Dirt: any foul or filthy substance, as mud, grime, or excrement.

From old Norse word drit
Outline

- Introduction
- Material specifications
- Understanding performance
- Summary
Introduction

- Unpaved roads
  - Function
  - Problems
  - Sustainability
- Range of management issues primarily funding and unpaved road expertise
- “Unpaving” projects are adding to the inventory
Air Pollution (PM10 & PM2.5)

Air Pollution (Fines Lost)

- Unpaved Roads
  - PM10: 8,000,000 Tons
  - PM2.5: 1,000,000 Tons
- Paved Roads
  - PM10: 2,000,000 Tons
- Construction
  - PM10: 1,000,000 Tons

Fines Lost

- In perspective
  - > 8 million tons per year
  - 267,000 30T trucks
- Fines loss from erosion (1mm/yr)
  - 14 million tons per year
Key National Issues

- No “owner” of unsealed road guides and specifications
- Often no owner of the problem
  - Oil, wind, solar, ethanol, etc.
- Limited unpaved road expertise and funding for
  - Road management
  - Research
- Fragmented products industry marketing solutions
- So what?
Outline

- Introduction
- Material specifications
- Understanding performance
- Summary
Key National Issues

- Sourcing unpaved road materials
  - Environmental constraints
  - Commercial sources dominate
  - Focus on base, asphalt, and concrete

- Material specifications
  - Everybody has one
  - Most based on AASHTO subbase requirements and adapted for local conditions
  - Most use grading envelope and PI range
  - Many specify non-plastic materials

- Construction specifications
  - Not often followed/enforced
  - Considered as an unnecessary expense
  - Life of gravel wearing course significantly reduced
Gravel Roads
Maintenance and Design Manual

South Dakota Local Transportation Assistance Program (SD LTAP)
November 2009
Guidelines?
Why Read Guidelines?
Why Read Guidelines?
Gravel Roads

Maintenance and Design Manual

South Dakota Local Transportation Assistance Program (SD LTAP)

November 2000
### Guidelines & Specifications – US

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Guidelines</th>
<th>FHWA Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FHWA</td>
<td>USFS</td>
</tr>
<tr>
<td>Sieve (mm. [US])</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FHWA</td>
<td>USFS</td>
</tr>
<tr>
<td></td>
<td>Haul</td>
<td>General Use</td>
</tr>
<tr>
<td>25</td>
<td>100</td>
<td>97 – 100</td>
</tr>
<tr>
<td>19</td>
<td>90 – 100</td>
<td>100</td>
</tr>
<tr>
<td>4.75</td>
<td>50 – 78</td>
<td>97 – 100</td>
</tr>
<tr>
<td>2.36</td>
<td>37 – 67</td>
<td>76 – 89</td>
</tr>
<tr>
<td>0.425</td>
<td>13 – 35</td>
<td>43 – 53</td>
</tr>
<tr>
<td>0.075</td>
<td>4 – 15</td>
<td>23 – 32</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>15 – 23</td>
</tr>
<tr>
<td></td>
<td>(3/4)</td>
<td>10 – 16</td>
</tr>
<tr>
<td></td>
<td>(#4)</td>
<td>or 6 - 12</td>
</tr>
<tr>
<td></td>
<td>(#8)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(#40)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(#200)</td>
<td></td>
</tr>
<tr>
<td>Plasticity Index</td>
<td>4 – 12</td>
<td>2 – 9 if 0.075 is &lt;12%</td>
</tr>
</tbody>
</table>

1 Range for 0.075 mm (#200) sieve is 6.0 to 12.0% if the PI is greater than 0
Guidelines & Specifications – SA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle size distribution factor ($G_c$)</td>
<td>15 – 35</td>
</tr>
<tr>
<td>Weighted clay factor ($S_p$)</td>
<td>100 – 365</td>
</tr>
<tr>
<td>Maximum size (in.)</td>
<td>1.5 – 2.0</td>
</tr>
<tr>
<td>Strength factor (CBR)</td>
<td>&gt;15</td>
</tr>
<tr>
<td>Hardness factor (TIV)</td>
<td>20 – 65</td>
</tr>
</tbody>
</table>

1 $G_c = \frac{((P_1 - P#8) \times P#4)}{100}$

2 $S_p = LS \times P#40$ or $\frac{1}{2} PI \times P#40$

** Calibrate for local use, conditions and test methods! Performance is always dependent on construction and maintenance quality!**
Linear Shrinkage

Shrinkage
Outline

- Introduction
- Material specifications
- Understanding performance
- Summary
# Understanding Performance - USFS

## GRAIN SIZE DISTRIBUTION
(Gradation Curve)

### SIEVE ANALYSIS

Table 3-18—Aggregate wear and durability requirements.

<table>
<thead>
<tr>
<th>Test Requirement</th>
<th>Base and Subbase</th>
<th>Surfacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Angeles Abrasion, AASHTO T 96</td>
<td>40 % maximum</td>
<td>40 % maximum</td>
</tr>
<tr>
<td>Sodium Sulfate Soundness Loss, AASHTO T 104</td>
<td>12 % maximum</td>
<td>12 % maximum</td>
</tr>
<tr>
<td>Durability Index (coarse and fine), AASHTO T 210</td>
<td>35 minimum</td>
<td>35 minimum</td>
</tr>
<tr>
<td>Fractured Faces, ASTM D 5821</td>
<td>50 % minimum</td>
<td>75 % minimum</td>
</tr>
<tr>
<td>Liquid Limit, AASHTO T 89</td>
<td>25 maximum</td>
<td>35 maximum</td>
</tr>
<tr>
<td>Plastic Limit, AASHTO T 90</td>
<td>Nonplastic</td>
<td>2 to 9 (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 2 (2)</td>
</tr>
</tbody>
</table>

**Note:**

(1) If the percent passing the 75 μm sieve is less than 12 percent.
(2) If the percent passing the 75 μm sieve is greater than 12 percent.

---

**PARTICLE SIZE IN MILLIMETERS**

<table>
<thead>
<tr>
<th>COBBLE: Coarse</th>
<th>Fine</th>
<th>COBBLE: Coarse</th>
<th>Medium</th>
<th>Fine</th>
<th>SILT</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRAVEL</td>
<td></td>
<td>GRANULAR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAND</td>
<td></td>
<td>SILT</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

UCPRC
Understanding Performance - SA

Grading coefficient

Increasing coarseness / increasing gap

Erodible

Good

Washboards and ravels

Slippery and dusty

Shrinkage product

Increasing plasticity
Understanding Performance - SA

- Increasing coarseness / increasing gap
- Shrinkage product
- Grading coefficient

- Slippery and dusty
- Erodible
- Washboards and ravels
- Good but
- Really good
- Good but dusty
- Ravels

Calibrate for local use!
Understanding Performance

Slippery and dusty

Erosion

Good

Corrugates and ravels

Grading coefficient

Shrinkage product

Erosion

0 15 35

0 100 365

0 100 365

UCPRC
Erosion
Understanding Performance

- Shrinkage product
- Slippery and dusty
- Erodible
- Good
- Ravels
- Corrugates and ravel
- Grading coefficient
- Corrugates and ravel

* UCPRC
Corrugations and Ravelling
Understanding Performance

- Shrinkage product
- Slippery and dusty
- Erodible
- Good
- Corrugates and ravels
- Grading coefficient
- Ravels

Grading coefficient:
- Good
- Corrugates and ravels
- Erodible
- Slippery and dusty

Shrinkage product:
- 365
- 100
- 0
Ravelling
Understanding Performance

**Slippery and dusty**

- Erodible
- Good
- Ravels

**Corrugates and ravels**

- Grading coefficient
- Shrinkage product

<table>
<thead>
<tr>
<th>Grading coefficient</th>
<th>Shrinkage product</th>
</tr>
</thead>
<tbody>
<tr>
<td>365</td>
<td>*</td>
</tr>
<tr>
<td>100</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Slipperiness
Understanding Performance

- Grading coefficient
- Shrinkage product

Increasing coarseness / increasing gap

- Really good
- Good but dusty
- Slippery and dusty
- Erodible
- Washboards and ravels
- Ravels

Increasing plasticity
## Guidelines & Specifications - US

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FHWA</th>
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</tr>
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<tbody>
<tr>
<td><strong>Sieve Size (US)</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1 in.</td>
<td>100</td>
<td>97 – 100</td>
<td>100</td>
</tr>
<tr>
<td>#4</td>
<td>50 – 78</td>
<td>43 – 53</td>
<td>51 – 63</td>
</tr>
<tr>
<td>#8</td>
<td>37 – 67</td>
<td>23 – 32</td>
<td>28 – 39</td>
</tr>
<tr>
<td>#40</td>
<td>13 – 35</td>
<td>15 – 23</td>
<td>19 – 27</td>
</tr>
<tr>
<td><strong>Plasticity Index</strong></td>
<td>4 – 12</td>
<td>2 – 9 if #200 is &lt;12%</td>
<td>&lt;2 if #200 is &gt;12%</td>
</tr>
<tr>
<td><strong>Grading Coefficient</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High range</td>
<td>26</td>
<td>36</td>
<td>38</td>
</tr>
<tr>
<td>Mid range</td>
<td>31</td>
<td>34</td>
<td>38</td>
</tr>
<tr>
<td>Low range</td>
<td>32</td>
<td>32</td>
<td>37</td>
</tr>
<tr>
<td>Worst case</td>
<td>49</td>
<td>41</td>
<td>45</td>
</tr>
<tr>
<td><strong>Shrinkage Product</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High range</td>
<td>420</td>
<td>207 / 23</td>
<td>243 / 27</td>
</tr>
<tr>
<td>Mid range</td>
<td>192</td>
<td>105</td>
<td>126</td>
</tr>
<tr>
<td>Low range</td>
<td>26</td>
<td>30</td>
<td>38</td>
</tr>
<tr>
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<td>23</td>
<td>27</td>
</tr>
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<tr>
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<tr>
<td>Worst case</td>
<td><strong>49</strong></td>
<td><strong>41</strong></td>
</tr>
<tr>
<td><strong>Shrinkage Product:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High range (100 – 365)</td>
<td>420</td>
<td><strong>207</strong></td>
</tr>
<tr>
<td>Mid range</td>
<td>192</td>
<td>105</td>
</tr>
<tr>
<td>Low range</td>
<td><strong>26</strong></td>
<td><strong>30</strong></td>
</tr>
<tr>
<td>Worst case</td>
<td><strong>420</strong></td>
<td><strong>23</strong></td>
</tr>
</tbody>
</table>

*Note: The USFS values for high range are given in bold for emphasis.*
Discussion

Stabilization and Rehabilitation Measures for Low-Volume Forest Roads
Discussion

- Materials that meet US federal guidance and specifications may still perform badly
  - Only two of the 14 potential in-spec materials are likely to perform well
  - Most materials are likely to washboard and ravel
  - Some materials are likely to be slippery/impassable when wet
  - Problematic for inexperienced engineers
  - Aggregate suppliers and contractors still meet the spec

- Importance of using PI (weighted) and grading together is clear
Outline

- Introduction
- Material specifications
- Understanding performance
- Summary
Summary

- Current US specs and guidance can be misleading
- Use a simple analysis tool for understanding unpaved road material performance
  - Proven to be effective in Africa, Australasia, S.E. Asia, and USA
- Use any specification, but understand performance
  - Select the best possible material
  - Blend
  - Construct properly
  - Change maintenance program
  - Improve with chemicals
- Testing is **not** expensive and will save money
Thank-you

www.ucprc.ucdavis.edu    www.unpavedroadsinstitute.org

djjones@ucdavis.edu
MAKING BETTER GRAVEL ROADS
PART 2: CHEMICAL TREATMENTS
AS PART OF A ROAD MANAGEMENT STRATEGY

David Jones

1 University of California Pavement Research Center

CEAC Annual Meeting
Palm Springs, December 01, 2016
DUST KILLS!
Keep your distance
Australian Version

DON'T DUST ME OUT!
IDLE PAST
OR YOUR ASSHOLE
Outline

- Introduction
- Status quo
- Additive categories
- Additive selection
- Summary
Introduction

- Gravel road problems
  - Fines loss (dust)
  - Wet weather passability
  - Safety
  - Environment

- Recommended approach
  - Focus on addressing above issues
  - Start with building the best possible road
  - Use chemical treatments to keep a good road good
  - Set up a simple GRMS
  - Justify approach through extended life of road and reduced maintenance
Outline

- Introduction
- Status quo
- Additive categories
- Additive selection
- Summary
Status Quo

- Timeline for road additive development
  - Chlorides since 1907
  - Lignosulfonates since 1913
  - Other organic non-petroleum and petroleum products since the 1930's
  - Electrochemicals since 1970’s
  - Enzymes and synthetic polymers since 1980’s
  - Synthetic fluids and mineral oils since 1990’s
Status Quo

- Research and implementation
  - US Forest Service
  - US Army Corps of Engineers
  - Other US
  - International

- Where are we after 110 years?
  - Fragmented industry selling mostly proprietary products
  - No specifications
  - Poor track record/skepticism
Outline

- Introduction
- Status quo
- Additive categories
- Additive selection
- Summary
Additive Categories

- Fines retention/surface stabilization
  - Water and water with surfactants
  - Water absorbing
  - Organic non-petroleum or natural polymers
  - Organic petroleum

- Stabilization/strength improvement
  - Organic petroleum
  - Synthetic polymer emulsions
  - Concentrated liquid stabilizers
Calibrate for local use!

Performance Prediction

- Increasing coarseness / increasing gap
- Increasing plasticity

Shrinkage product

Grading coefficient

- Slippery and dusty
- Really good
- Erodible
- Really good
- Washboards and ravel
- Ravels

Increasing coarseness / increasing gap
Water Absorbing

- **Water Absorbing**:
  - **Increasing plasticity**: Increasing coarseness / increasing gap
  - **Shrinkage product**: Increasing coarseness / increasing gap

- **Grading coefficient**:
  - **Erodible**: Good but dusty
  - **Slippery and dusty**: Fair with maintenance
  - **Ravels**: Good
  - **Washboards and ravels**: Good but dusty

- **Legend**:
  - **Green**: Good
  - **Orange**: Fair with maintenance
Water Absorbing
Organic and Synthetics

- **Grading coefficient**
- **Shrinkage product**

- Increasing coarseness / increasing gap
- Increasing plasticity

- **Slippery and dusty**
- **Erodible**
- **Ravels**
- **Washboard and ravel**

- Good
- Fair with maintenance

- Increasing coarseness / increasing gap
Conc. Liquid Stabilizers

- **Grading coefficient**
- **Shrinkage product**

Increasing coarseness / increasing gap

- **Erodible**
  - Good, may be dusty

- **Ravels**
  - Slippery and dusty

- **Washboard and ravel**
  - Good
  - Fair with maintenance
Outline

- Introduction
- Status quo
- Additive categories
- Additive selection
- Summary
Current Practice

- Currently based on:
  - Experience
  - Guides
    - US Army Corps of Engineers
    - FPInnovations (Canada)
    - FHWA
  - Preferred lists
  - Marketing by suppliers
Background

- 1999 US Forest Service Guide
- New developments since 1999
  - More products (±200 in USA)
  - More/refined categories
    - Dust control vs. stabilization
  - Additional experience
    - Documented field trials
  - Requests for more detailed guidance, preferably with ranking
New FHWA (UCPRC) Guide

- Ten-step process
- Have a clear objective
  - Temporary dust control
  - Long-term fines preservation
  - All weather passability
  - Unpaved road management
    - Reduced maintenance
    - Extended gravel replacement intervals
- Manual, spreadsheet, and web-based
- Focused on keeping a good road good
## Unpaved Road Chemical Treatment Selection Tool

### Road ID: EG1  Details: Road from X to Y

#### Material Test Results

<table>
<thead>
<tr>
<th>% Passing</th>
<th>100</th>
<th>% Passing</th>
<th>40</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Passing</td>
<td>45</td>
<td>% Passing</td>
<td>200</td>
<td>15</td>
</tr>
<tr>
<td>% Passing</td>
<td>35</td>
<td>PI</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

#### Objective

- **Short-term dust control** (spray-on)
- **Long-term fines preservation** (spray-on)
- **Long-term fines preservation** (mix-in)
- **Long-term stabilization** (mix-in)

### Roadway Parameters

- **Traffic (AADT):** < 100
- **Climate:** Damp-to-Dry

### Treatment Ratings

<table>
<thead>
<tr>
<th>Treatment</th>
<th>TR</th>
<th>CL</th>
<th>PI</th>
<th>FC</th>
<th>HV</th>
<th>SG</th>
<th>SC</th>
<th>Rating</th>
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</thead>
<tbody>
<tr>
<td>Calcium Chloride</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>0</td>
<td>0</td>
<td>1.0</td>
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<tr>
<td>Magnesium Chloride</td>
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<td>1</td>
<td>1</td>
<td>1</td>
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<td>0</td>
<td>0</td>
<td>1.0</td>
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<td>Glycerin Based</td>
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<td>1.0</td>
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<td>Lignosulfonate</td>
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<td>Molasses/Sugar</td>
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<td>1</td>
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<tr>
<td>Tall Oil</td>
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<td>1</td>
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<td>0</td>
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<td>Base Oil</td>
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<tr>
<td>Synthetic Fluid</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.0</td>
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<tr>
<td>Synthetic Fluid + Binder</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.0</td>
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<tr>
<td>Sodium Chloride Brine</td>
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<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.0</td>
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<tr>
<td>Asphalt Emulsion</td>
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<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.1</td>
</tr>
<tr>
<td>Synthetic Polymer</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.4</td>
</tr>
<tr>
<td>Water</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>NA</td>
</tr>
<tr>
<td>Water + Surfactant</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>NA</td>
</tr>
<tr>
<td>Concentrated Liquid Stabilizer</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>NA</td>
</tr>
<tr>
<td>Bentonite</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>NA</td>
</tr>
</tbody>
</table>

---

**Legend:**

- **TR:** Traffic
- **CL:** Climate
- **PI:** Plasticity
- **FC:** Fines Content
- **HV:** More Than 10% Trucks
- **SG:** Steep Grades
- **SC:** Sharp Curves
- **Rating:** Treatment Performance Ratings
Treatment Selection Tools

- Specifications
  - Example specification language to cover all product sub-categories in terms of procurement, environmental and application
- Based on certificate of compliance for procurement
  - Sub-category
  - Verifications
    - Meets category specifications
    - Safety data sheet
    - Environmental requirements
- Use as basis for QC/QA
## Example Provisional Specification: Calcium Chloride Solution

Clear odorless liquid intended for fines preservation, dust control and/or stabilization of unpaved roads. It has the following properties in its undiluted state.

<table>
<thead>
<tr>
<th>Test Parameter</th>
<th>Suggested Acceptance Limits</th>
<th>Suggested Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium chloride content</td>
<td>28 – 42%</td>
<td>ASTM E449</td>
</tr>
<tr>
<td>Total magnesium as MgCl₂</td>
<td>&lt; 6.0%</td>
<td>ASTM E449</td>
</tr>
<tr>
<td>Total alkali chlorides as NaCl</td>
<td>&lt; 6.0%</td>
<td>ASTM E449</td>
</tr>
<tr>
<td>Calcium hydroxide content</td>
<td>&lt; 0.2%</td>
<td>ASTM E449</td>
</tr>
<tr>
<td>pH (5% solution)</td>
<td>7.0 – 9.0</td>
<td>ASTM D1293</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>1.28 – 1.44</td>
<td>ASTM D1429</td>
</tr>
</tbody>
</table>

**Notes**

1. ASTM D98/AASHTO M144

## Example Provisional Specification: Lignosulfonate: Calcium

Dark brown lignin-based liquid or powder with woody odor derived from the wood pulping using the sulfite process used in the manufacture of cellulose products and designed for fines preservation, dust control and/or stabilization of unpaved roads. It has the following properties in its undiluted/undissolved state.

<table>
<thead>
<tr>
<th>Test Parameter</th>
<th>Suggested Acceptance Limits</th>
<th>Suggested Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin sulfonate content (ready to use)</td>
<td>&gt; 25%</td>
<td>ASTM D4900</td>
</tr>
<tr>
<td>Residue (total solids content)</td>
<td>≥ 52%</td>
<td>ASTM D4903/D2834</td>
</tr>
<tr>
<td>Lignin sulfonated content of residue</td>
<td>&gt; 50%</td>
<td>-</td>
</tr>
<tr>
<td>Reducing sugars content of residue</td>
<td>&gt; 25% of dry weight</td>
<td>ASTM D5896/D6406</td>
</tr>
<tr>
<td>pH</td>
<td>6.0 – 9.0</td>
<td>ASTM D1293</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>≥ 1.20</td>
<td>ASTM D1429</td>
</tr>
<tr>
<td>Absolute viscosity (Brookfield)</td>
<td>&lt; 1,000 cP @ 77°F (25°C)</td>
<td>ASTM D2196</td>
</tr>
</tbody>
</table>
Outline

- Introduction
- Status quo
- Additive categories
- Additive selection
- Summary
Summary

- Huge selection of additives
- There are no wonder products
- Select treatment based on
  - Problem/objective/capability
  - Traffic, climate and materials
  - Cost-benefit
  - Vendor credibility
- Understand performance
- Apply and maintain appropriately
- Testing is not expensive and will save money!
Thank-you

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