A Novel Fast Gas-Solid Separator for Pyrolysis Reactors

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- Introduction
- Novel Separator Design
- Experimental Setup
- Experimental Results
- Conclusions
Motivation for Current Study

- New downer reactor design for biomass pyrolysis at ICFAR

- Gas-solid separator in downer must achieve:
  - **Near plug flow** in gas phase
  - **Short contact time** (< 0.1 s)
  - **High efficiency** removal of hot particles from gaseous products
  - **High efficiency** removal of gaseous products from hot particles
  - **Low pressure drop** across separator

- Previous and existing designs are insufficient for pyrolysis
Previous Fast Gas-Solid Separators

Inertial U-Turn Separator¹:
✓ Fast separation time (< 20 ms)
✗ Poor solids collection efficiency (93%)

Uniflow Cyclone²:
✓ Excellent solids collection efficiency (> 99.9%)
✗ Significant gas backmixing
Two Configurations:

1. Swirl Vanes
2. Cone Deflector
Cone Separator Geometry

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_C$</td>
<td>64 mm</td>
</tr>
<tr>
<td>$D_{go}$</td>
<td>9.5 mm</td>
</tr>
<tr>
<td>$a$</td>
<td>6.4 mm</td>
</tr>
<tr>
<td>Separation Length $L_s$</td>
<td>6.4 – 127 mm</td>
</tr>
<tr>
<td>Included Cone Angle $\alpha$</td>
<td>60°; 90°; 120°</td>
</tr>
</tbody>
</table>
Swirl Vane Separator Geometry

- Dimension $D_C$: 64 mm
- Dimension $D_{go}$: 9.5 mm
- Separation Length $L_S$: 6.4 – 127 mm
- Vane Angle $\beta$: $30^\circ; 45^\circ; 60^\circ; 75^\circ$
Experimental Setup

**Apparatus**

- **Gas:**
  - Air (room condition)
  - Inlet velocity: 1.0 – 13 m/s

- **Solid particle media:**
  - Silica sand
    - \( d_{p_{sm}} = 200 \, \mu m \)
  - Glass beads
    - \( d_{p_{sm}} = 63 \, \mu m \)

**Test Conditions**

[Diagram of the experimental setup with labels for Solids Hopper, Gas Inlet, “Downer” Pipe, Separator, Blower, Orifice Meter, Manometer, Solids Collection Tank, Bag Filter, and Delta P.]
Effect of Separation Length (Silica Sand)

- Solids Collection Efficiency [%]
  - 99.90
  - 99.95
  - 100.00

- Gas Inlet Velocity = 4.4 m/s
- Gas Inlet Velocity = 8.7 m/s

- Silica Sand 45° Swirl Vanes

Graph indicating the relationship between normalized separation length and solids collection efficiency, showing two lines for different gas inlet velocities.
Experimental Results

Effect of Separation Length (Glass Beads)

Solids Collection Efficiency [%]

Solid Load = 2.1 wt/wt
Solid Load = 1.7 wt/wt
Solid Load = 1.3 wt/wt
Effect of Configuration and Geometry (Cone Deflector)

Silica Sand; $L_s / D_c = 0.1$;
Gas Inlet Velocity = 1.0 m/s

Solid Loading [wt/wt]
Effect of Solid Loading on Collection Efficiency (Silica Sand)

Silica Sand; 30° Swirl Vanes; $L_S / D_c = 0.1$

Gas Inlet Velocity = 1.0 m/s
Gas Inlet Velocity = 4.4 m/s
Gas Inlet Velocity = 8.7 m/s
Effect of Solid Loading on Collection Efficiency (Glass Beads)
Effect of Solid Loading on Separator Pressure Drop

Experimental Results

Silica Sand, $L_S / D_C = 0.1$

- 60° Cone Deflector
  - Gas Inlet Velocity = 13 m/s
- 30° Swirl Vanes
  - Gas Inlet Velocity = 8.7 m/s
Effect of Solid Loading on Separator Pressure Drop

![Graph showing the effect of solid loading on separator pressure drop with various inlet velocities.](image)

- **60° Cone Deflector**
  - Gas Inlet Velocity = 13 m/s
  - Solid Loading [wt/wt]

- **30° Swirl Vanes**
  - Gas Inlet Velocity = 8.7 m/s
  - Solid Loading [wt/wt]
**Experimental Results**

**Grade Efficiency Curves**

- **Solids Collection Efficiency [%]**
  - 99.4
  - 99.6
  - 99.8
  - 100.0

- **Particle Size [micron]**
  - 20
  - 40
  - 60
  - 80
  - 100
  - 120
  - 140
  - 160
  - 180
  - 200
  - 220
  - 240

- **Glass Beads 30° Swirl Vanes LS / DC = 0.1 Gas Inlet Velocity = 4.4 m/s**

- **Silica Sand 30° Swirl Vanes**

**Legend**
- Glass Beads
- Silica Sand

**Graph Details**
- Particle Size [micron]
- Solids Collection Efficiency [%]
- Gas Inlet Velocity = 4.4 m/s
Conclusions

- > 98.5% efficiency for particle sizes > 45µm

- 50% reduction in gas pressure losses at high solid loading when using cone deflector

- Most efficient configurations:
  - 30° Swirl Vanes: 99.99%
  - 60° Cone Deflector: 99.97%
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