Safety-Kleen Eco Addz (VDB’s)
Analysis Binder & Mix

Michigan DOT
What is RHVDB

- 3.5 Billion liters of used oil produced every year in North America.
  - 83% is burned as fuel
  - 17% re-refined
  - Re-refining produces 75% base oil, 12% fuel oil and 12% residue. Residue used to modify Asphalt

- RHVDO
  - Re-refined Heavy Vacuum Distillate Bottoms is the 12%.
The Refinery
The Refining Process

USED OIL FEEDSTOCK → DEHYDRATION → FUEL STRIPPING → VACUUM DISTILLATION → HYDROTREATING

GUARD TANKS FOR QUALITY TESTING

INDUSTRIAL FUELS → VACUUM DISTILLATION BOTTOMS → RE-REFINED OIL BASE STOCKS

ECO POWER

safety-kleen.

PROTECTION | CHOICES | PEOPLE
MAKE GREEN WORK
Re-refined Product
Why is RVHDB Used

- There is an increased demand for softer grade asphalt binders such as PG 58-28, 52-34.
  - Increased RAP usage
  - Use of RAS
    - Increased demand for improved low temperature grades to reduce cracking.
- Limits on the availability of crudes to produce softer grade straight binders.
Concerns with the use of RHVDB

- Does RHVDB negatively affect binder aging?
- Does RHVDB affect moisture sensitivity?
- Does RHVDB have separation issues?
List of Asphalt binders and RHVDB’s used in the study

<table>
<thead>
<tr>
<th>Asphalt Binder</th>
<th>RHVDO</th>
<th>Blend percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marathon; Detroit, MI</td>
<td>Safety-Kleen; East Chicago, IL RHVDB 1</td>
<td>0 2 4 6 8 20</td>
</tr>
<tr>
<td></td>
<td>Safety-Kleen; Breslau, Ontario, Canada RHVDB 2</td>
<td>0 2 4 6 8 20</td>
</tr>
<tr>
<td>BP; Calumet, IL</td>
<td>Safety-Kleen; East Chicago, IL RHVDB 1</td>
<td>0 2 4 6 8 20</td>
</tr>
<tr>
<td></td>
<td>Safety-Kleen; Breslau, Ontario, Canada RHVDB 2</td>
<td>0 2 4 6 8 20</td>
</tr>
</tbody>
</table>
Component makeup of the 2 RHVDB’s used in this study

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>RHVDB1</td>
</tr>
<tr>
<td>Basic Composition: As Received</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash, %</td>
<td>AASHTO T 111</td>
<td>5.7</td>
</tr>
<tr>
<td>Component Fractions, %</td>
<td>Asphaltenes</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Polar Aromatics</td>
<td>44.7</td>
</tr>
<tr>
<td></td>
<td>Naphthene Aromatics</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Saturates</td>
<td>52.7</td>
</tr>
<tr>
<td>Wax, %</td>
<td>EN 12606-1</td>
<td>0.28</td>
</tr>
<tr>
<td>Solubility, %</td>
<td>ASTM D 2042</td>
<td>99.3</td>
</tr>
</tbody>
</table>
RHVDB Components.

- These Materials contained no Wax.
- There are no Naphthene Aromatics.
- Basic make-up Saturates and Polar Aromatics.
Component makeup of the 2 asphalt binders used in this study

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Marathon</th>
<th>BP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash, %</td>
<td>AASHTO T 111</td>
<td>0.04</td>
<td>0.06</td>
</tr>
<tr>
<td>Solubility, %</td>
<td>ASTM D 2042</td>
<td>99.98</td>
<td>99.94</td>
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<tr>
<td>Component Fractions, %</td>
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<td></td>
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<tr>
<td>Asphaltenes</td>
<td>ASTM D 4124, SARA Fractions by Iatroscan</td>
<td>14.9</td>
<td>14.2</td>
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<tr>
<td>Polar Aromatics</td>
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<td>39.7</td>
<td>39.7</td>
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<tr>
<td>Naphthene Aromatics</td>
<td></td>
<td>34.6</td>
<td>36.9</td>
</tr>
<tr>
<td>Saturates</td>
<td></td>
<td>10.8</td>
<td>9.9</td>
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</table>
AASHTO Table 1 Continuous Grade for base asphalts and various RHVDB blends.

<table>
<thead>
<tr>
<th>Lab Blends %</th>
<th>AASHTO M 320, Table 1, PG continuous grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Marathon PG 64-22 w/RHVDB 1</td>
<td>67.3</td>
</tr>
<tr>
<td>Marathon PG 64-22 w/RHVDB 2</td>
<td>68.3</td>
</tr>
<tr>
<td>BP PG 64-22 w/RHVDB 1</td>
<td>65.9</td>
</tr>
<tr>
<td>BP PG 64-22 w/RHVDB 2</td>
<td>66.0</td>
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</table>
AASHTO Table 2 Continuous Grade for base asphalts and various RHVDB blends.

<table>
<thead>
<tr>
<th>Lab Blends %</th>
<th>AASHTO M 320, Table 2, PG continuous grade</th>
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<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Marathon w/RHVDB 1</td>
<td>PG</td>
</tr>
<tr>
<td>Marathon w/RHVDB 2</td>
<td>PG</td>
</tr>
<tr>
<td>BP w/RHVDB 1</td>
<td>PG</td>
</tr>
<tr>
<td>BP w/RHVDB 2</td>
<td>PG</td>
</tr>
</tbody>
</table>
RHVDB affect on high temp grade

- The effect on the high temperature grade is base binder, RHVDB dependent.
  - RHVDB 1 reduced the high temperature more than RHVDB 2.
  - Likely due to higher saturates in RHVDB 1.
  - There is minor differences between Marathon and BP binders.
BP RHVDB 1 ASSHTO Table 1 and Table 2 Continuous Low Temp Grade

Continuous Grade vs % RHVDB

- Continuous Grade vs % RHVDB
- Table 1 (Blue Diamond)
- Table 2 (Red Square)

Equations:

- $y = -0.1787x - 26.342$
  - $R^2 = 0.8915$
- $y = -0.4045x - 25.537$
  - $R^2 = 0.8557$
RHVDB affect on Intermediate DSR Marathon & RHVDB 1

\[ y = -0.6147x + 21.871 \]
\[ R^2 = 0.9609 \]
Linear trend 20hr/PAV

\[ y = -0.5627x + 23.901 \]
\[ R^2 = 0.9821 \]
Linear trend 35hr/PAV

Continuous grade °C
RHVDO %

20hr/PAV
35hr/PAV
RHVDB Affect on Low Temp Properties

- RHVDB reduced the low temperature grades of the base binders.
- Much smaller affect on Table 1 compared to Table 2.
- BBR m value not effected compared to stiffness
- DDT strength not effected
- DTT strain at failure increased
- Extended PAV conditioning caused little change in low temperature properties.
RHVDB affect on Intermediate DSR properties

- RHVDB reduced the Intermediate DSR values.
- Linear relationship between % RHVDB and reduction.
- Rate of aging is controlled by the base asphalt.
- RHVDB does not increase aging.
SARA fractions of the Asphalt RHVDB Blends

- The SARA fractions reflected the rheological properties of the binder blends.

- Minor reduction asphaltenes with larger increases in saturates and polar aromatics

- Change in fractions controlled by the base binder.
Conclusions

- The SARA fractions of the RHVDB’s indicated that the material is primarily made-up of half and half polar aromatics and saturates.

- The addition of RHVDB to the asphalt binder reduces the high, intermediate and low temperature properties of the asphalt binder. The extent of the reduction is binder and RHVDB dependent. The change in properties was linearly related to the percent addition of RHVDB.
Conclusions (continued)

- Rheological testing indicated that changes in properties from PAV conditioning was controlled by the base asphalt properties.

- SARA fractions of the asphalt binder RHVDB blends verified the results of the rheological testing. The addition of the RHVDB reduced the asphaltenes in the blends reducing he binder stiffness.
Mix Testing of RHVDB Modified Material

- Use two mixes from U. Illinois Moisture damage study N70, N90 mixes, 70 gyration and 90 gyration Mixes
- Use Illinois stone, Dolomitic Limestone
- Modify a PG 64-22 with 2, 4, 6 & 10% RHVDB
- Modify a PG 64-22 with 46-34 to produce 58-22 control for RHVDB binders.
## Binders Developed for Mix Testing

<table>
<thead>
<tr>
<th>Binder Blend</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP PG64-22</td>
<td>Control</td>
</tr>
<tr>
<td>BP PG64-22 with 2% EcoAddz</td>
<td>2% EcoAddz</td>
</tr>
<tr>
<td>80% BP PG64-22 blended with 20% BP PG46-34</td>
<td>Control&lt;sub&gt;4&lt;/sub&gt; and Control&lt;sub&gt;14&lt;/sub&gt;</td>
</tr>
<tr>
<td>BP PG64-22 with 4% EcoAddz</td>
<td>4% EcoAddz</td>
</tr>
<tr>
<td>75% BP PG64-22 blended with 25% BP PG46-34</td>
<td>Control&lt;sub&gt;6&lt;/sub&gt; and Control&lt;sub&gt;16&lt;/sub&gt;</td>
</tr>
<tr>
<td>BP PG64-22 with 6% EcoAddz</td>
<td>6% EcoAddz</td>
</tr>
<tr>
<td>BP PG64-22 with 10% EcoAddz</td>
<td>10% EcoAddz</td>
</tr>
</tbody>
</table>

Make the controls PG grade meet the RHVDB blends as close as possible.
Blends Continuous Grades

Grade temp

Control  2% EcoAddz  4% EcoAdzz PG Equiv.  4% EcoAddz  6% EcoAddz PG Equivalent  6% EcoAddz  6% EcoAddz & 0.5% AS  10% EcoAddz


Grade temp

-30  -20  -10  0  10  20  30  40  50  60  70
N70, N90 Mix Gradation from Illinois Study

FWHA .45 Power Chart

Percent Passing

Sieve Size mm, raised to .45 power

Max Density N90 N70
## N70 & N90 Mix Properties

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Control</th>
<th>2% EcoAddz</th>
<th>2% EcoAddz PG Equiv.</th>
<th>4% EcoAddz</th>
<th>4% EcoAddz PG Equiv.</th>
<th>6% EcoAddz</th>
<th>6% EcoAddz PG Equiv.</th>
<th>6% EcoAddz &amp; 0.5% AS</th>
<th>10% EcoAddz</th>
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<tbody>
<tr>
<td><strong>PG Grade</strong></td>
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<tr>
<td><strong>Percent Binder, Pb(%)</strong></td>
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<tr>
<td>N70</td>
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<td><strong>Air Voids in Compacted Mixture, Va, %</strong></td>
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<tr>
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<td>3.73</td>
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<td>N70</td>
<td>13.02</td>
<td>13.09</td>
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<td>12.87</td>
<td>12.58</td>
<td>12.69</td>
<td>12.29</td>
<td>12.91</td>
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<tr>
<td><strong>Percent Binder, Pb(%)</strong></td>
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<td></td>
<td></td>
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<tr>
<td>N90</td>
<td>5.4</td>
<td>5.4</td>
<td>5.4</td>
<td>5.4</td>
<td>5.4</td>
<td>5.4</td>
<td>5.4</td>
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<tr>
<td><strong>Air Voids in Compacted Mixture, Va, %</strong></td>
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<td></td>
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<td></td>
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<tr>
<td>N90</td>
<td>4.08</td>
<td>4.16</td>
<td>3.96</td>
<td>4.05</td>
<td>4.00</td>
<td>3.93</td>
<td>3.89</td>
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<tr>
<td><strong>Volume of Voids in Mineral Aggregate, VMA, %</strong></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
N70 T 283 Results

![Bar Chart]

- Control
- 2% EcoAddz
- 4% EcoAddz
- 6% EcoAddz
- 6% EcoAddz & 0.5% AS

EcoAddz PG Equiv.: 4%
EcoAddz PG Equiv.: 6%
EcoAddz & 0.5% AS: 10%
N90 T 283 Results

Control 2% 4% 4% 6% 6% 6% 6% 10%
EcoAddz EcoAddz EcoAddz EcoAddz EcoAddz EcoAddz EcoAddz EcoAddz
PG PG & 0.5%
Equiv. Equiv. AS

TSR %
75 80 85 90 95 100
T 283 testing

- The blends with RHVDB show no indication that they increase Moisture damage.
- ALL TSR ratios well above the 80 % minimum
HWT tests N70 mix Illinois Spec
7500 Reps for PG 64

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Rut mm @ 7500 passes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>4</td>
</tr>
<tr>
<td>2% EcoAddz</td>
<td>4</td>
</tr>
<tr>
<td>4% EcoAddz</td>
<td>6</td>
</tr>
<tr>
<td>4% EcoAddz PG Equiv.</td>
<td>6</td>
</tr>
<tr>
<td>6% EcoAddz</td>
<td>6</td>
</tr>
<tr>
<td>6% EcoAddz PG Equiv.</td>
<td>6</td>
</tr>
<tr>
<td>6% EcoAddz &amp; 0.5% AS</td>
<td>7</td>
</tr>
<tr>
<td>10% EcoAddz</td>
<td>8</td>
</tr>
</tbody>
</table>

Legend:
- Control
- 2% EcoAddz
- 4% EcoAddz
- 4% EcoAddz PG Equiv.
- 6% EcoAddz
- 6% EcoAddz PG Equiv.
- 6% EcoAddz & 0.5% AS
- 10% EcoAddz
RHVDB Blend Results

N70 Hamburg Loaded Wheel Wheel Results

Rut Depth, mm

Cycles

- Control
- 4% EcoAddz
- 6% EcoAddz & 0.5% AS
- PG 58-XX

- 2% EcoAddz
- Control6
- 10% EcoAddz
- PG 64-XX

- Control4
- 6% EcoAddz
- Failure

Failure
Hamburg LWT

- All mixes meet the rutting criteria for both PG 64 and 58 requirements.
- The RHVDB mixes typically performed better than the equivalent PG control mixes.
- None of the Mixes indicated any stripping inflection point except the 10% blend. This is likely not stripping but just a very soft binder.
N70 Master Curves at 20°C

Dynamic Modulus, $E^*$, ksi

Frequency, Hz

Control 2% EcoAddz 4% EcoAddz 6% EcoAddz PG Equiv. 6% EcoAddz 6% EcoAddz, 0.5% AS 10% EcoAddz
N90 Master Curves at 20°C

Dynamic Modulus, $E^*$, ksi vs. Frequency, Hz

- Control
- 2% EcoAddz
- 4% EcoAddz
- 6% EcoAddz PG Equiv.
- 6% EcoAddz
- 6% EcoAddz, 0.5% AS
- 10% EcoAddz
Master Curves

- The master curve data strictly matches binder PG grade.
- Softer binder lower $E^*$ data.
Beam Fatigue Testing

- The four point bending beam data clearly shows the mixes produced with RHVDB have better fatigue response than control binder.
DCT Fracture Energy N70 Mix

- Control
- 2% EcoAddz
- 4% EcoAddz
- 4% EcoAddz PG Equiv.
- 6% EcoAddz
- 6% EcoAddz PG Equiv.
- 6% EcoAddz & 0.5% AS
- 10% EcoAddz
The addition of EcoAddz increased the cycles to failure.

The mixtures susceptibility to cracking is reduced.

<table>
<thead>
<tr>
<th>% EcoAddz</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>N70</td>
<td>400</td>
<td>694</td>
<td>781</td>
<td>851</td>
</tr>
<tr>
<td>N90</td>
<td>781</td>
<td>1174</td>
<td>1200</td>
<td>1200</td>
</tr>
</tbody>
</table>

% Increase in Cycles Compared to the Control

<table>
<thead>
<tr>
<th>EcoAddz</th>
<th>N70</th>
<th>N90</th>
</tr>
</thead>
<tbody>
<tr>
<td>2%</td>
<td>74</td>
<td>50</td>
</tr>
<tr>
<td>4%</td>
<td>95</td>
<td>54</td>
</tr>
<tr>
<td>6%</td>
<td>113</td>
<td>54</td>
</tr>
</tbody>
</table>
Mix Testing

- T 283 Shows no increase in Moisture Damage with RHVDB Binders.
- For Same binder stiffness rutting equivalent for controls and RHVDB Binders
- Mix E* Equivalent for controls and RHVDB Binders
- Improved Fatigue Properties for RHVDB Binders
- Fracture tests show improved properties with RHVDV
Accelerated Pavement Weathering System (APWS)
APWS, continued
Experimental Design

- Compare short-term aged to long-term aged performance properties and the asphalt performance grade

- Short-term aged:
  - 2 hours at 135°C prior to compaction

- Long-term Aged:
  - 4 hours at 135°C prior to compaction

- APWS Aged
  - 3,000 hours total (≈ 15+ years)
  - High Temperature = 60-65°C (simulated pavement surface temperature)
  - Continuous sunlight
  - 1 cycle = 51 minutes dry, 9 minutes wet (‘rain’)
    - Thermal shock = Δ temperature ≈ 30-40°F
  - 24 cycles each day
Experimental Design, continued

- Performance Properties Evaluated:
  - Moisture Damage
    » AASHTO T 283 IL Modified
  - Dynamic Modulus and Flow Number
    » AASHTO TP 79
  - Hamburg Loaded Wheel
    » AASHTO T 324 IL Modified
  - Fracture Energy
    » ASTM D 7313
  - Flexural Beam Fatigue
    » ASTM D 7460
Results-Moisture Damage; AASHTO T 283 IL Modified

- **Short-term Aged:**
  - Conditioned Samples saturated to 70-80%, soaked at 60°C for 24 hrs, 25°C for two hours

- **Long-term Aged:**
  - Conditioned Samples soaked at 25°C for two hours
  - Improved with weathering

![Graph showing conditioned strength before and after APWS]
Results - Moisture Damage; AASHTO T 283 IL Modified

![Graph showing TSR (%)](chart)

- Before APWS
- After APWS

- 6% EcoAddz
- 6% EcoAddz PG Equivalent
Results- Hamburg Loaded Wheel; AASHTO T 324 IL Modified

- HLW ran at 50°C
- Results improved with Aging
Results- Fracture Energy; ASTM D 7313

- Fracture Energy tested at -12°C
- MN Research indicates 400 J/m² to be an acceptable minimum Fracture Energy for Unaged Samples
PRI Beams: N70 Series
ASTM 7460 4-point Flexural Fatigue
Cycles x Stiffness Analysis
20°C Test Temperature

Cycles to Failure, (nf)

Microstrain

- N70 6% LUWA
- N70 M6
- N70 M6-APWS
- N70 6%-APWS
Summary

- Initial studies have shown EcoAddz blends well with Asphalt and is not prone to Separation.
- EcoAddz did not increase aging of the binder, it is controlled by base Asphalt.
- EcoAddz reduces both the high and low temperature properties of the binder.
- Moisture damage studies indicate EcoAddz did not increase potential.
- EcoAddz improved Fatigue response of mixes.
- EcoAddz improved Fracture Energy properties on mixes.
Summary

- The Fracture energy properties of the 6% EcoAddz and the 6% control showed similar aging in the AWPS.

- Overall the 6% EcoAddz mix does not show any increase in negative performance with aging over the 6% control mixes after 3000 hours in the AWPS.