Improved Aircraft Deicing & Anti-Icing Fluids; Safety, Performance & Lower Environmental Impact

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Aircraft Deicing Fluid Myths and Facts

- **Myth # 1:** “The chemicals used to deice aircraft are ethylene glycol and propylene glycol, both deadly substances in small quantities.”
  - Fact: Today, most deicer fluids are based on propylene glycol (PG)
  - Fact: PG is essentially non-toxic to mammals and aquatic life
  - Fact: the US FDA considers PG safe for human consumption

- **Myth # 2:** Deicing fluids contain “10% to 20% highly toxic” additives including “triazoles, ethylene oxide, acetaldehyde, and dioxane”
  - Fact: New deicing fluids contain no listed toxics, triazoles or APEs
  - Fact: Fluid concentrates contain less than 2% additives

- **Myth # 3:** Strict guidelines are needed for Industry to develop safer products and manage runoff
  - Fact: ADF manufacturers have pro-actively improved their products
  - Fact: Airports safely manage millions of gallons of fluid every season

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1 AReCo web site www.areco.org
Types of Fluids

• Type I Aircraft Deicing Fluid (ADF)
  – Supplied as concentrate containing ~88% glycol
  – 1-2 % additives
  – 10% water
  – Typically applied diluted with water to 50% (44% glycol)
  – Dilution ranges from 60% to 20% ADF (53% to 17% glycol)
  – Applied at 180°F to remove surface ice

• Type II, III and IV Anti-icing Fluids (AAF)
  – Thickened versions of Type I fluids
  – Applied to prevent ice formation after deicing with Type I fluids
  – Applied as supplied (~50% glycol)
Environmental Concerns

• Toxicity of Fluid Additives

  – Aquatic toxicity from:
    • Corrosion inhibitors, esp. benzotriazoles
    • Surfactants, esp. APEs (alkyl phenol ethoxylates)

  – Chronic toxicity:
    • Potential endocrine disruption from APE biodegradation products

• Oxygen Demand (BOD5 and COD) of glycols

  – Rapid biodegradation can cause oxygen depletion in waters

EPA 821-R-00-016 Preliminary Data Summary, Airport Deicing Operations, August 2000
ACRP 02-01 interim report Nov 2007
### Aquatic Toxicity of Fluid Ingredients

<table>
<thead>
<tr>
<th>LC50/EC50 (mg/L)</th>
<th>Glycols</th>
<th>New ADPACs</th>
<th>Triazoles &amp; APEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relatively harmless</td>
<td>&gt;1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Practically nontoxic</td>
<td>100–1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slightly toxic</td>
<td>10–100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderately toxic</td>
<td>1–10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.1–1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.01–0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;0.01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

APE concentrations found in GMI Milwaukee Airport receiving streams in 2001-2 at these concentrations*

Lyondell Chemical Fluids

• New fluids developed, tested and commercialized since 2000
  – 2005-2006 season: Arctic Plus ADF Type I
  – 2007-2008 season: Arctic Shield ADAF Type IV

• New fluids
  – Are propylene glycol-based
  – Contain no listed toxics, APEs or triazoles
  – Are essentially non-toxic to mammals and aquatic life
  – Are not sensitizers or irritants
  – Meet or exceed all SAE standards
  – Are current state-of-the-art
Propylene Glycol is Essentially Non-Toxic

• Acute Mammalian
  – Rat Oral LD50: 22,000 mg/kg/day
  – Rabbit Skin LD 50: 20,800 mg/Kg/day

• Acute Aquatic:
  – Minnow 96 hour LC50: 51,400 mg/L
  – Trout 96 hour LC50: 51,600 mg/L
  – Salmon 96 hour LC50: 51,600 mg/L
  – Daphnia Magna 48 hour LC50: 43,500 mg/L
  – Freshwater algae 72 hour EC50: 24,200 mg/L

• Chronic Aquatic:
  – Waterflea 3-generation IC25: 13,470 mg/L
Aquatic Toxicity of Type I Deicing Fluids

<table>
<thead>
<tr>
<th>Aquatic Species</th>
<th>Test duration</th>
<th>Fluid containing 85% glycol</th>
<th>Diluted to of -26C FP</th>
<th>Fluid containing 85% glycol</th>
<th>Diluted to of -26C FP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ARCOPlus®</td>
<td></td>
<td>ARCTIC Plus®</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>measured</td>
<td>calculated</td>
<td>measured</td>
<td>calculated</td>
</tr>
<tr>
<td>Fathead Minnow</td>
<td>96</td>
<td>3,800</td>
<td>3,950</td>
<td>5,603</td>
<td>52,000</td>
</tr>
<tr>
<td>C. dubia</td>
<td>48</td>
<td>4,000</td>
<td>4,158</td>
<td>5,898</td>
<td>26,000</td>
</tr>
<tr>
<td>D. magna</td>
<td>48</td>
<td>6,000</td>
<td>6,237</td>
<td>8,847</td>
<td>27,000</td>
</tr>
<tr>
<td>Rainbow trout</td>
<td>96</td>
<td>3,200</td>
<td>3,327</td>
<td>4,719</td>
<td>38,000</td>
</tr>
</tbody>
</table>

- New ARCTIC Plus ADF safer to aquatic life than ARCOPlus ADF
- Exceeds current SAE standard of 4,000 mg/L @85% v/v glycol
- ARCTIC Plus ingredients are biodegradable and have low toxicities
- ARCTIC Plus concentrate is “relatively harmless” to aquatic species
Aquatic Toxicity of Type IV ARCTIC Shield Fluid

<table>
<thead>
<tr>
<th>Aquatic Species</th>
<th>Test duration</th>
<th>LC50 or EC50 in mg/L</th>
<th>Diluted to of -26C FP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>hours</td>
<td>ARCTIC Shield</td>
<td>measured</td>
</tr>
<tr>
<td>Fathead Minnow</td>
<td>96</td>
<td>8,750</td>
<td>10,507</td>
</tr>
<tr>
<td>D. magna</td>
<td>48</td>
<td>5,812</td>
<td>6,979</td>
</tr>
<tr>
<td>Rainbow trout</td>
<td>96</td>
<td>5,300</td>
<td>6,364</td>
</tr>
</tbody>
</table>

- ARCTIC Shield AAF much less toxic than other Type IV fluids
- ARCTIC Shield AAF is “relatively harmless” to aquatic species
Aquatic Toxicity of Fluids “As Supplied”

PG Not Environmentally Persistent

- Does not bioconcentrate or bioaccumulate (BCF<5)
- Biodegrades readily in water and soils
- Biodegradation rate increases with temperature

Anaerobic Biodegradation of PG-Based ADF Fluid in Sandy Loam from Tri-City Airport, Saginaw MI.

\[ y = 0.049x^2 + 1.700x + 6.604 \]

\[ R^2 = 1.000 \]
BOD5 or COD?

• COD (Chemical Oxygen Demand)
  – Theoretical amount of oxygen required to completely oxidize the chemical to CO₂ and water (in grams O₂/g)
  – Not a good measure of toxicity or potential harm to aquatic life
  – Microorganisms do not completely oxidize organics but convert them into a form they can use for energy
  – COD overestimates the potential impact to the environment

• BOD5 (5-day Biological Oxygen Demand)
  – Measure of actual rate of aerobic biodegradation by aquatic organisms (in grams O₂/g or % of COD)
  – High BOD5 effluents may cause localized oxygen depletion
  – BOD5 is a realistic measure of oxygen depletion potential
BOD5 & COD of Lyondell Fluids

- BOD5 and COD decrease with PG content
- Biodegradation is slow in winter and fast in spring and summer
- Environmental impact (BOD5) of effluent can be effectively managed by dilution, treatment, collection and recycling

<table>
<thead>
<tr>
<th>Lyondell Fluids</th>
<th>Type</th>
<th>% PG</th>
<th>BOD5 g O2/g</th>
<th>COD g O2/g</th>
<th>BOD5 as % of COD</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARCOPlus® @20°C</td>
<td>I</td>
<td>88%</td>
<td>0.81</td>
<td>1.55</td>
<td>52%</td>
</tr>
<tr>
<td>Arctic Plus® @20°C</td>
<td>I</td>
<td>88%</td>
<td>0.70</td>
<td>1.55</td>
<td>45%</td>
</tr>
<tr>
<td>Arctic Plus® @5°C</td>
<td>I</td>
<td>88%</td>
<td>&lt;0.01</td>
<td>1.55</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Arctic Shield® @20°C</td>
<td>IV</td>
<td>50%</td>
<td>0.45</td>
<td>0.75</td>
<td>60%</td>
</tr>
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</table>
Properties of Freeze Point Depressants (FPDs)

- Inorganic FPDs are likely excluded because of corrosion
- Organic FPDs must have the right balance of properties

<table>
<thead>
<tr>
<th>Deicer FPDs</th>
<th>CASNO</th>
<th>Melting Point °C</th>
<th>Flash Point °C</th>
<th>Water Solubility %</th>
<th>Surface Tension Dynes/cm</th>
<th>COD gO2/g</th>
<th>96 H LC50 mg/L</th>
<th>rat oral LD 50 mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glycerol</td>
<td>56-81-5</td>
<td>20</td>
<td>160</td>
<td>100</td>
<td>63</td>
<td>1.22</td>
<td>44,000</td>
<td>12,600</td>
</tr>
<tr>
<td>Propylene carbonate</td>
<td>108-32-7</td>
<td>-55</td>
<td>132</td>
<td>17.5</td>
<td>41</td>
<td>1.25</td>
<td>&gt;1,000</td>
<td>20,700</td>
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<tr>
<td>EG</td>
<td>107-21-1</td>
<td>-13</td>
<td>111</td>
<td>100</td>
<td>48</td>
<td>1.28</td>
<td>41,000</td>
<td>4,700</td>
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<tr>
<td>DEG</td>
<td>111-46-6</td>
<td>-10</td>
<td>143</td>
<td>100</td>
<td>45</td>
<td>1.51</td>
<td>75,200</td>
<td>12,565</td>
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<tr>
<td>TEG</td>
<td>112-27-6</td>
<td>-7</td>
<td>165</td>
<td>100</td>
<td>45</td>
<td>1.60</td>
<td>59,900</td>
<td>17,000</td>
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<tr>
<td>PG</td>
<td>57-55-6</td>
<td>-60</td>
<td>107</td>
<td>100</td>
<td>40</td>
<td>1.68</td>
<td>55,700</td>
<td>22,000</td>
</tr>
<tr>
<td>1,3-PDO</td>
<td>504-63-2</td>
<td>-27</td>
<td>129</td>
<td>100</td>
<td>46</td>
<td>1.68</td>
<td>&gt;9,720</td>
<td>4,773</td>
</tr>
<tr>
<td>DPG</td>
<td>25265-71-8</td>
<td>-40</td>
<td>138</td>
<td>100</td>
<td>34</td>
<td>1.84</td>
<td>&gt;5000</td>
<td>14,850</td>
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<tr>
<td>MPDiol glycol</td>
<td>2163-42-0</td>
<td>-54</td>
<td>127</td>
<td>100</td>
<td>72</td>
<td>1.95</td>
<td>&gt;1000</td>
<td>&gt;5000</td>
</tr>
</tbody>
</table>
SAE AMS 1424 Fluid Certification is Difficult and Costly

- Fluids must pass all 58 tests
Summary

• Suppliers have pro-actively addressed aquatic toxicity concerns

• PG is a superior glycol for aircraft deicing
  – Other organic FPDs offer at most a 25% COD benefit
  – Other properties and cost should be considered

• R&D working on incremental improvements in performance while maintaining excellent environmental profile