of the reactor
- This is one of the *distinct feature* of RFB-SG compared to gravitational fluidized bed reactors
At maximum solids content, centrifugal force is balanced by the gravity, resulting into *entrainment* of solid particles from the topmost position of the reactor exhaust.

- Increasing gas flow rate, increases the centrifugal force, leading to increase in solids capacity until *equilibrium* with gravity is reached.

- At lower particle size (~ 0.9 mm), *radial drag force* is dominant, resulting into early entrainment of solids from lateral positions of the reactor.
Solid particles velocity measurement

• Solids particle tracking by means of high-speed camera

• Measurement of solids velocity at several independent variables

• Image capturing at 3000 to 30000 frames per second

• Tracked particles further processed in x-y coordinate domain (only 2D measurements)
- Decrease in particle size, results into increase in the solid particles velocity

- Increase in radial drag due to decrease in particle size is compensated by higher centrifugal force, and hence higher solid particles velocity
- Under investigated operating range, *negligible* change in void fraction is observed with varying gas flow rate.

- This may be due to the constant *ratio* of centrifugal force to radial drag force, at given radial position, with varying gas flow rate.
Conclusions

- A *flexible* experimental set-up was designed and built for the experimental investigation of the RFB-SG at *wide range* of operating conditions

- A *stable* solid particles bed was achieved under investigated operating range

- For given solid particles, total pressure drop increases with increasing *solids content*

- For given solids content, total pressure drop increases with decreasing *particle size*

- *Maximum solids capacity* increases with increasing gas flow rate for given solid particles

- *Solids velocity* shows linear dependence on gas flow rate

- Solids *volume fraction* remains almost constant for given solids content, with varying gas flow rate