High Performance new mineral and PAG hybrid turbine oil

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Background
- Requirements of modern turbine oils
- Mineral turbine oil and PAG turbine oil
- Expected benefit of hybrid turbine oil

Development of hybrid turbine oils
- Oxidation stability test
- Sludge / varnish cleaning test
- Extreme pressure and Anti-wear test

Conclusion
Requirements of modern turbine oils

In order to improve thermal efficiency, current gas turbines must...

- Operate at higher temperatures
- Provide longer service life
- Ensure extended drain interval and superior performance, i.e., minimizing varnish/sludge formation
High Temperature and Long life Mineral Turbine Oil having EP Characteristics

- Long lifetime over 5 years
- Good water separability
- Reduced sludge and varnish formation by optimizing AO and EP additives

New PAG turbine oil that enable easy management and exchange from mineral oil

- Good compatibility with Mineral Turbine Oil
- Low sludge and varnish formation
- Excellent solubility of sludge and varnish
- Good EP Characteristics
Expected Benefits of using hybrid oil

Benefits compared with mineral oil

1. Low sludge and varnish formation
2. Can solve precipitated sludge and varnish
3. Longer life and extended drain interval
4. Superior extreme pressure and anti-wear performance

Benefits compared with PAG oil

1. Lower cost and almost similar performance
2. Better water separation properties

We evaluated hybrid oils in which Mineral Oil was blended with PAG Turbine Oil.
※Selected PAG Turbine Oil has compatibility with mineral Oil.
## Developing Oils

<table>
<thead>
<tr>
<th></th>
<th>Mineral oil</th>
<th>Developing oil A</th>
<th>Developing oil B</th>
<th>PG25</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mineral Turbine oil</strong></td>
<td>wt%</td>
<td>100</td>
<td>90</td>
<td>50</td>
</tr>
<tr>
<td><strong>PAG Turbine oil</strong></td>
<td>wt%</td>
<td>0</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td><strong>KV40C</strong></td>
<td>mm²/s</td>
<td>31.36</td>
<td>28.09</td>
<td>25.34</td>
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<tr>
<td><strong>KV100C</strong></td>
<td>mm²/s</td>
<td>5.681</td>
<td>5.106</td>
<td>5.283</td>
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<td><strong>VI</strong></td>
<td>-</td>
<td>123</td>
<td>112</td>
<td>128</td>
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<tr>
<td><strong>D</strong></td>
<td>g/cm³</td>
<td>0.8482</td>
<td>0.8581</td>
<td>0.9092</td>
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<tr>
<td><strong>Acid number</strong></td>
<td>mgKOH/g</td>
<td>0.10</td>
<td>0.16</td>
<td>0.23</td>
</tr>
</tbody>
</table>
Test Method 1 (Dry-TOST, ASTM D7873)

Test conditions

Temperature: 120 °C

Turbine oil: 360 ml, no water

Catalyst: Cu-Fe coil

Oxygen: 3 L/hr

Evaluation Items

✓ Millipore value (Sludge/Varnish) (mg/Kg)

✓ RPVOT remaining ratio (%)
Dry-TOST (ASTM D7873)

Test Subject:
RPVOT remaining ratio(%) Millipore (mg/100ml)

Developing Oil A and B indicates comparable life to Mineral Oil
Dry-TOST (ASTM D7873)

Test Subject:
RPVOT remaining ratio(%)  
Millipore (mg/100ml)

Millipore value

- Mineral oil
- Developing Oil A
- Developing Oil B
- PG25

Developing Oil B indicates low sludge and varnish
Piston pump

- Oil temperature: 80℃
- Pump pressure: 35MPa
- Air: 1.0L/h
- Test time: 1000h
- Evaluate: Residual ratio of RPVOT, and Millipore after the time

Cu catalyst

Air 1.0 L/h

22KW

P = 35MPa
A2F pump test JCMAS P045

Test Condition
- Oil temperature: 80℃
- Pump pressure: 35MPa
- Air: 1.0L/h
- Test time: 1000h
- Evaluate: Residual ratio of RPVOT, and Millipore after the time

Mineral oil (New oil) + Degraded mineral oil (10wt%)
A2F Pump test (JCMAS P045)

- Oil temperature: 80°C
- Pump pressure: 35MPa
- Air: 1.0L/h
- Test time: 1000h
- Evaluate: RPVOT residual ratio, TAN and Millipore after the time

Developing Oil B and PG25 has long life.
Developing Oil B and PG25 has little sludge and varnish.
Color change of developing oil A is milder than PAG turbine oil. The change in color of developing oil B and PG25 is due to solved sludge and varnish.
Appearance of Oil Cooler after 1\textsuperscript{st} A2F pump test (Before 2\textsuperscript{nd} A2F pump test)

Mineral turbine Oil

Appearance of Oil Cooler after 2\textsuperscript{nd} A2F pump test

Developing turbine oil A

Developing turbine oil B

PAG turbine oil

Developing oil B and PG25 can wash sludge and varnish
Extreme pressure, load carrying capacity

Four ball weld test (ASTM D2783)

- Contact: 3 points
- Operation type: Sliding
- Test ball: SUJ2
- Rotation: 1,800 rpm
- Test time: 10 seconds
- Filling: Room temperature

<table>
<thead>
<tr>
<th>Side</th>
<th>Top</th>
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<tbody>
<tr>
<td>Turn</td>
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<td>Road</td>
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<th>PG25</th>
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<tbody>
<tr>
<td>LNL,N</td>
<td>392</td>
<td>392</td>
<td>392</td>
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<tr>
<td>WL,N</td>
<td>1236</td>
<td>1569</td>
<td>1236</td>
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<tr>
<td>LWI,N</td>
<td>173</td>
<td>176</td>
<td>172</td>
</tr>
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</table>

Developing oil B has strong EP performance
**Anti-wear properties**

*Four ball wear test (ASTM D4172)*

- **Contact**: 3 points
- **Operation type**: Sliding
- **Test ball**: SUJ2
- **Rotation**: 1,200 rpm
- **Test time**: 60 min
- **Temperature**: 75°C
- **Load**: 294 N

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</table>

- **Wear diameter, mm**
  - 0
  - 0.2
  - 0.4
  - 0.6
  - 0.8

- Developing oil B has good anti-wear properties like PAG turbine oil
Extreme pressure and anti-wear performance

FZG Gear test (DIN 51354)

- Load: Load stage 1~12 stage
- Test time: 15 min/load stage
- Oil supply: Oil bath (90°C start)
- Evaluate: fail stages

FZG fail stage

- Mineral turbine oil
- Developing oil B
- PAG turbine oil

Developing oil B has good anti-wear properties like PAG turbine oil
Developing oil B have good water separability like Mineral turbine oil
Benefits of developing oil B

1. Wash out precipitated sludge and varnish
2. Long life and good EP performance
3. Good water separation properties
4. Excellent cost performance

By mixing 50% of mineral turbine oil with 50% of PAG turbine oil, the same benefits as developing oil B can be expected.
Thank you