“Review of Research into Fat, Oil and Grease (FOG) Deposits in Collection Systems”

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Background

• Large Contributor to Sanitary Sewer Overflows per EPA
• Issue Occurs Globally
• Viewed as “Cost of Doing Business”
• Presentation to Review Previous Research of:
  – Deposit Component Sources and Chemistry
  – Conditions and Mechanisms of Formation
  – FOG Control Challenges

- Characterized Chemical and Physical Makeup of 27 FOG Deposit Samples from Different U.S. Collection Systems.
- Deposits Contain High Amounts of Saturated Fats and Calcium
  - Higher Than Background Levels.
  - Average Ca at 4,300 ppm, Wastewater Ca Level < 200 ppm
  - Dry Content 85% Total Fat
- Determined that FOG Deposits are Formed Primarily by Saponification and are Metal Soaps.
- Evidence of Layering During Formation Process
FOG, Triglyceride and Free Fatty Acid Refresher

<table>
<thead>
<tr>
<th>Fats</th>
<th>Oils</th>
<th>Grease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal Based (Lard, Shortening)</td>
<td>Vegetable Based (Corn, Soybean)</td>
<td>Residue Left Over After Cooking</td>
</tr>
<tr>
<td>Liquid With Some Heat Added</td>
<td>Able to Withstand High Temperatures</td>
<td>Liquid To Semi-Solid at Room Temperature</td>
</tr>
<tr>
<td>Solid at Room Temperature</td>
<td>Liquid at Room Temperature</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fatty Acid</th>
<th>Model</th>
<th>Carbon Atoms</th>
<th>Molecular Formula</th>
<th>Solubility In Water</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palmitic Acid</td>
<td><img src="image" alt="Model" /></td>
<td>C16:0</td>
<td>C_{16}H_{32}O_2</td>
<td>Insoluble</td>
<td>0.82 g/cm³</td>
</tr>
<tr>
<td>Stearic Acid</td>
<td><img src="image" alt="Model" /></td>
<td>C18:0</td>
<td>C_{18}H_{36}O_2</td>
<td>3 mg/L</td>
<td>0.94 g/cm³</td>
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<tr>
<td>Oleic Acid</td>
<td><img src="image" alt="Model" /></td>
<td>C18:1</td>
<td>C_{18}H_{32}O_2</td>
<td>Insoluble</td>
<td>0.89 g/cm³</td>
</tr>
<tr>
<td>Linoleic Acid</td>
<td><img src="image" alt="Model" /></td>
<td>C18:2</td>
<td>C_{18}H_{32}O_2</td>
<td>0.14 mg/L</td>
<td>0.90 g/cm³</td>
</tr>
</tbody>
</table>
# Fatty Acid Profiles of Common Animal Fats, Vegetable Oils and FOG Deposits

<table>
<thead>
<tr>
<th>Lipid Type</th>
<th>Saturated Fat (%)</th>
<th>Primary Saturated Fat</th>
<th>Mono-Unsaturated Fat (%)</th>
<th>Primary Unsaturated Fat</th>
<th>Polyunsaturated Fat (%)</th>
<th>Primary Polyunsaturated Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Animal Fats</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chicken Fat</td>
<td>33.0</td>
<td>Palmitic (C16:0)</td>
<td>45.2</td>
<td>Oleic (C18:1)</td>
<td>21.4</td>
<td>Linoleic (C18:2)</td>
</tr>
<tr>
<td>Lard (pig)</td>
<td>41.8</td>
<td>Palmitic (C16:0)</td>
<td>47.9</td>
<td>Oleic (C18:1)</td>
<td>9.9</td>
<td>Linoleic (C18:2)</td>
</tr>
<tr>
<td>Tallow (beef)</td>
<td>47.9</td>
<td>Palmitic (C16:0)</td>
<td>47.4</td>
<td>Oleic (C18:1)</td>
<td>3.3</td>
<td>Linoleic (C18:2)</td>
</tr>
<tr>
<td><strong>Vegetable Oils</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canola</td>
<td>7.3</td>
<td>Palmitic (C16:0)</td>
<td>62.9</td>
<td>Oleic (C18:1)</td>
<td>30.5</td>
<td>Linoleic (C18:2)</td>
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<tr>
<td>Corn</td>
<td>13.6</td>
<td>Palmitic (C16:0)</td>
<td>25.6</td>
<td>Oleic (C18:1)</td>
<td>60.8</td>
<td>Linoleic (C18:2)</td>
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<tr>
<td>Olive</td>
<td>12.1</td>
<td>Palmitic (C16:0)</td>
<td>80.9</td>
<td>Oleic (C18:1)</td>
<td>7.0</td>
<td>Linoleic (C18:2)</td>
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<tr>
<td>Palm</td>
<td>49.4</td>
<td>Palmitic (C16:0)</td>
<td>39.5</td>
<td>Oleic (C18:1)</td>
<td>11.1</td>
<td>Linoleic (C18:2)</td>
</tr>
<tr>
<td>Peanut</td>
<td>19.4</td>
<td>Palmitic (C16:0)</td>
<td>48.5</td>
<td>Oleic (C18:1)</td>
<td>32.0</td>
<td>Linoleic (C18:2)</td>
</tr>
<tr>
<td>Soybean</td>
<td>15.4</td>
<td>Palmitic (C16:0)</td>
<td>23.3</td>
<td>Oleic (C18:1)</td>
<td>61.3</td>
<td>Linoleic (C18:2)</td>
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<tr>
<td><strong>Average FOG Profile (Keener et al, 2008)</strong></td>
<td>61.3</td>
<td>Palmitic (C16:0)</td>
<td>22.3</td>
<td>Oleic (C18:1)</td>
<td>4.4</td>
<td>Linoleic (C18:2)</td>
</tr>
</tbody>
</table>

- Formed FOG Deposits in Lab Using CaCl$_2$ and GI Effluent.
- Without Free Fatty Acids (FFAs), Calcium Salts Do Not Form.
- Analysis Results Showed Both Lab and Field Deposits Similar to Calcium Soap.
- Field Deposits Contain Un-reacted FFAs / Calcium Limited

<table>
<thead>
<tr>
<th>FOG Study</th>
<th>Saturated Fat %</th>
<th>Primary Saturated Fat</th>
<th>Mono-Unsaturated Fat %</th>
<th>Primary Mono-Unsaturated Fat</th>
<th>Poly-Unsaturated Fat %</th>
<th>Primary Poly-Unsaturated Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keener (2008)</td>
<td>61.3</td>
<td>Palmitic (C16:0)</td>
<td>22.3</td>
<td>Oleic (C18:1)</td>
<td>4.4</td>
<td>Linoleic (C18:2)</td>
</tr>
<tr>
<td>He (2011)</td>
<td>61.1</td>
<td>Palmitic (C16:0)</td>
<td>23.3</td>
<td>Oleic (C18:1)</td>
<td>3.2</td>
<td>Linoleic (C18:2)</td>
</tr>
</tbody>
</table>

- Study Notes Mechanisms That May Affect FOG Deposits Physical Properties.
- Calcium Accumulation Occurred Where Higher Water Hardness Levels Lead to Harder Deposits.
- Bacteria Transform Fatty Acids from Unsaturated to Saturated Forms.
  - Similar to *Brooksbank*, 2006, Where Wastewater Bacteria Degraded Unsaturated FFAs to Saturated FFAs.
In 2012, Reyes and Dominic each studied factors affecting FOG formation in collection systems.

- FFAs produced from cooking processes & discharged with kitchen wastewater to sewer.
- Formations more likely to occur at pipe fitting ridges, roots and sags, rather than in straight pipe sections.
  - Indicates nucleation site may be necessary.
- Sticky solid formed after saponification adsorbing FFAs, calcium and debris.
- Surfactants appear to inhibit FOG deposit formation.
- FFAs partition in FOG and float on wastewater surface.
  - Alkali conditions at the air-water surface may lead to hydrolysis of FOG.

FOG FFA densities range from 0.82 to 0.94 g/cm³.
Sources of FOG Components

- Sewer FOG Deposits are Insoluble Calcium Soaps
- FOG Hydrolysis
  - Physically From Heating
  - Chemically Under Basic pH Conditions
  - Microbially Through Enzymatic Lipase
- Free Fatty Acid Sources
  - Hydrolyzed FOG
    - Vegetable Oils
    - Animal Fats
  - Bacteria
  - Personal Care Products
  - Human Waste
    - Total Fecal Fat is 5-6% FFAs
- Calcium Sources
  - Water Hardness
  - Concrete
  - Diet
  - Human Waste
    - Urine Has ~300 mg/L of Calcium
“Mechanisms of Fat, Oil and Grease (FOG) Deposit Formation in Sewer Lines.” He, 2013.

- Low pH from Fatty Acid Creation Release of Calcium From Concrete
- Deposits Formed at Higher pH
- Locations with Low Flow Velocities or Turbulence More Likely Formation
- Unreacted FFAs Attract Additional Fatty Acids and Calcium
- Deposit Formation Model
  - DLVO (Derjaguin, Landau, Verwey, Overbeek) theory

Consider Concrete Coatings or Alternative Materials
“Efficient Fractionation and Analysis of Fatty Acids and Their Salts in FOG Deposits.”

_Benecke, 2017._

- Separated into Component Parts
- Dry Content 85% Fatty Acids (Similar to Keener and He Research)
- 27% FFAs Were Saponified; 73% Free and Unreacted
  - Supports Calcium May Be a Limiting Factor
- FOG Triglyceride Levels at 0% to 1%
  - New Cooking Oil and Yellow Grease at 100% & 90% Triglycerides
Grease Interceptor Chemistry

• GI Influent Neutral to pH > 8 Due to Alkali Detergents
• FOG Hydrolysis Releases FFAs
• Acidic Conditions Develop
  — Leaching Calcium Ions
  — GI Effluent < 5
• FFA Ladened Discharge Combines with Calcium in Neutral pH Wastewater in Main Downstream of Sewer Lateral
What Can Be Done?

• Continued Messaging on Proper FOG Management
• Debris Free, Well Flowing Sewers
• Less Abrupt Transition Pipe Joints (Y’s Instead of T’s)
• Minimize Use of Concrete in Sewer Construction
• Shorter GI Pump Out Frequencies
• Control FFAs and Calcium
• Consider FOG Remediation Additives That Degrade FFAs to < C14

<table>
<thead>
<tr>
<th></th>
<th>Myristic - C14</th>
<th>Palmitic - C16</th>
<th>Stearic - C18</th>
<th>Oleic - C18:1</th>
<th>Linoleic - C18:2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benecke - 2017</td>
<td>4%</td>
<td>68%</td>
<td>16%</td>
<td>6%</td>
<td>1%</td>
</tr>
<tr>
<td>Nieuwenhuis - 2018</td>
<td>5%</td>
<td>31%</td>
<td>5%</td>
<td>14%</td>
<td>9%</td>
</tr>
</tbody>
</table>
QUESTIONS?

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