DEVELOPMENT OF A NOVEL VIBRATING REACTOR FOR TESTING BIO-OIL GASIFICATION CATALYSTS

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BioenergyIII: An ECI Conference
Canary Islands, Spain
May 22-27, 2011
TEST REACTORS FOR CATALYTIC ENDOOTHERMIC REACTIONS

- Many important catalytic reactions are endothermic e.g.:
  - catalytic cracking
  - gasification

- Issues with traditional test reactors:
  - Heat is transferred from the wall into reactor
    - Low heat transfer coefficient
    → High temperature gradient
    → Parasitic thermal cracking reactions
  - Seals for agitator may leak
Develop new test reactor:

- Batch-wise reactor
- Low temperature difference between heating surface and catalyst bed
  → induction heating of rods within bed
- No mechanical seal
  → jiggle bed (up and down motion)

Test new reactor
Advantages of induction heating:

- Very fast heating rate
- Heat transfer from within the bed, not from the wall
- Temperature profile as in industrial units
CERAMIC CRUCIBLE AND INDUCTION HEATING ELEMENTS

Ceramic crucible
Alumina 99.8%

Induction heating elements
8 Inconel heating wires

Reaction zone of the JBR
AGITATION OF JBR

Upward actuator extension
Bed contraction

Downward actuator retraction
Bed expansion
1. on/off feed valves
2. Inlet of carrier gas
3. Thermocouple
4. Inlet of feed and carrier gas
5. Ceramic crucible with insulation
6. Insulation disk
7. Insulation disk
8. Linear pneumatic actuator
9. Outlet gas valve
10. Stainless steel support rods
11. Copper coil
12. Copper disk
13. aluminum disk
14. Stainless steel scalloped disk
\[ CV_{\text{space}} = \frac{\sigma}{\mu} \text{_{space}} = \sqrt{\frac{1}{N_t} \sum_l \left( y_{l,i} - \frac{\sum_i y_{l,i}}{N_t} \right)^2} \]

**Digitized Gray Pictures**

Expanded bed  Retracted bed

Variation of the horizontally averaged gray value along the crucible length

Bed of sand particles: 10 g mass and size distribution of 149-212 μm
FREQUENCY OF ACTUATOR VERSUS AIR PRESSURE

\[ f_{\text{actuator}}(Hz) = \frac{\text{No. of complete cycles}}{\text{No. of frames}} \times \left( \frac{\text{Frame}}{\text{second}} \right) \]

- A = 8.9cm
- A = 7.6cm
- A = 6.4cm
FREQUENCY OF ACTUATOR VERSUS DOMINANT FREQUENCY OF PARTICLES BED

mass of sand particles: 5 g
FREQUENCY OF ACTUATOR VERSUS DOMINANT FREQUENCY OF PARTICLES BED

sand particles size: 212-355 μm
Effect of size distribution of the sand particles on dominant frequency of bed motion

mass of sand particles 5 g; amplitude 6.4cm
Effect of mass of the particles on dominant frequency power of bed motion

sand particles size 212-355 μm; amplitude 6.4cm
Heat balance during cooling step:
Heat lost by particle bed = heat losses
→ heat losses vs. bed temperature

power outlet 20%, mass of sand particles 10gr, amplitude 6.4cm

HEAT TRANSFER IN THE JBR
EFFECT OF ACTUATOR FREQUENCY ON COOLING STEP
Heat balance during heating step:
Heat gain of particle bed = electrical power to heaters – heat losses
→ electrical power transferred to in-bed heaters
→ heat transfer coefficient between heaters and bed

Power outlet 20%, mass of sand particles 10 g, amplitude 6.4 cm
## Heat Transfer in the JBR
### Temperature Profile Between Bed and Heating Wires

<table>
<thead>
<tr>
<th>Power level (%)</th>
<th>$T_w$ (°C)</th>
<th>$T_s$ (°C)</th>
<th>$(T_w - T_s)$ (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>198</td>
<td>204</td>
<td>6</td>
</tr>
<tr>
<td>12</td>
<td>205</td>
<td>210</td>
<td>5</td>
</tr>
<tr>
<td>15</td>
<td>246</td>
<td>249</td>
<td>3</td>
</tr>
<tr>
<td>20</td>
<td>247</td>
<td>249</td>
<td>2</td>
</tr>
</tbody>
</table>

$T_w$: temperature on the surface of heating wires

$T_s$: temperature of bed

Air pressure 207 kPa, sand particles: mass 10g, size 149-212 µm; amplitude 6.4cm
## Estimation of Heat Transfer Coefficients and Transferred Power Versus Power Outlet

<table>
<thead>
<tr>
<th>Power level (%)</th>
<th>( h_0 \left( \frac{W}{m^2 \cdot ^\circ C} \right) )</th>
<th>( P \ (w) )</th>
<th>( h_w \left( \frac{W}{m^2 \cdot ^\circ C} \right) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.265</td>
<td>1.67</td>
<td>45</td>
</tr>
<tr>
<td>12</td>
<td>0.257</td>
<td>2.46</td>
<td>80</td>
</tr>
<tr>
<td>15</td>
<td>0.270</td>
<td>4.06</td>
<td>220</td>
</tr>
<tr>
<td>20</td>
<td>0.269</td>
<td>6.05</td>
<td>493</td>
</tr>
</tbody>
</table>

\( h_0 \): Heat loss; \( P \): Electrical transferred power; \( h_w \): Heat transfer coefficient between wires and bed.

Air pressure 207 kPa, sand particles: mass 10g, size 149-212 µm; amplitude 6.4cm
ESTIMATION OF HEAT TRANSFER COEFFICIENTS AND TRANSFERRED ELECTRICAL POWER VERSUS POWER OUTLET
<table>
<thead>
<tr>
<th>Air pressure (kPa)</th>
<th>$h_o \left( \frac{w}{m^2 \cdot \circ C} \right)$</th>
<th>$P \ (w)$</th>
<th>$h_w \left( \frac{w}{m^2 \cdot \circ C} \right)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>207</td>
<td>0.269</td>
<td>6.06</td>
<td>493</td>
</tr>
<tr>
<td>276</td>
<td>0.290</td>
<td>6.05</td>
<td>492</td>
</tr>
<tr>
<td>345</td>
<td>0.299</td>
<td>5.97</td>
<td>486</td>
</tr>
</tbody>
</table>

$h_o$: Heat loss; $P$: Electrical transferred power; $h_w$: Heat transfer coefficient between wires and bed

Air pressure 207 kPa; sand particles: mass 10g, size 149-212 µm; amplitude 6.4cm
Advantage of Induction Heating for Endothermic Reactions

Injections of 2mg water

Close loop temperature control
After water injection, temperature dropped by less than 2 °C
Temperature recovery time was 4-8 seconds
CONCLUSION

- The jiggle bed reactor (JBR) is a batch micro reactor to test gasification catalysts.

- A linear pneumatic actuator was successfully designed to achieve fluidization conditions in the reaction zone of the JBR.

- A new induction heating system was designed and implemented.

- A new image processing technique was developed to monitor the fluidization dynamics of the catalyst bed.

- The size distribution and mass of the catalyst particles can be optimized for enhanced fluidization.

- Induction heating provides a minimum temperature difference between the heating wires and the catalyst bed.

- The maximum fluidization intensity of the bed corresponds to the highest heat transfer coefficient between the heating wires and the catalyst bed.
THANKS FOR YOUR KIND ATTENTION
GRACIAS POR SU AMABLE ATENCIÓN