Rejuvenators: Where do we Stand?

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Global Technical Manager,
Asphalt Solutions

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A Global Leader in Asphalt Chemistries

To empower a more sustainable life and keeping people safe on the road through high-performance and advanced bio-based asphalt additives.

- Rejuvenation
- Warm Mix
- Cold Mix
- Emulsions
- Rheology
- Stabilizers

State-of-the-art Asphalt Lab

- Customer custom formulation services
- Compositional and analytical evaluation
- Advanced rheology and thermal analysis

Our commitments

$115 million
Total charitable contributions last year across 56 countries

<table>
<thead>
<tr>
<th>Responsible</th>
</tr>
</thead>
<tbody>
<tr>
<td>We strive to strengthen the communities where we live and work.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sustainable</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Agriculture is how we will protect the planet and our shared future.</td>
</tr>
<tr>
<td>• Climate change: Reducing supply chain emissions per ton of product 30% by 2030, and absolute operational emissions 10% by 2025</td>
</tr>
<tr>
<td>• Water resources: Achieving sustainable water management in all priority watersheds by 2030</td>
</tr>
<tr>
<td>• Land use: Eliminating deforestation in our supply chains by 2030</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>2017</th>
<th>2020</th>
<th>2030 goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2 million</td>
<td>10 million</td>
<td>Attendance at our farmer trainings for sustainable agricultural practices totaled 860,000 last year</td>
</tr>
</tbody>
</table>

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Agenda

• RA Implementation: Best Practices
• RA-BMD Spec. Implementation Examples
Recycling Agents

“Rejuvenation” is an inaccurate, but popular term for Recycling Agents.

- Rejuvenators do not undo oxidative aging!!!

A Recycling Agent reverses the impact of aging on asphalt, reactivating the asphalt, to restore performance, and durability.

A “Rejuvenating” Recycling Agent reverses the impact of aging by:
- Restoring cracking resistance, maintain rutting performance
- Improving workability, compaction, and appearance
- Improving aging susceptibility of the pavement
- Providing predictable and reliable results
Rejuvenation Mechanism

Link to video: https://youtu.be/uwfYjy4PHDU
Oxidative Aging

Unaged: Balanced and disassociated polars (“Sol”)

Aged: Unbalanced, polar clusters and “gelling”

- Link to video: https://youtu.be/uwfYjy4PHDU
Rejuvenation Mechanism

Aged: Unbalanced, polar clusters and “gelling”

Rebalance Fractions

Compatibilize Gel Structures

Rejuvenated: Rebalanced and disassociated polars

- Link to video: https://youtu.be/uwfYjy4PHDU
Classification of RAs

• Early classifications of Recycling Agents focused on raw material type (e.g. aromatic oil vs. tall oil).
  – This was adequate when most additives were chemically unmodified.
  – However, with advent of engineered and chemically modified additives, raw material designations are less useful.
• There are several recently completed and on-going efforts to develop a system and corresponding specification to accurately describe the chemical, physical, and engineering properties of recycling agents, and classify them, regardless of their composition.
• Currently only one ASTM standard addressing Recycling Agents exists:
  – ASTM D4552: Classification of Hot Mix Recycling Agents
This step ensures that rejuvenator meets basic requirements for safety, thermal stability, storage stability, and compatibility to be used in Hot Mix Asphalt production.

<table>
<thead>
<tr>
<th>Test</th>
<th>ASTM Test Method</th>
<th>RA 0</th>
<th>RA 1</th>
<th>RA 5</th>
<th>RA 25</th>
<th>RA 75</th>
<th>RA 250</th>
<th>RA 500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity • 60°C [140°F] mm²/s</td>
<td>D2170</td>
<td>10</td>
<td>49</td>
<td>50</td>
<td>175</td>
<td>176</td>
<td>900</td>
<td>901</td>
</tr>
<tr>
<td>Saturates, wt. %</td>
<td>D2007</td>
<td>...</td>
<td>30</td>
<td>...</td>
<td>30</td>
<td>...</td>
<td>30</td>
<td>...</td>
</tr>
<tr>
<td>Tests on Residue from RTFO 163 °C [325 °F]</td>
<td>D2872</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viscosity Ratio</td>
<td></td>
<td>...</td>
<td>3</td>
<td>...</td>
<td>3</td>
<td>...</td>
<td>3</td>
<td>...</td>
</tr>
<tr>
<td>%T Change ± %</td>
<td></td>
<td>...</td>
<td>4</td>
<td>...</td>
<td>4</td>
<td>...</td>
<td>4</td>
<td>...</td>
</tr>
<tr>
<td>Specific Gravity at 25 °C [77 °F]</td>
<td>D70 or D1298</td>
<td>0.900</td>
<td>1.100</td>
<td>0.900</td>
<td>1.100</td>
<td>0.900</td>
<td>1.100</td>
<td>0.900</td>
</tr>
</tbody>
</table>

**Example Bio-based Rejuvenator**

- 30 >290°C
- ~ 0% (Iatroscan)
- 1.05 <0.5%
- 0.94

\[ \text{Viscosity Ratio} = \frac{\text{Viscosity of Residue from RTFO Test at 60°C [140°F]}}{\text{Original Viscosity at 60°C [140°F]}} \]
How do we Differentiate Rejuvenators from Softeners?

• The difference between “Rejuvenation” and “Softening” is in the ability to “compatibilize” asphaltene-association structures in asphalt.

• Directly measuring asphalt compatibility is not easy. However:
  - We know that long term-aging decreases the compatibility of asphalt
  - We can measure the change in properties as a result of aging.

• Examples of property changes compared after long term aging:
  - Measuring the change in Analytical indices (e.g. “Colloidal Instability Index”, AFM structures)
  - Measuring change in Miscibility thermal analysis (i.e. Tg properties)
  - Measuring the change in BBR m-grade or ΔTc
Plant Implementation

Typically, 1-3% wt. of the binder or 0.05-0.15% wt. of the mix, added via:

1. **In-line into virgin binder using additive pump**
2. Treatment of RAP (at collar or during processing)
3. Injection into pugmill or mixing drum
4. Pre-blended into virgin binder (least common)

![Drum Plant Example](image1)

- Cargill can provide portable easy-to-install trial pump skid
- Manual controls with no need for plant computer hookup
- Pump can be simply hooked up to tote and piped into AC line

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First Impressions: Improved workability

- Rejuvenation significantly improved the Compactability, even after a 20% increase in RAP content.
  - A large improvement in compaction temperatures achieved
  - No over-compaction at hot mix temperatures.
Overview: High RAP-Rejuvenated Design

1. Check if RA meets basic safety / physical requirements
2. Establish dosage using binder properties (e.g. LT PG or change in $\Delta T_c$ with aging)
3. Perform Balanced Mix Design using Reliable Test (e.g. HWT vs. DCT or Overlay Tester)
4. Quality Management: Standard material test + surrogate performance test (e.g. IDEAL-CT)

Performed By
- Supplier
- Contractor
- Agency

References:
- ASTM D4552-20
- NCHRP 9-58
- NAPA RA Guide
Step 1: Initial RA Dosage Determination (By Supplier)

- RAP samples are extracted, graded and rheologically fingerprinted for initial dosage determination.

Extraction & Recovery  
Grading and Analysis  
Dosage Determination Report for Target Mix Designs
Step 2: Balanced Mix Design (By Producer)

AC% and gradation for 4% Air Voids
- Check Performance
- Redesign AC% and Gradation at 4% AV and check again

AC% and gradation for 4% Air Voids
- Check Performance
- Change AC% as needed to meet performance, regardless of AV%

AC% and gradation optimized to meet performance
- Allow Air voids and volumetrics to vary outside typical spec ranges

Validate JMF / production.

Cracking Performance
- Increase moisture susceptibility
- Decrease moisture content

Rutting Performance
- Rejuvenator (% of Total AC)
- AC Content (%)
Step 3: Quality Management (All Parties)

Supplier:
- Product delivered with verifiable Certificate of Analysis
- Support producer with periodic material sampling and verification throughout season.

Producer:
- Maintain appropriate frequency of RAP analysis (binder content and gradation control.)
- Maintain RAM processing protocols and consistency
- Mix performance verification as needed.

Owner/Agency (in development across country):
- Per agency specification
- Frequent Quality verification of mix composition/volumetrics
- Full mix design performance verification on first plant production of a specific design
- Periodic simple/surrogate mix performance verification

Well-established process for Commercial Mixes

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Examples of Current or Considered BMD Systems  
(Some details may have changed or no longer be accurate)

<table>
<thead>
<tr>
<th>Agency:</th>
<th>New Jersey DOT</th>
<th>Chicago DOT</th>
<th>Illinois Tollway</th>
<th>Illinois DOT</th>
<th>City of Janesville</th>
<th>Virginia DOT</th>
<th>City of Columbus</th>
<th>ODOT (Trial)</th>
<th>City of Phoenix (Trial)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cracking Test</td>
<td>Overlay Tester</td>
<td>DCT</td>
<td>DCT + IFIT</td>
<td>IFIT</td>
<td>DCT + IFIT</td>
<td>IDEAL-CT</td>
<td>IDEAL-CT</td>
<td>IDEAL-CT</td>
<td>IFIT</td>
</tr>
<tr>
<td>Rutting Test</td>
<td>APA</td>
<td>Hamburg</td>
<td>Hamburg</td>
<td>Hamburg</td>
<td>Hamburg</td>
<td>APA</td>
<td>HWT</td>
<td>HWT</td>
<td>HWT to approve RA</td>
</tr>
<tr>
<td>Binder Specification</td>
<td>None</td>
<td>Extracted pass PG XX-22, ΔTc &gt; 5</td>
<td>None</td>
<td>None</td>
<td>Extracted pass PG XX-16</td>
<td>None</td>
<td>Extracted pass climate PG + 6</td>
<td>Extracted pass climate PG + 6</td>
<td>Meet virgin grade of 70-28</td>
</tr>
<tr>
<td>QC Process</td>
<td>Trial Strip + performance test</td>
<td>Extracted PG</td>
<td>Trial Strip + Performance test</td>
<td>TBD</td>
<td>Performanc e test</td>
<td>Surrogate tests, TBD</td>
<td>IDEAL-CT</td>
<td>IDEAL-CT</td>
<td>Basic VMD QC</td>
</tr>
<tr>
<td>State of Implementation</td>
<td>Active as of 2018</td>
<td>Active as of 2018</td>
<td>Active as of 2018</td>
<td>Active as of 2019</td>
<td>Active as of 2017</td>
<td>Trial spec as of 2019</td>
<td>Implementation in 2022</td>
<td>Trial in 2021</td>
<td>Trials in 2021</td>
</tr>
</tbody>
</table>
Field Evaluation Projects

**NCAT: Warm Climate**
- 30% RAP (24% ABR); PG64-22 Binder + Warm Mix Additive
- 45% RAP (38% ABR); PG64-22 Binder + Rejuvenator
- Aggregates and RAP were shipped in from Virginia for the project

**MNROAD: Cold Climate**
- 25% RAP (20% ABR); PG58-28 Binder
- 45% RAP (31% ABR); PG5828 Binder + Rejuvenator
- Aggregates and RAP were supplied locally in Minnesota for the project
NCAT High RAP and WMA Project

• Designs were done using BMD system under consideration by VADOT at the time (IDEAL vs. APA)

• Rejuvenation of the high RAP mix achieved comparable passing performance compared to the WMA mix.

• Both the RA and WMA mix outperform the high-RAP control mix.
To demonstrate performance Cargill built a test section on the NCAT track using the typical 30% RAP mix with Cargill Anova® WMA, and 45% RAP with Cargill Anova® Rejuvenator.

After 10 million loadings, zero cracks appeared in the test section.

* Data provided and measured by NCAT using plant produced mix.
Balanced Mix Design for Delaware: DelDOT Approved Mix

1. Plant samples were prepared based on Cargill dosage recommendations and HMA producer’s mix design.
2. DOT directly sampled plants and carried out Laboratory performance tests.
3. Binder extraction tests were conducted on lab samples by Cargill.

- 25% RAP + 4% RAS + Rejuvenator vs. Control: 25% RAP
- 40% RAP + Rejuvenator vs. Control: 25% RAP
  - AC% optimized by VMD, standard densities
  - Performance checked with Overlay Tester, IdealCT and Hamburg

<table>
<thead>
<tr>
<th>Description</th>
<th>Extract AC %</th>
<th>HT PG</th>
<th>LT S PG</th>
<th>LT m PG</th>
<th>ΔTc</th>
</tr>
</thead>
<tbody>
<tr>
<td>25% RAP + 4% RAS Rej</td>
<td>5.58%</td>
<td>82.5</td>
<td>-22.4</td>
<td>-22.2</td>
<td>-0.2</td>
</tr>
<tr>
<td>35% RAP + 5% RAS Rej</td>
<td>5.91%</td>
<td>73.9</td>
<td>-23.6</td>
<td>-26.6</td>
<td>2.9</td>
</tr>
</tbody>
</table>
### Project Highlights: New Jersey

#### 50% RAP, 9.5 mm, Surface Course

<table>
<thead>
<tr>
<th>Project Property</th>
<th>Value / Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>June 2018</td>
</tr>
<tr>
<td>Tonnage</td>
<td>&gt; 10,000 tons</td>
</tr>
<tr>
<td>Mix Type</td>
<td>NJDOT Surface Mix Dense Graded</td>
</tr>
<tr>
<td>Performance</td>
<td>Overlay Tester Cycles : 1200 &gt; 200</td>
</tr>
<tr>
<td></td>
<td>APA Rutting at 64C &lt; 7 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Extract AC %</th>
<th>HT PG</th>
<th>LT S PG</th>
<th>LT m PG</th>
<th>$\Delta T_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% RAP Rejuvenator</td>
<td>5.44%</td>
<td>67.4</td>
<td>-30.1</td>
<td>-28.0</td>
<td>-2</td>
</tr>
</tbody>
</table>

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• 12.5 mm NMAS, 40% RAP + Rejuvenator was used in surface mix in place of a typical 20% RAP mix.

• Success of project (appearance, compaction and workability, performance) has led to incorporation of allowance for similar designs in bids this season
Conclusions and Summary

• Today rejuvenation technology has been used successfully for years in millions of tons of HMA.

• Implementation of high RAP + Rejuvenators in both “non-spec” commercial mixes and spec’d Agency mixes can be highly practical and feasible today:
  – Work with rejuvenator supplier on the appropriate dosage to produce higher RAP mixes with quality consistent with normally supplied mix designs.

• The NCAT and MNROAD studies demonstrated that even for high-performance and high-service pavements a framework can be used that provides transparency and reliability for all stakeholders:
  – Step 1: Recycling Agent Property Certification (e.g. through ASTM D4552-20) - by supplier
  – Step 2: Initial dosage determination based on rheology, led by supplier
  – Step 3: Balanced Mix Design (BMD) process, led by producers
  – Step 4: Robust quality management practices by all parties
REFERENCES:


