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USE & MAINTENANCE OF PHOSPHATE ESTER HYDRAULIC FLUIDS IN STEAM TURBINE GOVERNOR SYSTEM

-A CASE STUDY

By

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Presentation Outline

- Fire Resistance Fluid
- Case Study
- Root cause Analysis
- Conclusion
- Remedial Action
- Recommendation
Mineral Oils have traditionally been used as Hydraulic Fluids and Lubricants in steam and gas turbines,

Steam temperatures and the Hydraulic oil pressures have increased in search for the greater operating efficiency

Fire risks associated with the use of mineral oils have also grown.

Modern turbines steam temperatures are very high ($\geq 540 \, ^\circ\text{C}$) which is higher than the autoignition temperature of mineral oil ($\sim 350 \, ^\circ\text{C}$).

With the above backdrop the Phosphate ester based fire-resistant hydraulic fluids were introduced in early 1960s in steam turbine governor control systems and now widely used in large units.
The Fluid and Why it Degrades

- **Tri Xylenyl Phosphate Ester (TXP)**
  - [TXP adv.ppt](#)

- High pressure, temperature, shear stress.

- Exposed to air, water and dirt.
Fluid Degradation
Oxidation, Hydrolysis, Break Down

Forms Degradation Products
- Acids, metallic salts, gum and varnish
- Rising Total Acid Number (TAN)
- Rising particle counts
- Lowered resistivity

Increases air release time.
Results of Fluid Degradation

- Sluggish or sticky valve operation
- Short fluid life
- Short filter life
- Foaming
- Unscheduled downtime
<table>
<thead>
<tr>
<th>Fluid Monitoring for Assessing Degradation.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rising TAN, Change Purifier Media.</td>
</tr>
<tr>
<td>High Particle Counts, Check Particulate Filters.</td>
</tr>
<tr>
<td>Keep Fluid Topped Up with Fresh Fluid.</td>
</tr>
<tr>
<td>Always Maintain TAN on the Shallow Slope (Figure 1)</td>
</tr>
</tbody>
</table>
The Hydrolytic Degradation Curve
Acid Increase Over Time

Figure 1
Fluid Degradation Over Time

HIGH ON THE CURVE,
STEEP SLOPE,
RECLAMATION MODE

TAN > .18

TAN < .18, SHALLOW SLOPE, MAINTAINANCE MODE
Fluid Maintenance

- Phosphate ester fluid is unstable
- Prone to Degradation
- Filtration and purification required to remove degradation products
- If removed faster than produced, low on the curve, Figure 1
- If removed slower than produced, high end of curve
The Maintenance Zone

Acid production is auto-catalytic reaction.

Slope of acid rise over time (Figure 1) increases over TAN of .18

Therefore fluid TAN must be controlled under .18 TAN.
Fuller’s Earth

- The classic purifier media
- Natural clay mineral product
- Aluminosillicate with calcium, magnesium and iron oxides.
- High porosity, large surface area.
- Adsorbs polar contaminants (acids).
- Neutralizes acids by giving up metal salts.
Fuller’s Earth

The Problem

- Leached salts form pyrophosphates
- Pyrophosphates precipitate out as black gels
- Composition varies as it is natural occurring material

These gel deposits:
- Plug particulate filters
- Form gum and varnish
- Lowers resistivity
- Causes valve sticking
- Accelerate the degradation reaction
The Case Study
The Incidence

In its 500 MW units Trixylenyl Phosphate Ester (First Generation fluid) based control fluids are in use for more than 25 years.

No complete replacement of FRF.

One drum of FRF of Trixylenyl Phosphate Ester which also contained the product of Trixylenyl Phosphate Ester were topped up for maintaining normal oil level.

Within 24 hr, sudden increase in FRF tank level were reported.

On inspection of FRF tank heavy foaming of FRF was observed.

Turbine trip oil pressure decreased down to 6 kg/cm².
FRF Foaming
Action taken

Immediately decision was taken to scum off foam from top layer to avoid further deterioration in trip fluid pressure.

Installation of portable mechanical fine filter to remove mechanical impurities from bulk fluid.

Level was maintained by regular top up of oil during execution of above activities.
Installation of 3 stage mobile portable filtration unit for reconditioning of FRF

Portable Mechanical Fine Filter M/C
Root cause analysis

**Cause-1**
- It was apprehended that the fresh drum may be wrongly marked.
- Actual product may be Blend of Butylated Phenol and Trixylenyl Phosphate Ester

**Analysis**
- As per OS guideline, the products of different make/brands should not be mixed.
- To confirm, whether both are 100% TXP or blend of different TXP, Chromatography analysis were carried out.
Chromatographic Study of the various Fluids
(Samples of B, C & D are identical and different from the Sample A)

- Mixing of two different types of fluid is also eliminated
- 4 Pointed * peaks corresponds to tri-phenyl phosphate and 3 isomers of tertiary butylated triaryl phosphates.

Sam A: TXP + Tert butylated triaryl phosphate
Sam B: Reservoir sample
Sam C: 100% TXP
Sam D: Fresh drum sample
Root cause analysis

**Cause-II**
- Foaming characteristics of fresh drum sample (lot of topped up FRF drum) within the acceptable limit or not.

**Analysis**
- The analysis of the reservoir sample & Fresh drum sample were done for foaming characteristics & TAN.
<table>
<thead>
<tr>
<th>Sample Source</th>
<th>TAN</th>
<th>Foam (ml)</th>
<th>Collapse time</th>
<th>Foam in ml after 30 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir</td>
<td>0.15</td>
<td>510</td>
<td>&gt;1hour</td>
<td>300</td>
</tr>
<tr>
<td>Fresh Drum</td>
<td>&lt;0.01</td>
<td>30</td>
<td>35 Seconds</td>
<td>Nil</td>
</tr>
</tbody>
</table>

Foaming is not attributable to fresh drum fluid
Root cause analysis

**Cause-III**
- Whether Event of formation of stable foam linked with metal contamination of the fluid

**Analysis**
- The analysis of the reservoir sample & Fresh drum sample were done for metal content.
<table>
<thead>
<tr>
<th>Sample Source</th>
<th>Mg in ppm</th>
<th>Ca in ppm</th>
<th>Zn in ppm</th>
<th>Al in ppm</th>
<th>Fe in ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir Sample</td>
<td>14</td>
<td>9</td>
<td>7</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Drum Sample</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

- Metal content (Mg + Ca) in the reservoir sample is 23 ppm.
- High amount of metal salts can lead to the formation of soaps and or gels.
- Have a negative effect on foaming and or air release value.
- As per literature available warning limit of Calcium, magnesium & Sodium levels are >10 ppm of any one and 30 ppm in combination.
- The reason of higher metal content in the reservoir sample is due to leaching of Ca & Mg from Fuller’s earth over a period of last 25 years of long service life.
Conclusion

The metal salts that are present in the Fuller's have got leached out in the reservoir sample on account of higher TAN.

When their solubility got exceeded those get deposited on the reservoir walls.

As the fluid level in the reservoir has fallen those metals still remain deposited on the side walls of the reservoir forming a deposit ring slightly above the fluid level in the reservoir.

When additional quantity of fluid was added in the reservoir the fluid level got increased and the metal from the deposit ring in the reservoir was brought in contact with the bulk fluid in the reservoir which supported the formation of foam.
Further analysis of the used Fuller's Earth was conducted and it is found that the same is completely stable and is 100% suitable with the used fluid and are in use in plants throughout the world.

The used fullers earth was of mesh size 30/60 and the grain size 0.25 to 0.6mm.

It can be concluded that fullers earth quality can not be attributable for the above problem.
Remedial Action

OEM(FRF) Recommendation

- Remove the complete charge of the fluid from the reservoir and physically clean the residues which have built up on the surfaces within the reservoir

Concerns

- However considering the downtime expected of the running unit and also the cost of fluid of a new charge @ INR 2050 per Kg alternatives were explored
Remedial Action Taken

**Foam Removal**
- Continuously scum off the foam from the top since the contaminants that is metal salts impurities are trapped into the top layers of the foam.

**Fluid Dilution**
- Simultaneously fresh fluid additions were continued in order to dilute down the concentration levels to a point where the metal ion concentration is reduced sufficiently lower to avoid supporting of any stable foam inside.
- Approximately 12.5% level dilution was done.

**Result**
- The problem was mitigated within a week time
Sustainable Action Plan

• the service life of the Fuller’s earth was optimized so as to limit the TAN creep which increases the amount of metal contamination within the fluid.

• Fuller’s Earth replacement from twice in a year to four times in a year.

• For better operating practices both Fuller’s earth kidney filters are kept into service.

• Use of portable type mechanical filter system in addition to dedicated filtration system to improve NAS value.
Recommendation

Retrofitting

- It is felt that the retrofitting the more advanced technology of vacuum dehydration unit may help in restricting the creep in Water content in bulk fluid and the service life of the fluid can be extended further.

Condition Monitoring

- Utmost care of FRF (governing fluid) by means of stringent condition monitoring in those units/projects where service period of FRF has exceeded more than 25 years.
ACKNOWLEDGMENT

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Thank You!