MES – The Future Surfactant

Walter Jessup
Challenges to the Detergent Industry

- Raw Material Cost Increases
- Formulating with Alternative Detergent Actives
- Available & Sustainable Source of Supply
- Environmental and Regulatory Concerns
Alternative Surfactants Require:

- Adequate Volume to Supply the Industry
- Equivalent Surfactant Properties
- Developed Processing Technology
- Developed Formulation Technology
- Lower Cost
The Case for MES

Methyl Ester Sulfonates (MES)

- Methyl Ester Raw Material Widely Available – renewable natural oils
- Trans-esterification of fatty acids with Methanol followed by refining and hydrogenation – all known technologies
- Sulfonation Process Available that can be adapted to Existing Sulfonation Plants
- Excellent Surfactant Properties
Advantages of MES

- Derived from renewable oil resources
  - Natural fats and oils
  - Supply of palm oil steadily increasing
  - ME Cost per ton historically has been less than LAB (subject to changing market conditions)

- High detergency and calcium ion stability
  - Less MES for equivalent washing power
  - Good co-active
Advantages of MES

- Attractive biological properties
  - Low toxicity
  - Biodegrades similar to AS and soap
  - Biodegrades quicker than LAS
## Cost Compare MES & LABS

**February, 2006**

### Relative Sulfonation Cost of MES and LABS

<table>
<thead>
<tr>
<th>Raw Materials</th>
<th>MES</th>
<th>LABS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sulfur</strong></td>
<td>0.11</td>
<td>0.102</td>
</tr>
<tr>
<td><strong>LAB</strong></td>
<td>0.112</td>
<td>0.102</td>
</tr>
<tr>
<td><strong>ME</strong></td>
<td>0.775</td>
<td>--</td>
</tr>
<tr>
<td><strong>NaOH</strong></td>
<td>0.158</td>
<td>--</td>
</tr>
<tr>
<td><strong>MeOH</strong></td>
<td>0.08</td>
<td>--</td>
</tr>
<tr>
<td><strong>H2O2</strong></td>
<td>0.06</td>
<td>--</td>
</tr>
<tr>
<td><strong>Na2SO4</strong></td>
<td>0.02</td>
<td>--</td>
</tr>
<tr>
<td><strong>N2</strong></td>
<td>0.035</td>
<td>--</td>
</tr>
<tr>
<td><strong>Total Raw Materials</strong></td>
<td><strong>$582.84</strong></td>
<td><strong>$1,131.90</strong></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Utilities</th>
<th>MES</th>
<th>LABS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electricity</strong></td>
<td>US$102/MWH</td>
<td>0.209 MWH</td>
</tr>
<tr>
<td><strong>Steam</strong></td>
<td>8.70/MT</td>
<td>2.05 T</td>
</tr>
<tr>
<td><strong>Cooling Water</strong></td>
<td>21.74/KT</td>
<td>0.055 KT</td>
</tr>
<tr>
<td><strong>Total Utilities</strong></td>
<td><strong>$40.35</strong></td>
<td><strong>$20.77</strong></td>
</tr>
</tbody>
</table>

**Total Cost Excluding Labor, Capital & OH**

<table>
<thead>
<tr>
<th>MES</th>
<th>LABS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$623.18</strong></td>
<td><strong>$1,152.67</strong></td>
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</table>
## Relative Sulfonation Cost of MES and LABS

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Sulfur</td>
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<td>0.11</td>
<td>52.25</td>
<td>0.102</td>
<td>48.45</td>
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<tr>
<td>LAB</td>
<td>1800</td>
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<td>--</td>
<td>0.721</td>
<td>1297.8</td>
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<tr>
<td>ME</td>
<td>1250</td>
<td>0.775</td>
<td>968.75</td>
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<tr>
<td>NaOH</td>
<td>650</td>
<td>0.158</td>
<td>102.7</td>
<td>0.26</td>
<td>169</td>
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<tr>
<td>MeOH</td>
<td>550</td>
<td>0.08</td>
<td>44</td>
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<tr>
<td>H2O2</td>
<td>700</td>
<td>0.06</td>
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<tr>
<td>Na2SO4</td>
<td>400</td>
<td>0.02</td>
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<tr>
<td>N2</td>
<td>75</td>
<td>0.035</td>
<td>2.625</td>
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<tr>
<td><strong>Total Raw Materials</strong></td>
<td><strong>$1,220.33</strong></td>
<td></td>
<td></td>
<td><strong>$1,515.25</strong></td>
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</table>

<table>
<thead>
<tr>
<th>Utilities</th>
<th>MES US$/102/MWH</th>
<th>T/M</th>
<th>US$/100 MWH</th>
<th>LABS US$/102/MWH</th>
<th>T/M</th>
<th>US$/100 MWH</th>
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</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>US$102/MWH</td>
<td>0.209 MWH</td>
<td>21.318</td>
<td>0.180 MWH</td>
<td>18.36</td>
<td></td>
</tr>
<tr>
<td>Steam</td>
<td>8.70/MT</td>
<td>2.05 T</td>
<td>17.835</td>
<td>0.14</td>
<td>1.218</td>
<td></td>
</tr>
<tr>
<td>Cooling Water</td>
<td>21.74/KT</td>
<td>0.055 KT</td>
<td>1.1957</td>
<td>0.055 KT</td>
<td>1.1957</td>
<td></td>
</tr>
<tr>
<td><strong>Total Utilities</strong></td>
<td><strong>$40.35</strong></td>
<td></td>
<td></td>
<td><strong>$20.77</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| **Total Cost Excluding Labor, Capital & OH** | **$1,260.67** | **$1,536.02** |

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ME Feedstocks

- From Variety of Animal and Vegetable Oils
- Part of Normal Synthesis Route to Fatty Alcohols, Ethoxy Alcohols and Bio-Diesel
- Enjoys Natural Economic Advantage
ME Feedstocks

- Fats or Oils
  - Esterification & Purification
    - Low Pressure Hydrogenation
      - Methylesters
  - High Pressure Hydrogenation
    - Fatty Alcohols
  - Ethoxylation
    - Ethoxy Alcohols
Approximate Production and Use of Natural Fats and Oils

- Vegetable Oils: ~71 Million Metric Tons
- Animal Oils: ~29 Million Metric Tons
- Total Natural Fats and Oils: ~100 Million Metric Tons
- Food: ~80 Million Metric Tons
- Industrial Uses: ~20 Million Metric Tons
  - Animal Feeds: ~8 Million Metric Tons
  - Oleochemical Uses: ~12 Million Metric Tons
MES Surfactant Uses

- **Liquid Household Cleaners** (C\textsubscript{12} to C\textsubscript{14})
  - Dishwash, Fine Fabrics, Hard Surfaces
- **Personal Care** (C\textsubscript{12} to C\textsubscript{14})
  - Shampoos, Bubble Bath, Liquid Hand Soaps, Bar Soap
- **Laundry Powders and Bars**
  - C\textsubscript{1416} used by Lion
  - C\textsubscript{1618} used by Henkel and others
- **Industrial Surfactants**
Detergency Vs. Hardness

Water Hardness (ppm CaCO₃)

Surfactant Concentration 210 ppm
Detergency Vs. Concentration

- C1416 MES
- LAS
- C12 AS

Water Hardness: 54 ppm

Concentration of Surfactant (ppm)

Detergency (%)
Why Isn’t MES in Widespread Use?

- Traditional Process Technology Has Been Inadequate
  - Poor color compared to other anionics
  - Poor yield of MES from feedstock
  - Only low active aqueous paste products
- More complex to manufacture compared to other anionics
Why Isn’t MES in Widespread Use

- **Feed Stock Availability**
  - ME production and refining
  - Price and supply of natural oils

- **Product Formulation**
  - MES is hydrolytically unstable at high pH
  - Requires formulation techniques specific to MES

- **Competition from Bio-fuels for Feedstock**
Making High Quality MES

- **Color**
  - MESA digestion step causes color darker than typical anionics
  - MES requires bleaching to achieve acceptable final color

- **Di-Salt**
  - Undesirable by-product – sulfonated soap
  - Can be a major component
  - Conversion to MES
Methods to Improve Color in MES

- **Feed Stock**
  - Lowest cost method to improve product quality
  - R&B Oil
  - Lower Iodine Value
    - Fractionation
    - Hydrogenation
Methods to Improve Color in MES

- **Sulfonation**
  - Good Mole Ratio Control
  - Color Inhibitor

- **Bleaching – Required for Consumer Products**
  - Sodium Hypochlorite – Unacceptable byproducts
  - Hydrogen Peroxide – Safety Issues but Required for an Acceptable Product
Bleaching Methods

- **Neutral Bleaching**
  - Less Effective
  - Requires Extended Times - Large Storage Vessels

- **Acid Bleaching**
  - Fast and Best Product Color
  - Requires Special Materials of Construction
Di-Salt in MES

- Di-Salt is Sulfonated Soap
- Two Sources in MES Manufacture

\[
\begin{align*}
R-\text{CH-}(\text{C-OCH}_3):\text{SO}_3 \quad \text{(I)} + 3 \text{NaOH} & \rightarrow R-\text{CH-C-ONa} \quad \text{(III)} + 2 \text{H}_2\text{O} + \text{CH}_3\text{OSO}_3\text{Na} \\
\text{SO}_3\text{H} & \quad \text{SO}_3\text{Na} \\
\end{align*}
\]

\[
\begin{align*}
R-\text{CH-}(\text{C-OCH}_3) \quad \text{(II)} + \text{H}_2\text{O} & \rightarrow R-\text{CH-C-ONa} \quad \text{(III)} + \text{CH}_3\text{OH} + \text{H}_2\text{O} \\
\text{SO}_3\text{Na} & \quad \text{SO}_3\text{Na} \\
\end{align*}
\]
Detergency of Di-Salt

75 ppm Mg++

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Impact of Di-Salt

- **Poorer Surfactant Properties**
  - MES has 50% higher detergency
  - MES has similar surface tension at 1/10 conc.

- **Poor Cold and Hard Water Properties**
  - Di-salt has much higher Kraft points
  - Di-salt precipitates even in soft water

- **Di-Salt is a Yield Loss**
  - Blends of di-salt / MES similar to Soap / MES – at much higher cost
Formulation with MES

- **Form of Product Critical for MES**
  - MES hydrolytically unstable
  - Will hydrolyze rapidly if formulation is aqueous and basic

- **Example – Spray Drying**

<table>
<thead>
<tr>
<th>Time</th>
<th>Initial</th>
<th>After Spray Dry</th>
<th>After 1 month</th>
<th>After 2 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Di-Salt</td>
<td>4.40%</td>
<td>33%</td>
<td>89%</td>
<td>98%</td>
</tr>
</tbody>
</table>
Need MES in Dry Form

- Dry Neural Paste to Remove Methanol
- Laundry Powder Formulations
  - Agglomerate / blend to final product
- Detergent Bar Formulation
  - Co-mix molten or powder dry MES
  - Co-extrude / form final product
- Liquid Formulations – Dilute to Desired Concentration
Challenges of MES Production

- High SO$_3$:ME mole ratios and high temperatures for high yields
  - Resulting dark MESA requires bleaching
- Di-salt an undesirable by-product
- Stricter formulation requirements for shelf-stable product
- Safety Issues
  - Peroxides and Methanol
  - Organic Peroxides
Meeting the Challenges

- **Best Practice MES process**
  - MeOH re-esterification w/ $\text{H}_2\text{O}_2$ acid bleaching

- **Critical parameters**
  - Low residual oil, low color
  - Minimal di-salt
  - Neutral dried product
Best Practice MES Process

- Uses Conventional Air/SO$_3$ Film Sulfonation
- Special Acid Digester
- Re-Esterfication with Methanol
- Acid Bleaching with 50% H$_2$O$_2$
- Drying of Neutral MES
- Monitoring Equipment for O2
- Peroxide Control in Off-streams
Acid Bleaching MES Process Flow Diagram

- Sulfur Supply
- SO₃ Gas Generator
- Air Supply
- Optional SO₃ Absorber
- Sulfonation Reactor
- Organic Raw Material
- Effluent Gas Treatment
- Acid Digestion
- Product Drying TTD
- Product
- Bleaching
- Neutralization
- Neutralizing Agent
- Methanol Recovery
- Methanol
- H₂O₂
MES Sulfonation Chemistry

- **Formation of adduct(II) from methyl ester (I):**
  \[
  R-CH_2-C-OCH_3 \text{(I)} + So_3 \quad \text{<----->} \quad R-CH_2-(C-OCH_3):SO_3 \text{(II)}
  \]

- **Sulfonation of adduct(I) to sulfonated adduct(III):**
  \[
  R-CH_2-(C-OCH_3):SO_3 \text{(II)} + So_3 \quad \text{----->} \quad R-CH-(C-OCH_3):SO_3H \text{(III)}
  \]

- **Elimination of SO$_3$ to form MESA(IV):**
  \[
  R-CH-(C-OCH_3):SO_3 \text{(III)} \quad \text{----->} \quad R-CH-C-OCH_3 \text{(IV)} + So_3
  \]

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By-product Sulfonation Chemistry

▲ Dimethyl sulfate (trace)
   \[ \text{CH}_3\text{OSO}_3\text{H} + \text{CH}_3\text{OH} \rightarrow \text{CH}_3\text{OSO}_2\text{OCH}_3 + \text{H}_2\text{O} \]

▲ Dimethyl ether
   \[ \text{CH}_3\text{OSO}_2\text{OCH}_3 + \text{CH}_3\text{OH} \rightarrow \text{CH}_3\text{OSO}_3\text{H} + \text{CH}_3\text{OCH}_3 \]

▲ Reduction of SO$_3$ to SO$_2$, and Oxidation of the alkyl chain:
   \[ \text{SO}_3 + \text{R-C-C-C-C-C-R'} \rightarrow \text{R-C-C-C}=\text{C-C-R'} + \text{SO}_2 + \text{H}_2\text{O} \]

▲ Sulfonation to form Color Bodies
Effect of SO$_3$ Mole Ratio on MESA Color and Free Oil

![Graph showing the effect of SO$_3$ mole ratio on MESA color and free oil](image)
Effect of Mole Ratio & Digestion Temperature on Extractable Oil
Effect of Mole Ratio & Digestion Temperature on Color

Color (5% Klett)

Mole Ratio

Digest Temp

Low

High

4,000

8,000

12,000

16,000

20,000
Effect of Digestion Time & Temperature on Extractable Oil

% Extractable Oil

Low  High

Low

Digest Temp

High

Digest Time

Low

High
Effect of Digestion Time and Temperature on MESA Color
Bleaching Chemistry

- Reaction of sulfonated adduct (III) to MESA (IV)
  \[
  R\text{-CH-(C-OCH}_3\text{):SO}_3\text{H} \text{ (III) + CH}_3\text{OH} \rightarrow R\text{-CH-C-OCH}_3\text{ (IV) + CH}_3\text{OSO}_3\text{H}
  \]

- Reaction with SO\textsubscript{2} to form Sulfuric Acid

- Decomposition of Hydrogen Peroxide
  \[
  2 \text{H}_2\text{O}_2 \rightarrow \text{O}_2 + 2 \text{H}_2\text{O}
  \]

- Epoxidation with Hydrolysis of unsaturates
  \[
  R\text{-C=C + H}_2\text{O}_2 \rightarrow R\text{-C-O-C-R + H}_2\text{O} \rightarrow R\text{-C-O-C-R}
  \]

- Hydrolysis of MESA to Di-Acid
  \[
  R\text{-CH-C-OCH}_3\text{ (IV) + H}_2\text{O} \leftrightarrow R\text{-CH-C-OH (VI) + CH}_3\text{OH}
  \]
Development of Acid/MESA Bleaching Technology

- **Developmental Goals**
  - Eliminate halogen bleaching
  - Decrease sensitivity to feedstock
  - Reduce extremely long bleaching times
  - Reduce di-salt level in product

- **Technical Problems for Aggressive Bleaching**
  - $\text{H}_2\text{O}_2$ decomposed at higher temperatures
  - Highly viscous sulfonic acid during bleaching
  - Hydrolysis to di-acid was favored as bleaching became more aggressive
Aggressive Bleaching Technology

- Alcohol Addition was Increased
  - Decreased viscosity
  - Suppressed hydrolysis
- Non-Metallic or Low-iron Corrosion Resistant alloys
  - Reduced decomposition of hydrogen peroxide
  - Higher temperature operation possible
- Optimum Operating Conditions were Determined
- Part of an Integrated MES Process
Effect of Temp in Metallic Systems

Bleaching Time (min)

5% Klett color

T= 65 C
T= 72 C
T= 80 C

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Non-Metallic Bleaching of MES

- Bleaching Rate Very Temperature Sensitive
- H₂O₂ Decomposition Same at Higher Temperature

![Graph showing bleaching rate and H₂O₂ decomposition](chart.png)
Minimizing Di-Salt

% Yield to Di-Salt

Methanol Addition (%)

H2O2 Conc. (%)
Minimizing Neutral Color

C1618 MES

Color (5% Klett)

Bleach Time (min)

Bleacher Temp (°C)

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Minimizing Unreacted Oil

% Extractable Oil

Mole Ratio

Digest Temp (°C)

1.1
1.2
1.3
1.4
1.5
70
75
80
85
90

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Iodine Value Needed with Aggressive Bleaching

- Only IV is Shown, but Hydroxy Groups Should Have an Equivalent Effect
- Iodine Values Above Two Will Produce Inferior MES
  - Oil levels become excessive at reasonable SO$_3$ mole ratio
  - Large H$_2$O$_2$ requirement increases di-salt
- IVs Below Two Produce Good Quality MES
  IVs Below One Produce Excellent MES
Neutralization Chemistry

- MESA neutralization

\[
\text{R-CH-C-OCH}_3 \text{ (IV)} + \text{NaOH} \rightarrow \text{R-CH-C-OCH}_3 \text{ (VII)} + \text{H}_2\text{O}
\]

- MESA:SO$_3$ adduct neutralization to form Di-Salt

\[
\text{R-CH-} \langle \text{C-OCH}_3 \rangle : \text{SO}_3 \text{ (III)} + 3 \text{NaOH} \rightarrow \text{R-CH-C-ONa (V)} + 2 \text{H}_2\text{O} + \text{CH}_3\text{OSO}_3\text{Na}
\]

- Hydrolysis of MES

\[
\text{R-CH-C-OCH}_3 \text{ (IV)} + 2 \text{NaOH} \rightarrow \text{R-CH-C-ONa (V)} + \text{H}_2\text{O} + \text{CH}_3\text{OH}
\]
MES Hydrolytic Stability

- MES is prone to hydrolysis at high and low pH

Hydrolysis data for C1214 SASME from Stein and Baumann, JAOCs, September, 1975

- Concern in Neutralization is high point temperatures and pH
Product Characteristics

- Flake has excellent characteristics
  - Non-clumping in storage at 5% moisture
  - Excellent flowability
  - Non-dusting

- Formed Flake can be ground as needed
MES Drying: Residual Water

% Residual H2O

Fed Rate of SASME (Kg/hr)

Inlet Feed Temperature (°C)
Minimizing Residual Methanol

% Residual Methanol

Inlet Feed Temperature (°C)

Feed Rate of SASME (Kg/hr)

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Pilot Plant ME Sulfonation Tests

- Over 25 different ME feeds sulfonated
  - Chemithon MES pilot plant, Seattle U.S.A

- Will present the results for five ME’s
  - All products stripped or dried
  - Includes low quality, low cost, unsaturated ME’s
    - Cheap source of surfactant

- Building a product database for a wide variety of feedstocks

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# Methyl Ester Comparison

<table>
<thead>
<tr>
<th>Carbon chain length (wt%)</th>
<th>Coconut C12-C14</th>
<th>Palm Kernel C8-C18</th>
<th>Palm Stearin C16-C18</th>
<th>Tallow C16-C18</th>
<th>Soya C18</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;C10</td>
<td>0.0</td>
<td>5.2</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>C10</td>
<td>0.0</td>
<td>4.4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>C12</td>
<td>71.5</td>
<td>51.0</td>
<td>0.2</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>C14</td>
<td>28.0</td>
<td>15.1</td>
<td>1.5</td>
<td>3.1</td>
<td>0.0</td>
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<tr>
<td>C16</td>
<td>0.6</td>
<td>7.2</td>
<td>65.4</td>
<td>31.6</td>
<td>10.4</td>
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<td>C17</td>
<td>0.0</td>
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<td>0.0</td>
<td>1.2</td>
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<tr>
<td>C18</td>
<td>0.0</td>
<td>17.2</td>
<td>32.2</td>
<td>63.6</td>
<td>89.6</td>
</tr>
<tr>
<td>&gt;C18</td>
<td>0.0</td>
<td>0.0</td>
<td>0.7</td>
<td>1.8</td>
<td>0.0</td>
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</table>

<table>
<thead>
<tr>
<th>Property</th>
<th>Coconut 222</th>
<th>Palm Kernel 227</th>
<th>Palm Stearin 279</th>
<th>Tallow 287</th>
<th>Soya 295</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular weight</td>
<td>222</td>
<td>227</td>
<td>279</td>
<td>287</td>
<td>295</td>
</tr>
<tr>
<td>Iodine value (cg iodine/g ME)</td>
<td>0.1</td>
<td>1.4</td>
<td>0.3</td>
<td>0.1</td>
<td>1.1</td>
</tr>
<tr>
<td>Carboxylic Acid (wt%)</td>
<td>0.1</td>
<td>0.2</td>
<td>n/a</td>
<td>0.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Acid value (mg KOH/g ME)</td>
<td>0.2</td>
<td>0.5</td>
<td>0.4</td>
<td>3.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Saponification no. (mg KOH/g ME)</td>
<td>252</td>
<td>240</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Freeze Point (C)</td>
<td>0</td>
<td>18</td>
<td>26</td>
<td>31</td>
<td>33</td>
</tr>
<tr>
<td>Moisture (wt%)</td>
<td>0.03</td>
<td>0.03</td>
<td>0.02</td>
<td>0.04</td>
<td>0.01</td>
</tr>
</tbody>
</table>

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## Dried MES Product Quality

<table>
<thead>
<tr>
<th></th>
<th>Coconut C12-C14</th>
<th>Palm Kernel C8-C18</th>
<th>Palm Stearin C16-C18</th>
<th>Tallow C16-18</th>
<th>Soya C18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium methyl ester sulfonate ($\alpha$-MES)</td>
<td>71.5</td>
<td>69.4</td>
<td>83.0</td>
<td>77.5</td>
<td>75.7</td>
</tr>
<tr>
<td>Disodium carboxy sulfonate (di-salt)</td>
<td>2.1</td>
<td>1.8</td>
<td>3.5</td>
<td>5.2</td>
<td>6.3</td>
</tr>
<tr>
<td>Methanol (CH$_3$OH)</td>
<td>0.48</td>
<td>0.60</td>
<td>0.07</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>Hydrogen peroxide (H$_2$O$_2$)</td>
<td>0.10</td>
<td>0.04</td>
<td>0.13</td>
<td>0.15</td>
<td>0.05</td>
</tr>
<tr>
<td>Water (H$_2$O)</td>
<td>14.0</td>
<td>15.2</td>
<td>2.3</td>
<td>2.9</td>
<td>1.4</td>
</tr>
<tr>
<td>Petroleum ether extractables (PEX)</td>
<td>2.6</td>
<td>2.7</td>
<td>2.4</td>
<td>4.8</td>
<td>7.2</td>
</tr>
<tr>
<td>Sodium carboxylate (RCOONa)</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Sodium sulfate (Na$_2$SO$_4$)</td>
<td>1.2</td>
<td>1.8</td>
<td>1.5</td>
<td>2.3</td>
<td>2.4</td>
</tr>
<tr>
<td>Sodium methyl sulfate (CH$_3$OSO$_3$Na)</td>
<td>8.0</td>
<td>8.4</td>
<td>7.2</td>
<td>7.7</td>
<td>2.5</td>
</tr>
<tr>
<td>10% pH</td>
<td>5.0</td>
<td>5.3</td>
<td>5.3</td>
<td>5.4</td>
<td>5.8</td>
</tr>
<tr>
<td>Klett color, 5% active ($\alpha$-MES + di-salt)</td>
<td>30</td>
<td>310</td>
<td>45</td>
<td>180</td>
<td>410</td>
</tr>
</tbody>
</table>

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MES Product Specifications

- **Color of MES:**
  - < 100 (5% Klett) usually is adequate, < 20 is possible

- **Extractable Oils in MES:**
  - < 4 ± 1% AMB

- **Volatile Oils in MES:**
  - < 2 ± 1% AMB

- **By-product Di-Salt:**
  - Less than 6% AMB

- **Actives concentration:**
  - 25% to 85% (alcohol free)

- **Residual Alcohol to Required spec.**
MES Dried Product

- Palm Kernel (C8-C18)
- Coconut (C12-C14)
- Soya (C18)
- Palm Stearin (C16-C18)
- Tallow (C16-C18)
MES Product

<table>
<thead>
<tr>
<th>C16 Sodium Methylester Sulfonate (Feedstock MW 270.2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Active</td>
</tr>
<tr>
<td>Disalt (100% Al)</td>
</tr>
<tr>
<td>wt % Soap</td>
</tr>
<tr>
<td>5% Active Klett</td>
</tr>
<tr>
<td>% Pet Ether Extractable (100% Al)</td>
</tr>
<tr>
<td>wt % H2O</td>
</tr>
<tr>
<td>wt % Methanol</td>
</tr>
<tr>
<td>Condition 764; dried Feb. 5, 2003</td>
</tr>
</tbody>
</table>
MES Product Quality

- MES Active (%): 88.7%
- Disalt (100% AI basis): 5.6%
- Color (5% Klett): 18
- PEE (100% AI basis): 2.00
- Water (%): 2.3%
- Methanol (%): < 0.1%
MES Dryers and Chilled Belt
MES Profitability

- Savings est. ~US$275/MT vs. LABS
- Potential Annual Savings
  US$11,000,000 for a 40,000MT/y plant
Conclusion

- MES is a Viable Alternative Surfactant
  - Still Show Lower Cost than LABS
  - >100 Million MT/y Produced in North America
  - Proven Process Technology
  - Successful Use in Detergent Market