New and Old Equations Tie Together 75 Years of FCC Standpipe Experience

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75 Years of FCC Standpipe Experience

Presentation Outline

- Framing the standpipe problem
- Standpipe performance issues
- Actual and apparent density
- Where aeration goes
- Theoretical aeration rates
- Different aeration mediums
- Catalyst properties
- Available tools
- Commercial examples

Niccum, P.K., Update on the catalytic cracking process and standpipes—Parts 1 & 2, Hydrocarbon Processing, March & April, 2015
Invention of Fluid Solids Standpipe

*FCC Demonstration Plant in 1940*

Fig. 4. Drawing (June 21, 1940) of new "standpipe system" for installation at PCL. There was also a circuit for catalyst flow from the 32-inch hopper to a catalyst cooler and into the bottom of the regenerator.
Invention of Fluid Solids Standpipe

1942 - First Commercial FCC Unit
Idealized Fluid Solids Standpipe

Static head builds pressure above catalyst valve

Standpipe Inlet

Normal Pressure Increase

Increasing Depth

Slide Valve

Increasing Pressure
Recognizing Standpipe Performance Issues

• Symptoms of Standpipe Problems
  – Low or erratic standpipe pressure build-up
  – Over-sensitivity to changes in FCC unit operating conditions or catalyst physical properties.

• Common Problem Areas
  – Standpipe inlet design
  – Standpipe geometry
  – Standpipe aeration
  – Catalyst issues

• Not Standpipe Problems
  – Riser pressure drop is high
  – Reactor – Regenerator pressure differential is limiting
  – Required catalyst circulation rate has increased
Frictional Forces Offset Static Head

Minimum Fluidization Density: 41.0 lb/ft³, Loose Settled Density: 45.2 lb/ft³, Packed Density: 50 lb/ft³

Actual vs. Apparent Standpipe Density

Actual density is not apparent from $\Delta P/\Delta L$

Minimum Fluidization Density: 45 lb/ft³, Loose Packed Density: 45 lb/ft³, Packed Density: 50 lb/ft³

Simplified Solids and Gas Modeling

Mixed Phase
(Density = $\rho$)

Separate Phases
(Density = $\rho$)

Bubble Phase
(Density = 0)

Emulsion Phase
(Density = $\rho_0$)
**Phase Parameters – Without Slip**

*Derived from simple mass/volume balances*

<table>
<thead>
<tr>
<th></th>
<th>Mixed Phase</th>
<th>Bubble Phase</th>
<th>Emulsion Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase Density</td>
<td>$\rho$</td>
<td>0</td>
<td>$\rho_o$</td>
</tr>
<tr>
<td>Phase Voidage</td>
<td>$1 - \rho/\rho_s$</td>
<td>1</td>
<td>$1 - \rho_o/\rho_s$</td>
</tr>
<tr>
<td>Phase Fraction</td>
<td>1</td>
<td>$1 - \rho/\rho_o$</td>
<td>$\rho/\rho_o$</td>
</tr>
<tr>
<td>Phase Velocity</td>
<td>$w/\rho$</td>
<td>$w/\rho$</td>
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### Phase Parameters – With Slip

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<tr>
<td>Phase Fraction</td>
<td>$1 - \rho / \rho_o$</td>
<td>$\rho / \rho_o$</td>
</tr>
<tr>
<td>Phase velocity</td>
<td>$w / \rho + U_b$</td>
<td>$w / \rho$</td>
</tr>
<tr>
<td>Contribution to Gas SVV</td>
<td>$(w / \rho + U_b) \left(1 - \rho / \rho_o\right)$</td>
<td>$w \left(1 / \rho_o - 1 / \rho_s\right) + U_o \rho / \rho_o$</td>
</tr>
<tr>
<td>Total SVV, $U_t$</td>
<td>$w \left(1 / \rho - 1 / \rho_s\right) + U_b \left(1 - \rho / \rho_o\right) + U_o \rho / \rho_o$</td>
<td></td>
</tr>
</tbody>
</table>

$U_b$ – Relative Bubble Rise Velocity, $U_o$ – Minimum Fluidization Velocity
Density as a Function of $U_t$ and Mass Flux

$$U_t = U_b \left(1 - \frac{\rho}{\rho_o}\right) + w \left(\frac{1}{\rho} - \frac{1}{\rho_s}\right) + U_o \frac{\rho}{\rho_o}$$

$$\rho^2 + \rho \left[\frac{(U_t - U_b + w/\rho_s)}{(U_b - U_o)}\right] \rho_o - \frac{w \rho_o}{(U_b - U_o)} = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Quadratic equation can yield two roots
Velocity of Emulsion Phase

The emulsion phase always travels down.
The bubble phase can travel up or down.
SVV Contribution from Emulsion Phase

Gas SVV From Emulsion Phase
Ub = 3.5 fps

- W = 0 lb/ft²s
- w = 40 lb/ft²s
- w = 80 lb/ft²s
- w = 120 lb/ft²s
- w = 160 lb/ft²s
- w = 200 lb/ft²s
- w = 240 lb/ft²s

SVV, fps

Density, pcf
SVV Contribution from Bubble Phase

Gas SVV from Bubble Phase
Ub = 3.5 fps

- W = 0 lb/ft²s
- w = 40 lb/ft²s
- w = 80 lb/ft²s
- w = 120 lb/ft²s
- w = 160 lb/ft²s
- w = 200 lb/ft²s
- w = 240 lb/ft²s
Total SVV Through Standpipe

Sum of emulsion and bubble phase contributions
Density in Gas Upflow Standpipe

Gas velocity increases as the gases move up

- $w = 20 \text{ lb/ft}^2\text{s}$
- $w = 30 \text{ lb/ft}^2\text{s}$
- $w = 40 \text{ lb/ft}^2\text{s}$
Density in Gas Downflow Standpipe

Without aeration, gas slows as it moves down
Density in Gas Downflow Standpipe

Based on $U_b = 3.5$ fps

- Two Real Solutions
- Based on $u_b = 3.5$ fps
Theoretical Aeration Rate

Derived from equations to keep $U_t$ constant

$$\Delta R = U_t A \left( \frac{520}{T + 460} \right) \times \left( \frac{\rho \Delta L}{144 \times 14.7} \right)$$

$$U_t = U_b \left( 1 - \frac{\rho}{\rho_o} \right) + w \left( \frac{1}{\rho} - \frac{1}{\rho_s} \right) + U_o \frac{\rho}{\rho_o}$$
Theoretical Aeration Rate

Derived from equation for $U_t$

$$\frac{\Delta R}{\Delta L} = \frac{A \times 520 \rho \left[ U_b \left(1 - \frac{\rho}{\rho_o} \right) + w \left(\frac{1}{\rho} - \frac{1}{\rho_s} \right) + U_o \frac{\rho}{\rho_o} \right]}{2116 (T + 460)}$$

Multiply by 60 for SCFM

$$\frac{\Delta R}{\Delta L} = \frac{A \times 520 \rho \times w \left(\frac{1}{\rho} - \frac{1}{\rho_s} \right)}{2116 (T + 460)}$$

Simplified Equation

Ignoring Slip
Theoretical Aeration Rates at 37 lb/ft$^3$

Required to maintain constant SVV and density
Good fluidization at inlet is of prime importance

- **Feed Standpipe Well Fluidized Catalyst**
  - Draw catalyst from a well fluidized area of bed
  - Disengage excess bubbles
  - Target desired standpipe density

- **Inlet Types**
  - Hole in the bottom head of vessel
  - Internal hopper
  - Externally fluidized side-draw hoppers
Impact of Aeration Medium

Based on a 70 micron FCC catalyst particle

![Graph showing the impact of aeration medium on terminal velocity vs temperature in F for different gases: CH4, C3H8, H2O, Air, H2. The graph illustrates decreasing terminal velocity with increasing temperature.]

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**KBR**

**We Deliver**
Impact of Aeration Medium

Based on representative FCC catalyst at 1150 °F

![Graph showing the impact of aeration medium on M, S, E, and R across different pressures and gases.](image-url)
Impact of Aeration Medium

Based on a representative FCC catalyst at 1150 °F
Conclusion: Impact of Aeration Medium

- **Air or Nitrogen**
  - Best Aeration Mediums

- **Steam**
  - Not as effective as air
  - Condensation complicates application

- **Hydrocarbons**
  - Low gas viscosity makes hydrocarbons ineffective as aeration mediums

- **Hydrogen**
  - Low gas viscosity and very low density makes hydrogen a very ineffective aeration medium

*Based on three indicators*
# Impact of Fines, $D_p$ and Density

*Based on MSER changes over range of interest*

<table>
<thead>
<tr>
<th>Fraction &lt; 45 microns</th>
<th>MSER % of base</th>
<th>Particle Density, g/cc</th>
<th>MSER % of base</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.20</td>
<td>103.2</td>
<td>0.80</td>
<td>102.9</td>
</tr>
<tr>
<td>0.15</td>
<td>102.4</td>
<td>0.83</td>
<td>102.1</td>
</tr>
<tr>
<td>0.10</td>
<td>101.6</td>
<td>0.86</td>
<td>101.4</td>
</tr>
<tr>
<td>0.05</td>
<td>100.8</td>
<td>0.89</td>
<td>100.7</td>
</tr>
<tr>
<td>0.00</td>
<td>100.0</td>
<td>0.92</td>
<td>100.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dp, microns</th>
<th>MSER</th>
</tr>
</thead>
<tbody>
<tr>
<td>65</td>
<td>104.8</td>
</tr>
<tr>
<td>70</td>
<td>103.5</td>
</tr>
<tr>
<td>75</td>
<td>102.2</td>
</tr>
<tr>
<td>80</td>
<td>101.1</td>
</tr>
<tr>
<td>85</td>
<td>100.0</td>
</tr>
</tbody>
</table>

- **Conclusion**
  - All three parameters are important
Simplified Fluidization Factors

Based on E-cat data from 15 FCC units

\[ e^{0.158 F_{40}} \]

\[ APS^{0.176} \quad ABD^{0.205} \]
Available Tools

For diagnosing standpipe issues

- Pressure Profile Data
  - Single gauge pressure surveys
  - DCS data print-outs and trends
  - High speed multipoint data recordings
- Aeration and Fluidization Gas Rate Trials
- Computational Fluid Dynamic (CFD) and Cold Flow Modelling Studies
- Gamma Ray Scans
Example 1: Geometric Gas Trap

Preventing upward migration of bubbles

Bubble held stationary by down-flowing solids

58 Inch ID
1.9 fps Solids Velocity
80 lb/ft$^2$s Mass Flux

35.5 Inch ID
5.4 fps Solids Velocity
227 lb/ft$^2$s Mass Flux

45.5 Inch ID
3.1 fps Solids Velocity
129 lb/ft$^2$s Mass Flux
Example 2: Geometric Trap

Preventing bubble migration

- **Vertical Section**
  - Catalyst drags bubbles down

- **Inclined Section**
  - Catalyst slides down under rising bubbles

- **Process Dynamic**
  - Bubbles accumulate in bend until catalyst circulation is reduced enough that the bubble finally vents upward
  - The process then repeats itself
Example 3: Data Analysis

*Clues from 80 ft standpipe*

- Located the Origin of Trouble
  - Loss of standpipe DP started with high DP in the hopper
- Used Feedback to Guide Optimization
  - Changed aeration and fluidization gas rates
  - Changed fluid bed levels
  - Mechanical modifications improved fluidization around hopper
  - More changes to aeration and fluidization gas rates
Example 3: Results

**Standpipe Characteristics**
- 25 inch ID
- 136 lb/ft²s
- 80 ft total length from hopper to slide valve

### Pressure Delta Measurement Locations ($\Delta L$)

<table>
<thead>
<tr>
<th>Location</th>
<th>$\Delta L$, psi</th>
<th>Apparent Density, lb/ft³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hopper (7 ft)</td>
<td>1.8</td>
<td>36.3</td>
</tr>
<tr>
<td>SP Top (14 ft)</td>
<td>3.5</td>
<td>36.9</td>
</tr>
<tr>
<td>Upper SP (14 ft)</td>
<td>3.6</td>
<td>35.9</td>
</tr>
<tr>
<td>Middle SP (14 ft)</td>
<td>3.9</td>
<td>41.5</td>
</tr>
<tr>
<td>Lower SP (14 ft)</td>
<td>4.1</td>
<td>42.0</td>
</tr>
<tr>
<td>SP Bottom (14 ft)</td>
<td>4.8</td>
<td>50.3</td>
</tr>
<tr>
<td>Total Standpipe (70 ft)</td>
<td>20.6</td>
<td>42.3</td>
</tr>
</tbody>
</table>

After optimization and mechanical changes
Example 4: Change of Aeration Medium

Air replaces steam

• History of Regenerated Catalyst Standpipe
  – Steam used for aeration
  – Pressure build-up erratic
  – Efforts to optimize rates and ensure dry steam provided little improvement
  – Resisted recommendations to switch from steam to air

• Change Made to Air for Standpipe Aeration
  – Improvement in standpipe pressure build-up and stability were immediate and marked
Example 5: Upgrading Aeration System

Applying theoretical aeration rates

Cumulative Aeration Rate, SCFM vs Elevation, ft

Graph showing the cumulative aeration rate in SCFM as a function of elevation in feet before and after adjustment, and following a revamp.

Legend:
- Blue diamonds: Before Adjustment
- Pink triangles: After Adjustment
- Red squares: Following Revamp

Elevation, ft

Cumulative Aeration Rate, SCFM
Example 5: Upgrading Aeration System

Applying theoretical aeration rates
Example 6: Optimizing Aeration Rates

Empirical optimization leads to solution

• Before
  – 24 lb/ft³ apparent density
  – Erratic pressure build-up
  – High vibration

• After
  – 35 lb/ft³ apparent density
  – Steady pressure build-up
  – Little vibration

• Standpipe Design Data
  – ID: 20 Inches
  – Mass Flux: 217 lb/ft²s
Stay Positive – Get Started

• Recognize the Root of the Problem
  – Consider issues upstream and downstream of the standpipe
  – Is the standpipe really to blame?
• Compare Historic vs. Recent Catalyst and Operating Data
• Apply Available Tools
  – Tabulate pressure data
  – Perform aeration trials
  – CFD and cold flow modeling
  – Gamma ray scans
Conclusions

• Standpipe Performance Can Be Improved
  – Cat must be fluidized before entering standpipe
  – Standpipe sizing / geometry must not trap gas
  – Aeration must be correctly applied
  – Catalyst properties should support fluidization

• Empirical Optimization is Required
  – Guided by feedback from trials and unit modifications in addition to theory

• Quick Success is Less Common than Success Following Months of Focused Work
  – And maybe some unit modifications
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