Turbine Lubricant Maintenance and Analysis

Frame 6B Users Group
June 20, 2013

Richard Trent
Hypro Filtration

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EPT
Located in Calgary, Canada

Specialists in
- Turbine Varnish prevention
- EHC fluid maintenance
- Onsite lubricant flushing
- Oil Testing Services

Operating in 20 countries
- Installed on largest plants in Asia, Europe, Middle East and North America

Partnered with Hypro Filtration
Hypro Filtration, Fishers Indiana
“The acid level in our hydraulic fluid was reduced from 3.3 to 0.07. The results were nothing less than outstanding!”
...the fluid has run for over 1-1/2 years

“trouble free”

without a single gallon of new fluid added.

W.A. Parish Generating Station, Texas Gen. Co. 4000MW
4972 MW
• Turbine oil testing guidelines are established and published in ASTM 4378-03
Oil testing guidelines for auxiliary power plant equipment are established and published in ASTM D 6224-02.
Turbine Oil Analyses

Suggested Frequency:

<table>
<thead>
<tr>
<th>Regular Analyses</th>
<th>Periodic Analyses</th>
<th>As Required Analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Every 1 – 3 months</td>
<td>Every 3 – 12 months</td>
<td>Problem investigation</td>
</tr>
</tbody>
</table>

Testing frequency depends on:
- Unit criticality: critical systems should be tested more often.
- Unit age: new units should be tested more frequently during break-in (first 6 months).
- Fluid age: fluids should be tested more frequently when they begin to approach the end of their lifetime (RPVOT < 50% new oil value).

Testing should also be completed 24 hours after any oil change.
## Turbine Oil Analyses

### Analyses Recommended for Gas and Steam Turbine Users:

<table>
<thead>
<tr>
<th>Regular Analyses</th>
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<tbody>
<tr>
<td>Appearance (Clean and Bright)</td>
<td>RULER (ASTM D6971)</td>
<td>FT-IR (ASTM E2412)</td>
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<tr>
<td>Viscosity at 40°C (ASTM D445)</td>
<td>RPVOT (ASTM D2272)</td>
<td>Rust Test – for GT (ASTM D664)</td>
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<td>Total Acid Number (ASTM D664)</td>
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<td>ISO Particle Count (ISO 4406)</td>
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<td>Air Release (ASTM D3427)</td>
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<tr>
<td>MPC (ASTM D7843)</td>
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<td>Demulsibility (ASTM D1401)</td>
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<tr>
<td>Moisture (ASTM D6304 / D7546)</td>
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<td>Insolubles (ASTM D2273)</td>
</tr>
<tr>
<td>Metals (ASTM D5185)</td>
<td></td>
<td>Flash Point (ASTM D92)</td>
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Source: ASTM D4378
Appearance:
- User visual check – quick and efficient.
- Frequency: at least weekly.
- Appearance should be “clean and bright”.
  - Haziness indicates > 100 ppm water.
  - Turbine oils often darken slowly over years of service, however, rapid changes in color may be due to contamination or accelerated degradation and should be investigated.
Viscosity at 40C (100F):

- ASTM D445
- Frequency: Every 1 – 3 months.
- Warning limit: ± 10% new oil.
- Most important characteristic: dictates thickness of lubricating film.
  - Very sensitive to contamination or severe oil degradation.
  - Increase: incorrect oil or formation of a water emulsion.
  - Decrease: incorrect oil or contamination with solvent.
Total Acid Number (TAN):

- ASTM D664
- Frequency: Every 1 – 3 months.
- Warning limit: 0.1 – 0.2 mg KOH/g above new oil.
- Severe oxidative degradation causes increases in TAN.
  - Increase may indicate depletion of anti-oxidants. Compare with results of RULER or RPVOT to evaluate anti-oxidant levels.
  - Hot spots/elevated operating temperatures accelerate degradation.
  - Elevated acid levels cause corrosion.
ISO Particle Count:

- ISO 11500 and 4406
- Frequency: Every 1 – 3 months.
- Warning limit: > 18/16/13.
- Quantifies particles produced by wear or contamination.
  - Once present, particles contribute to accelerated wear.
  - A sudden increase of ≥ 2 codes is cause for concern.
  - Strong correlation between lower ISO code and increased equipment reliability and lifetime.

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<tr>
<th>ISO 4406 - Number of particles per ml</th>
<th>More than</th>
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Servo Failure Vs ISO Code

Figure 3: ISO particle count vs. System Changes time Line

Particle Count (per mL)

Date (dd/mm/yy)

1/14/04 8/01/04 2/17/05 9/05/05 3/24/06 10/10/06 4/28/07

ISO(4) ISO(6) ISO(14) Servo Failure Filter Change Polishing Filter Conditioning Filter Fluid change
Varnish Potential (MPC):

- ASTM D7843
- Frequency: Every 1 – 3 months.
- Warning limit: 30 – 40.
- Fluid degradation leads to the formation of compounds that are precursors to insoluble varnishes.
  - Fluid’s potential to form varnishes quantified on a scale of 0 – 100.
  - 0 – 15: low varnish potential.
  - 16 – 30: possible varnishing.
  - > 41: current level of fluid degradation will lead to varnish. Unit trips likely.
Graphing Varnish Potential Numbers

**MPC ΔE Reduction using SVR**
**Mobil DTE 732**

![Graph showing MPC ΔE reduction over dates from May 2011 to November 2011. The x-axis represents the dates, and the y-axis shows the MPC ΔE values.]
Moisture

- ASTM D6304/D7546
- Frequency: Every 1 – 3 months.
- Warning limit (ppm): GT = 100, ST = 200
- Water hinders lubricating ability of fluid while promoting accelerated fluid degradation and equipment corrosion.
  - Quick check of fluid appearance is a useful screening test.
  - Moisture sources: leaking seals (ST), leaking heat exchangers and/or atmospheric condensation.
Regular Turbine Oil Analyses

Metals

- ASTM D5185
- Frequency: Every 1 – 3 months.
- Warning limit (ppm): statistically determined.
- The presence of metals may indicate equipment wear or fluid contamination. Additive levels may also be monitored.
  - Metal identity used to identify wear/contamination source.
  - Only sees metals < 8 μm. A sudden decrease may indicate that the problem has worsened and larger wear particles are being produced.
Periodic Turbine Oil Analyses

RULER

• ASTM D6971
• Frequency: Every 3 – 6 months.
• Warning limit: 50% of new oil amines.
• Determines levels of antioxidants (generally phenols and amines) remaining in the oil.
  • Oxidation is the primary degradation route for turbine oils. Antioxidants control the rate of oxidative degradation.
  • When antioxidants are depleted, rapid degradation can occur.
RPVOT

• ASTM D2272
• Frequency: Every 6 – 12 months.
• Warning limit: 50% of new oil.
• Determines oxidative resistance.
  • Test more frequently once RPVOT value falls below 50% of new oil.
  • Replace oil once RPVOT value falls below 25% of new oil.
Rust Test (Corrosion Inhibition)

- ASTM D665
- Frequency: Every year for ST, as required for GT.
- Warning limit: failed test (rust formed).
- Turbine oils contain rust inhibitors designed to protect metal surfaces.
  - Test oil if corrosion issues are suspected or when severe contamination (water etc.) may have depleted rust inhibitors.
  - Steam turbines are more susceptible to rusting and it may be beneficial to test them on an annual basis.
Condition Monitoring by FT-IR

- ASTM E2412
- Frequency: As needed.
- Warning limit: statistically determined.
- Used to monitor oxidative degradation of oils by spectral subtraction or direct trending methods.
  - Spectral subtraction method offers simplified interpretation but requires a valid new oil sample.
- Data provided is complimentary to that obtained from:
  - Acid number, MPC and RULER tests.

Source: Noria.
Foam Test

- ASTM D892
- Frequency: As needed.
- Warning limit: 450 mL tendency, 10 mL stability.
- Foaming is often mechanical in origin, however, it can also be caused by anti-foaming additive depletion or oil degradation.
  - Some foaming is normal.
  - Test if foaming is excessive.
  - Excessive foaming can lead to rapid fluid degradation by micro-dieseling.
Air Release

- ASTM D3427.
- Frequency: As needed.
- Warning limit: air release < reservoir residence time.
- The following issues can arise if oil is not given sufficient residence time in the reservoir to release entrained air:
  - Poor lubrication.
  - Poor hydraulic performance.
  - Inability to maintain oil pressure.
  - Degradation due to micro-dieseling.
  - Wear due to cavitation.
Demulsibility/Water Separability

- ASTM D1401
- Frequency: As needed.
- Warning limit: 15 mL emulsion after 30 minutes.
- In GTs, heat drives off free water while in STs, free water can be drained off.
  - If the fluid has poor Demulsibility, water can form stable emulsions.
  - Emulsions hinder the lubricating ability of the fluid and expose both equipment and fluid to the damaging effects of water.
Insolubles by Ultra-Centrifuge

- ASTM D2273
- Frequency: As needed.
- Warning limit: UC rating of 4 – 6.
- Used to detect finely-suspended insolubles for poorly soluble sludge precursors.
  - Complimentary to ISO particle count and MPC.
Flash Point

• ASTM D92
• Frequency: As needed.
• Warning limit: 17 C (30 F) decrease from new oil.
• Degradation has little effect upon flash point, however, contamination by lower-boiling solvents lowers flash point.
  • Such contamination may also lead to a decrease in oil viscosity which can impede lubricating ability.
## Summary:

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<tr>
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**Note:** Check appearance of the turbine oil for color and haziness frequently (at least weekly).
FLEET ASSESSMENT –
TRENDING RATES OF RPVOT AND ADDITIVE LOSS TO DETERMINE NORMAL AND TO IDENTIFY PROBLEM UNITS, AND TO ESTIMATE LUBRICANT CHANGE-OUT INTERVAL
<table>
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<tr>
<th>Age of Oil Months</th>
<th>RPVOT</th>
<th>Amine</th>
<th>Phenol</th>
<th>MPC</th>
<th>Loss Rate RPVOT</th>
<th>Loss Rate Amine</th>
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<th>Increase Rate MPC</th>
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Calculating Loss Rates

• Common question. Will my oil last until the next change out interval in 18 months?

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KNOWLEDGE REVIEW - LUBRICANT COMPOSITION AND FORMULATION
Composition of Lubricant Base stock
• The majority of turbine fluid is base oil (approximately 99%) blended with about one percent additive.

• These additives may consist of antioxidants, rust inhibitors, foam inhibitors, demulsifiers, anti-wear and/or extreme pressure compounds.
Main additive in turbine oil (90%) usually consists of phenol derivatives & amine derivatives.
Amine and Phenol Anti oxidants

No Performance Problems with sufficient levels of phenols.

- Applied voltage increased over time and the corresponding current is measured. All molecules respond to different voltages
Mitsubishi Heavy Industries (MHI)

- developed a test to study sludge formation in turbine oils, Modified TOST test (D943)
  - Run at 120°C, without water
- Tested 20 commercially available turbine oils
- Passing limit: <100mg/kg @ 25% residual RPVOT
Formulation Comparison
6 Different Turbine Lubes
• Formulation chemistry plays a significant role in the varnish tendencies of the lubricant

• Oils with a mixed antioxidant system appear to perform better than oils with an amine or Phenol only systems.

• Phenyl-alpha-napthylamine (PANA) is a commonly used antioxidant. Upon depletion, PANA can cause significant deposits.
What is Varnish? A thin, hard, lustrous, oil-insoluble deposit, composed primarily of organic residue, & most readily definable by color intensity. It is not easily removed by wiping with a clean, dry, soft, lint-free wiping material and is resistant to saturated [light hydrocarbon] solvents. Its color may vary, but it usually appears in gray, brown or amber hues. *ASTM.D02C.01 definition*

Varnish can be soft and gooey *(Sludge)*

Varnish can be hard and brittle *(Lacquer)*

Varnish on reservoir ceiling *(Stalactites)*

Varnish deposits on reservoir floor *(Plated)*
When gas turbines fall casualty to unit trip or fail-to-start conditions, lube oil varnish is the usual suspect!

- Varnish deposits on element (GE F6B)
- Servo valve deposits (stiction)
- Varnish on load gear (GE F6)
- Reservoir deposits

Filter element cross section (lacquer)
Lubricant Oxidation Mechanisms

- Oxidation
  - Water
  - Oxygen
  - Metals

- Thermal Degradation
  - Spark Discharge
  - Micro-dieseling
  - Hot Spots
Sparks on the return line in a steam turbine.

A video of spark events from the return line in a steam turbine lube system.
Varnish Formation Step 1: Lubricant Upset

- **Oxidation**
  - #1 cause of fluid breakdown by water, entrained air, and heat.

- **Oxidation**
  - loss of electron = polar free radical

- **Oxidation byproducts (free radical)**
  - Acids
  - Alcohols
  - Lactones
  - Esters

- **Oxidation byproducts**
  - attack hydrocarbons

- **Anti-oxidant additives**
  - Oxidation inhibitor = arrest free radicals
  - Sacrificial (depletes)
**Lube Oil Varnish**

- **Varnish Formation Step 2: Soluble Impurities**

**Soluble oxidation byproducts**

- Absorbed in oil as byproduct is created
- Polar
- Oil darkens as soluble level increases
- Foul or Burnt odor may develop
- Acid Number (AN) may begin to increase
Lube Oil Varnish

- **Varnish Formation Step 3: Insoluble Suspensions**

**Insoluble oxidation byproducts**

- Oil saturation point is reached
- Oxidation byproducts
  - no longer absorbed in oil
- **Insoluble** oxidation byproduct created
  - Polar oxides (attracted to metal surfaces)
  - Agglomerate into larger soft particles
**Lube Oil Varnish**

**Varnish Formation Step 4: Varnish Deposits**

Insoluble oxidation byproducts

- Affects on metal surfaces
  - Layers of dark, soft gel build up on metal surfaces
  - Cure to form lacquer
  - Reduces tolerance in critical components

- Affects on oil
  - Additive package depletes rapidly
  - AN increases
  - Viscosity increases
  - Sludge & sediment build-up
Lube Oil Varnish

Varnish Formation

• The first surfaces that collect Varnish
  – Cooler zones
  – Low clearance areas
  – Low flow areas

• Because that is where
  – Solubility / Saturation Point drops as temperature drops
  – Precipitation can start
  – Agglomeration is allowed to be un-disturbed
Video- Varnish formation as a function of temperature

50.0 °C (122 °F)
• Varnish potential increases as soluble & insoluble contamination increase.
• Varnish Potential Rating (VPR) can be measured before varnish forms.
• Soluble & Insoluble oxidation by-products are sub-micron and cannot be measured by traditional oil analysis (ISO laser particle counts).
• Patch test & analysis determine the potential of a fluid to form varnish.
  – QSA – Quantitative Spectro Analysis (Analysts, Inc.)
  – MPC – Membrane Patch Colorimetric (ASTM standard, Insight Services)
  – Others – Some independent labs have their own patch method.
• Darker the patch = more soluble, insoluble oxidation by-products in fluid.
• Value increase = Potential increase for varnish to form.
ISO 32 R & O

- Only 30ml of baseline through patch before blocked

---

The sample taken November 19, 2010 was analyzed by membrane patch colourimetry on November 30, 2010 following the recommended method outlined in ASTM D02.C0.01 - WK 13070.

The MPC ΔE is at the monitor range. This means the production of varnish within the system could be approaching soon and the oil condition should be watched.

MPCΔE on 9/15/10: 88.000
MPCΔE on 10/29/10: 17.107
MPCΔE on 11/05/10: 16.735
MPCΔE on 11/12/10: 15.903
MPCΔE on 11/19/10: 12.115
Lube Oil Varnish

RULER Test Measure Anti-Oxidant Levels

- RULER – Remaining Useful Life Evaluation Routine
- Measures Antioxidants relative to a new sample (%).
- Gets around the limitations with RPVOT in which failure point of lubricant can be difficult to measure with modern GT lube formulations.
- Shows relative consumption of additives at the time of sample
- Depletion of AO additives is one reason oil is condemned.
Oil production capacity is moved from Group I to Group II oils

- Group II oils are hydro-cracked versus traditional refining
- Group II oils have lower solvency than Group I
- Group II ability to hold oxidation by-products in suspension is lower than Group I
- Group II oils do not have the conductivity of Group I (charge dissipation)
- Group II oils have higher thermal and oxidation stability
- Role of anti-oxidant additives (Amines & Phenols)
  - Amines react with free radicals / polar oxides (sacrificial)
  - Prevent varnish and deposit formation
  - Phenols recharge the amines so show low RULER levels first
  - Once levels < 20% of new oil condemned Oxidation Rate INCREASES
- Re-additization of oil - Replenishing Phenol Additives
  - New additive might not be compatible with changed oil chemistry
  - New additive typically not soluble in the in-service oil (short life)
Varnish Formation “Clock”
Soluble Varnish Removal

Reversing the chemical reaction of varnish deposit formation

1. Off-line SVR connects to main lube reservoir up to 8000 gal/30,000 liters
2. Oil is circulated through ICB vessel & post filter
3. Soluble oxidation byproducts removed by ICB cartridge
4. Oxidation byproduct level in oil drops below saturation point
5. Oil regains solubility
6. Insoluble oxidation byproducts are dissolved back into oil and removed by ICB cartridge
7. Oil regains solubility (oxides removed as created)
8. Varnish is dissolved back into oil and removed by ICB cartridge
Soluble Varnish Removal

VTM Insoluble Filter Element

ICB Soluble Varnish Element
Ion Charge Bonding (ICB) is the only technology that can remove the soluble impurities

1. Eliminates varnish forming insoluble oxidation byproducts
2. Restores oil solubility (health), allowing the oil to clean the system
3. Varnish deposits dissolved back into the oil and removed by ICB element

Polar soluble oxidation byproducts must be removed before oil saturation point is reached. Not doing so leads to insoluble molecules and varnish formation.
Lube Oil Varnish

Graph: Varnish Potential (MPC) Trend After SVR Installation
Lube Oil Varnish

Varnish Potential (MPC) Trend After SVR Installation

- SVR1200 Installed (MPC ΔE Critical)
- MPC value plateau (change elements)
- MPC ΔE Normal

Days in Service vs. MPC ΔE Value

Copyright © EPT 2012, All rights Reserved
The sample taken April 14, 2011 was analyzed by membrane patch colourimetry on April 21, 2011 following the recommended method outlined in ASTM D202.05.01 - WK 13070.

The MPC ΔE is at the good range. This indicates that there are low levels of the precursors that lead to soft contaminants (varnish).
SVR installation GE Frame 7FA

**VARNISHING POTENTIAL ANALYSIS**

| Lube Type: | MOBIL DTE 832 |
| Machine MFG: | GENERAL ELECTRIC |
| Machine MOD: | 7FA |
| Machine Type: | Industrial Turbine |
| Received: | 11/04/2009 |
| Report: | 11/11/2009 2:41:00PM |
| Sample No: | 1328-45-2004 |

**VARNISH STATUS**

- Normal

**UC VALUE**

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**COLOR VALUE**

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**ULTRA CENTRIFUGE TEST**

| UC VALUE | 1 | 1 | 1 | 3 |

**MEMBRANE PATCH COLORIMETRY**

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**PHYSICAL PROPERTIES**

| ACID NUMBER mg KOH/g | 0.110 | 0.090 | 0.070 | 0.110 |
| KARL FISCHER WATER ppm | 50 | 40 | 40 | 10 |

**RULER TEST**

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Filter Element Sparking

- Friction through filter media creates static charge on elements
  - Group II oils not conductive & some elements use non-conductive materials
  - Charge arcs through filter media to nearby metal surfaces (core, housing)
  - Excessively high heat results in thermal degradation (pyrolysis)
  - Spark Damages filters (reduced efficiency) and oil (creates acids & fines)
  - Sparking can be heard as popping / clicking (lube or hydraulic elements)

Evidence of sparking
Filter Element Sparking

Plastic Mesh Element - Electrical Arcing Damage

Non-conductive filter materials can’t shed static charge

Static Arc Burn Hole
Hy-Pro Non-Spark Discharge (NSD) Elements

- Reduced resistance to prevent charging / friction
- NSD uses all conductive filter element materials
- Available in all Hy-Pro series (lube & Hydraulic)
- Primary apps main lube duplex and EHC elements
- P/N HP102L18-12MV = HP102L18-12EV-NSD
- Some report lower MPC after NSD elements (40 to 30)
- Minimizes thermal degradation
- Prevents one of the causes of varnish
Hy-Pro Non-Spark Discharge (NSD) Elements

Varnish deposits on NSD lube element

- Does varnish deposits on elements = sparking?
- No, Hy-Pro NSD elements will collect varnish on ferrous metal surfaces
- This is an indicator that varnish could soon form in the lube system
Varnish Test Equipment - MPC

MPC patch test kits (VFTK field kit, VLTK lab kit)
- Photospectrometer reports results as $\Delta E > 0$ (included in kit)
- Kit available w/out Photospectrometer & P-meter available individually
- Includes detailed reference and results interpretation manual

VFTK - Field kit

VLTK - Lab kit
Many users don’t react until QSA / MPC is critical

- Installing SVR without high QSA / MPC extends oil life
- Phenol is the low temp AO additive that fights varnish & deposit formation
- GE Frame 7 without SVR was consuming 20% of phenols annually
- Oil was replaced and SVR installed
- After 16 months of operation (+ SVR) phenol levels were unchanged
- SVR is extending oil life by removing soluble oxidation byproducts
- Phenol anti-oxidant additives aren’t consumed as quickly, with SVR
- Lube oil with < 20% remaining phenols is typically replaced
- In this case SVR performs role of sacrificial phenol anti-oxidant
- Turbine can continue to run with no risk of varnish on the same oil

SVR - The case for prevention
- Gas turbine was losing 20% of AO additives annually
- After changing oil installed SVR on the lube reservoir
- After 20 months AO levels are still near new levels with < 5% depletion
- Life of the oil has been extended with SVR by slowing AO depletion
- Oil typically condemned once AO are 20% of new values
Lube Oil Varnish Prevention

The Solution - Summary

- Determine oil condition & oil type (Shell CC 32)
  - OA reports for QSA or MPC (varnish potential)
  - OA reports RULER for additive levels

- SVR (soluble varnish removal) skid
  - Removes soluble oxidation by-products
  - Restores oil health
  - Healthy oil removes varnish deposits
  - Installation requirements

- Non-Spark filter elements
  - Lube duplex
  - Pump discharge filters (combined L&H reservoir)
  - Pilot valve filters (combined L&H reservoir)
  - Off-line filters, sparking typically not a problem
• Mobil 732 on GE 7FA
• IGV filter elements before SVR installed with varnish deposits
• Support tube coated with varnish
• Valve failures and heavy deposits

• New resin implemented for 732 / 832
• MPC dropped from high 30’s to < 10
• No more deposits on IGV filter elements
• No more valve deposits
• New resin will be future standard
Thank you. If we can be of any support please contact us.

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