Gas Turbine Lubrication

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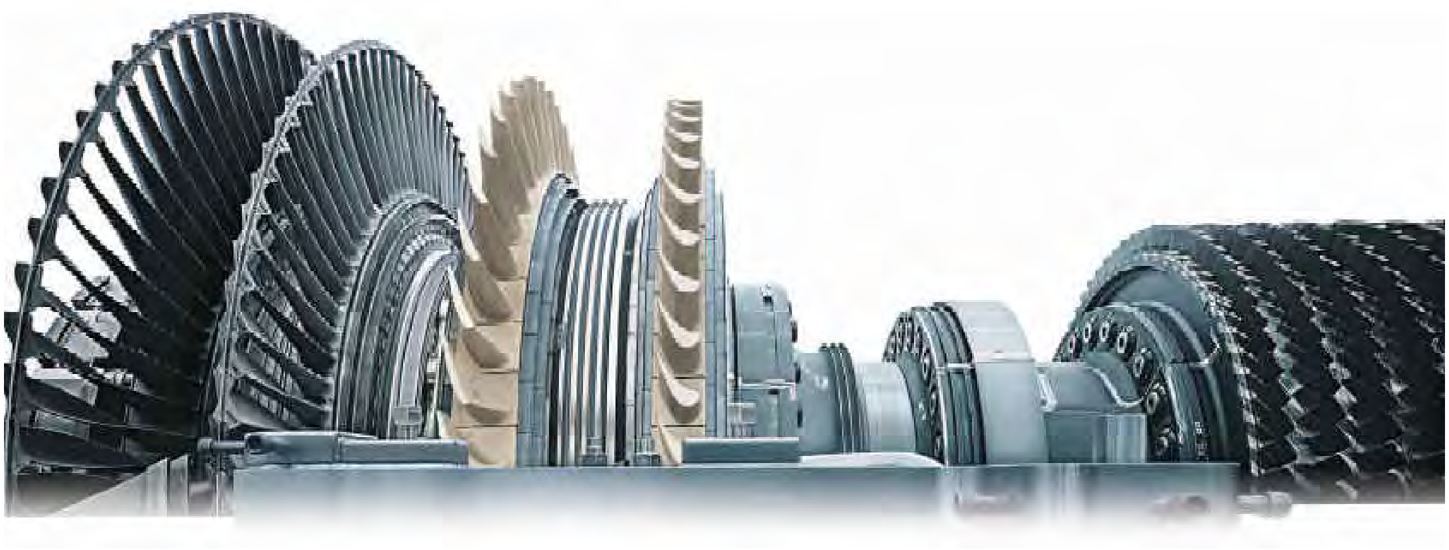
ExxonMobil Lubricants and Specialties



Agenda

- Definitions
- Varnish/Deposit Issues
  - Industry Drivers
  - Oil Factors
  - Operating Factors
  - Maintenance Factors
  - Detection
  - Prevention
- Oil Analysis
- Recommendations
- Best Practice Recommendations

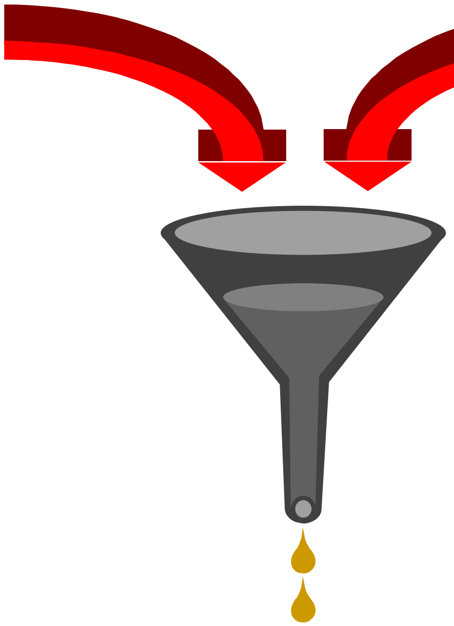
Definitions

- Viscosity – a fluids resistance to flow
- Viscosity Index – how viscosity changes with temperature
- Turbine Oil Composition
- Mineral Base Oils
  - Components of mineral base oils
  - Saturates
- Oxidation
- TOST
- RPVOT
- Varnish

Turbine Oils Made Of Two Things

BASE STOCK

ADDITIVE

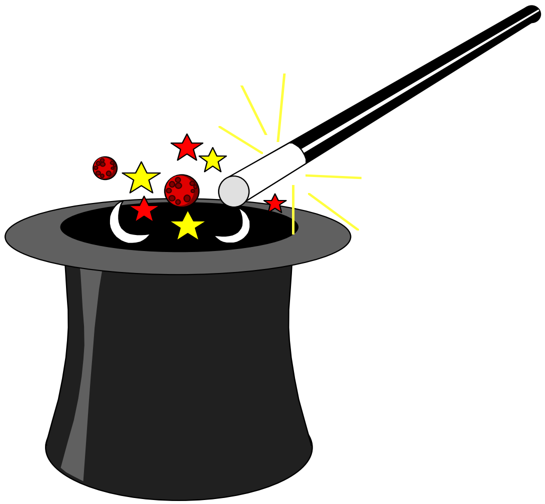


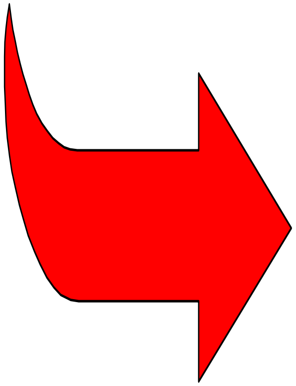
FINISHED LUBRICANT

- **Base Oil**
  - Several Base Oil Types and Technologies are Available
    - API Category I, II, III, IV and V
  - Properties and Quality of Base Oil have a Strong Impact on
    - Thermal and Oxidative Stability of the oil
    - Viscosity Index
    - Oil Consumption via base oil volatility
- **Additives**
  - Needed to enhance base oil lubricating qualities and life
    - Oxidation Inhibitors – increase the service life of the lubricant
    - Rust Inhibitors – prevent rust and corrosion
    - Foam Inhibitors – reduce foaming tendencies
    - Antiwear and Extreme Pressure Additives – increase load carrying ability
  - Additives must be properly balanced and matched to base oil properties and specific application requirements
  - More is not necessarily better!

A Balanced Formulation is Most Important!

Mineral Base Stocks

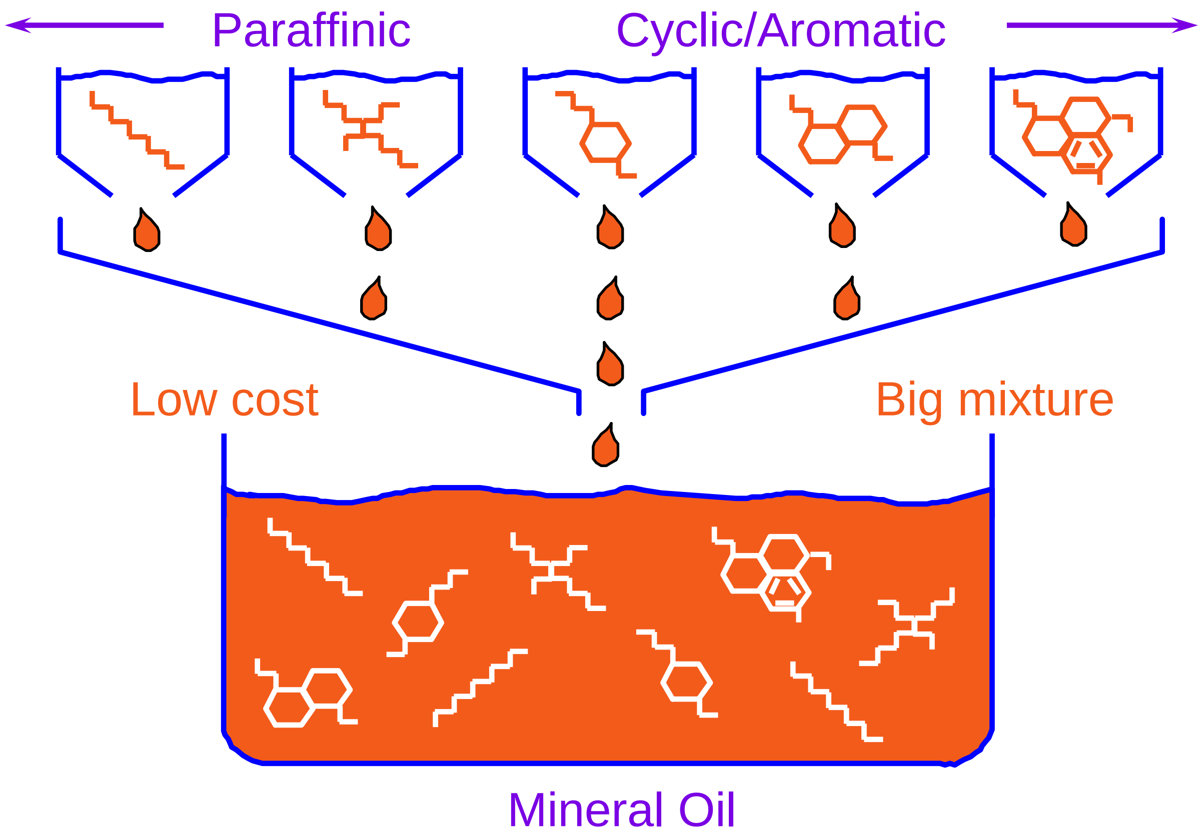




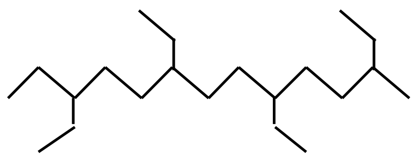
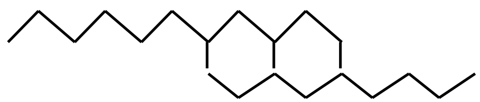
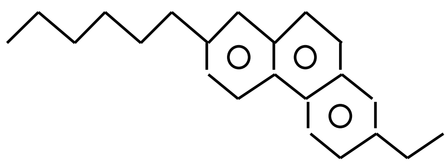
Complex mixture

Molecules not chosen for their lubrication properties

Mineral Base Stocks

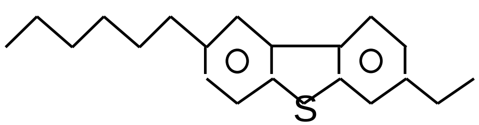


Mineral Oil Molecular Make-Up

		VI	POUR POINT	VOLATILITY
N - PARAFFINS		VERY HIGH	HIGH	LOW
IS0 - PARAFFINS		HIGH	LOW	LOW
NAPHTHENES (CYCLO PARAFFINS)		MODERATE	LOW	MODERATE
AROMATICS		LOW	LOW	HIGH

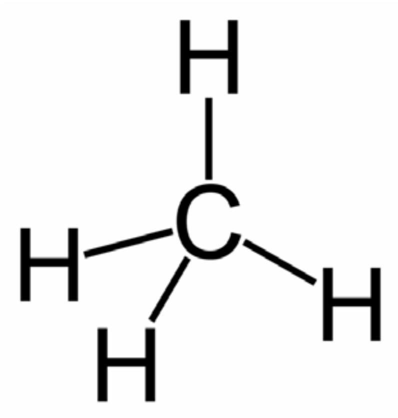
BASE OILS ALSO CONTAIN SULPHUR COMPOUNDS

e.g



What is a Saturate or Saturated Hydrocarbon?

- Hydrocarbons are composed of atomic Carbon and Hydrogen in varying proportions and configurations
- Each Carbon atom has four available sites for chemical bonds to form
- The most simple example, Methane or CH_4

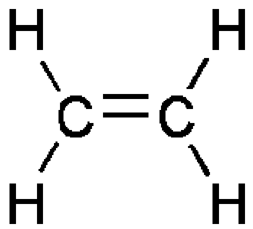


- The molecule cannot combine with other elements without giving up a hydrogen atom

What is a Saturate or Saturated Hydrocarbon?

•***Un***saturated hydrocarbons have double or triple bonds and are more reactive.

•A simple example of an unsaturated hydrocarbon, Ethylene, C_2H_4.



•Unsaturated hydrocarbons are less stable than a saturated hydrocarbon because of the double bonds

•In lubricating base oils, more highly refined base oils contain more saturated hydrocarbons and therefore have better oxidation stability

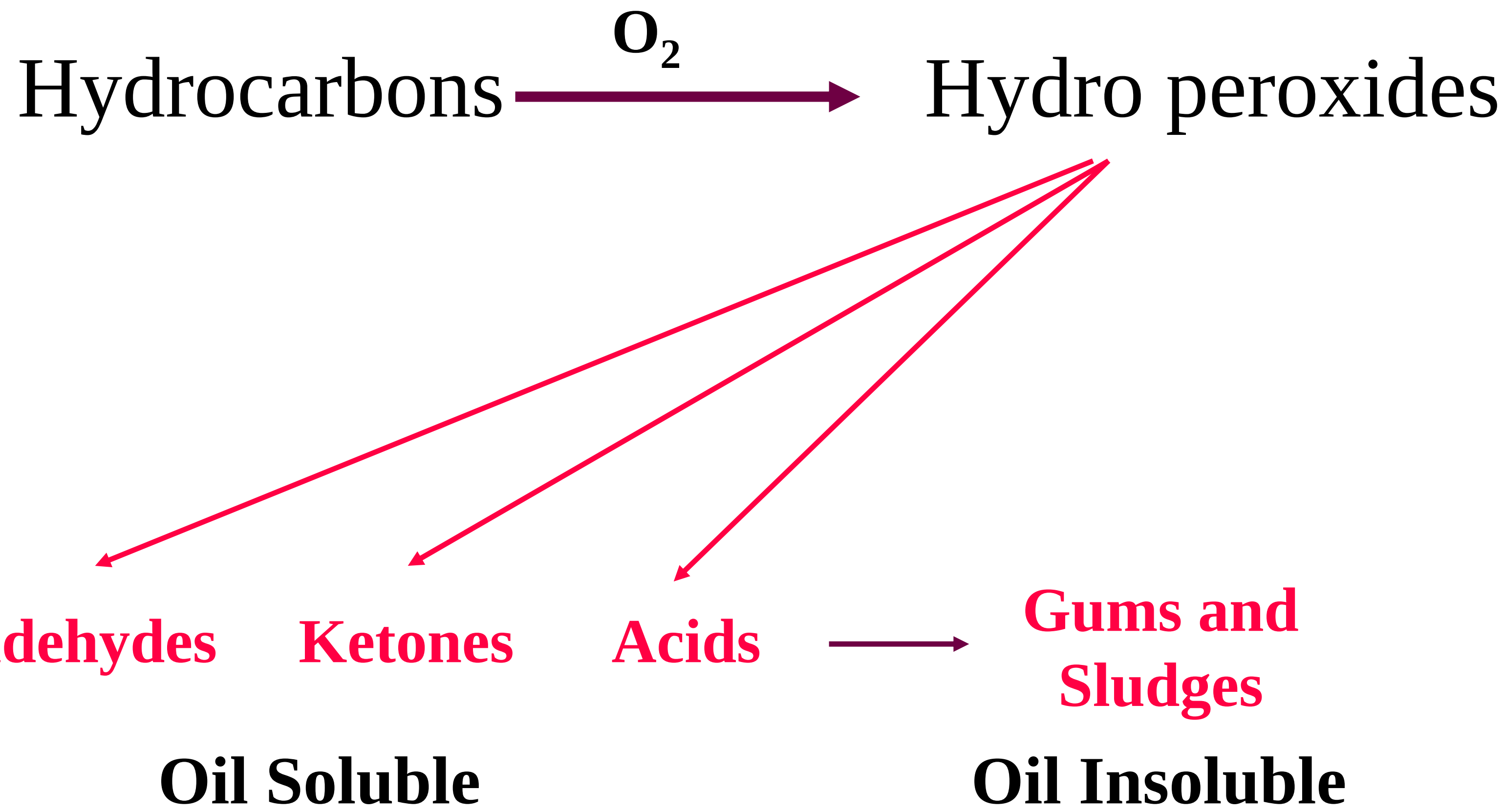
•Everyday Example - Saturated Fat is bad since it is not readily broken down in your body. Unsaturated fat is better since there are available chemical bonds to react.

OXIDATION

CHEMICAL REACTION OF OIL AND OXYGEN TO FORM ORGANIC ACIDS

Indications - Dark Color,
Burnt Smell, Increased Viscosity,
Sludge/Varnish

Oil Oxidation



Oxidation Tests

Total Acid Number / Neutralization Number
ASTM D 664

The weight, in milligrams, of potassium hydroxide needed to neutralize the acid in 1 gram of oil

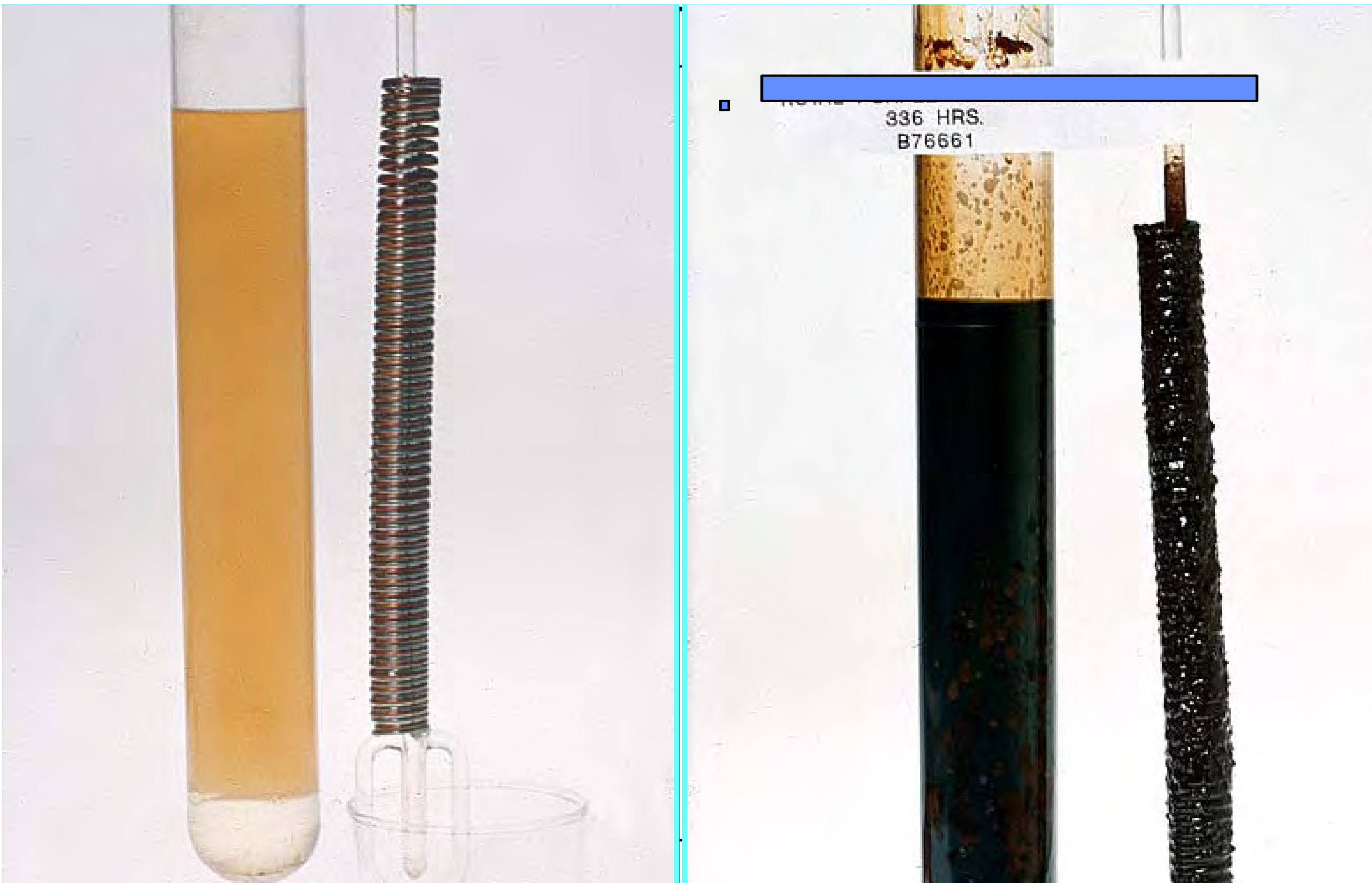
Oxidation Tests

Inhibited Oil Oxidation Test or TOST
ASTM D 943

- Accelerated Oxidation Test Measured in Hours
- Oil in the Presence of Water, a Catalyst and Oxygen
- Number of Hours to TAN of 2
- *Developed to Evaluate New Turbine Oil Anticipated Performance*
- Reporting above 10,000 hours is not Possible within ASTM D 943 test Protocol

Oxidation Tests

Inhibited Oil Oxidation Test - ASTM D 943

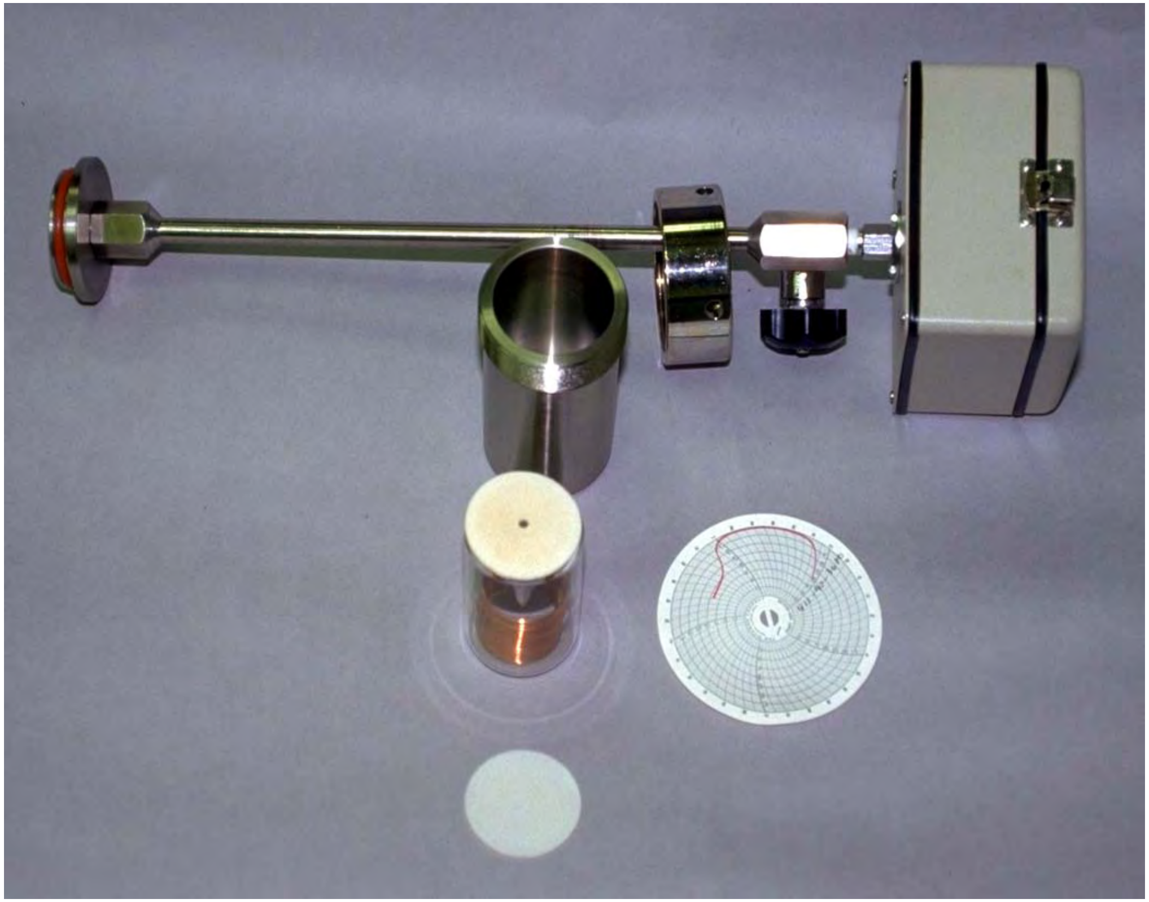


Oxidation Tests

Rotary Pressure Vessel Oxidation Test (RPVOT) ASTM D 2272

- Pressurized Cylinder with Oxygen
- Number of Hours to Specified Pressure Drop as Oxygen is Consumed
- ***RPVOT was Designed for Oil Condition Assessment, NOT Competitive Comparisons***

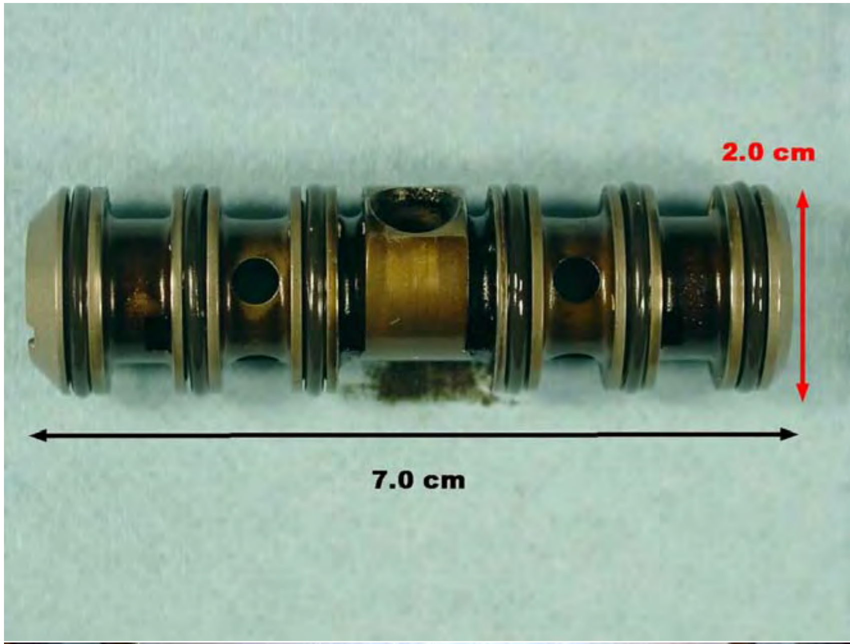
RPVOT Test Pressure Vessel & Recorder



What is Varnish?

Varnish:

- is a thin, insoluble film deposit occurring on lubricated components
- is a contaminant composed of lubricant degradation by-products that can be light yellow to black in color.
- is a high molecular weight substance that is unstable in oil
- is difficult to remove by wiping.
- Unlike most oil-related problems, it does not directly lead to wear or corrosion
- Is considered a “soft” contaminant



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Turbine Varnish Deposits

- The Industry Drivers
  - New competitors, increasing fuel costs, increasing equipment costs, increasing maintenance costs
- The Design Drivers
  - Increasing thermal efficiency - hotter running
  - Move to smaller footprint - decreasing reservoir size
- The Operational Drivers
  - Lengthening maintenance intervals, longer oil drain intervals, more peaking and cyclic service than ever before

Turbine Varnish Deposits

- Drivers leading to increasing deposits in control valves and upstream filters and unplanned outage on turbines

- Analysis of deposits in several cases show them to be very fine particles created as oxidation by-products of the turbine oils in service

- Investigation has provided insight to causes and effects, how to detect them, how to mitigate them, and how to reduce them

Cause & Effect

- <u>Oil Formulation Factors</u>
  - Not readily correlated to industry tests
    - TOST, RPVOT, TAN, and Viscosity Increase not good indicators of deposit presence or tendency
    - *Higher New Oil RPVOT or TOST ≠ Decreased Varnish Potential*
  - Balanced formula critical - additives and basestocks
    - Additives – over-treating to achieve high oxidation test results may lead to more deposits
    - Basestocks are a double-edged sword - higher saturates typically means better oxidation performance, but less natural deposit control

BASE STOCKS - API CLASSIFICATION				
Group	Physical Specifications			Production Process
	Visc. Index	Sulfur, wt %	Saturated Hydrocarbons, wt %	
I	80-120	>0.03	<90	Mineral Oil Conventional (Solvent Refined)
II	80-120	<0.03	>90	Mineral Oil - Hydrofinishing required
III	>120	<0.03	>90	Severe Hydrofinishing required
IV	>140	0.00	>90	Chemical Synthesis - PAO
V				All other types

Cause & Effect

- Oil Formulation Factors
  - Turbine oil formulations are driven to use of More API Group II and Group III base stocks
  - **Positives** - Group II and III base stocks:
    - Higher percentage of saturates
    - More oxidation stability
    - Higher Viscosity Index
    - Fewer undesirable constituents
  - **Negatives** - Group II and Group III base stocks
    - Have reduced solvency for oxidation by-products and additives
    - Reduced solvency leads to more difficulty in detecting varnish pre-cursors
    - Increase the potential to leave deposits since the materials are less soluble in the oil

Cause & Effect

- Operation Factors
  - High operating temperatures
    - 150°C (300 °F) not uncommon in bearings today
    - Hydraulic circuits around combustion turbine may also see higher temperatures
  - Aeration
    - Leads to increased surface contact between oil and oxygen - may increase rate of oxidation
  - Cyclic Service
    - Shut down - soak-back heat oxidizes oil next to hot components
    - Static oil - turbine oils designed to drop contaminants out when static, good in reservoirs but may leave deposits elsewhere
    - Oil temperature decreases - the oil has reduced capacity to hold contaminants suspended as temperature drops - lower than ~ 40°C (100°F) will accelerate drop out

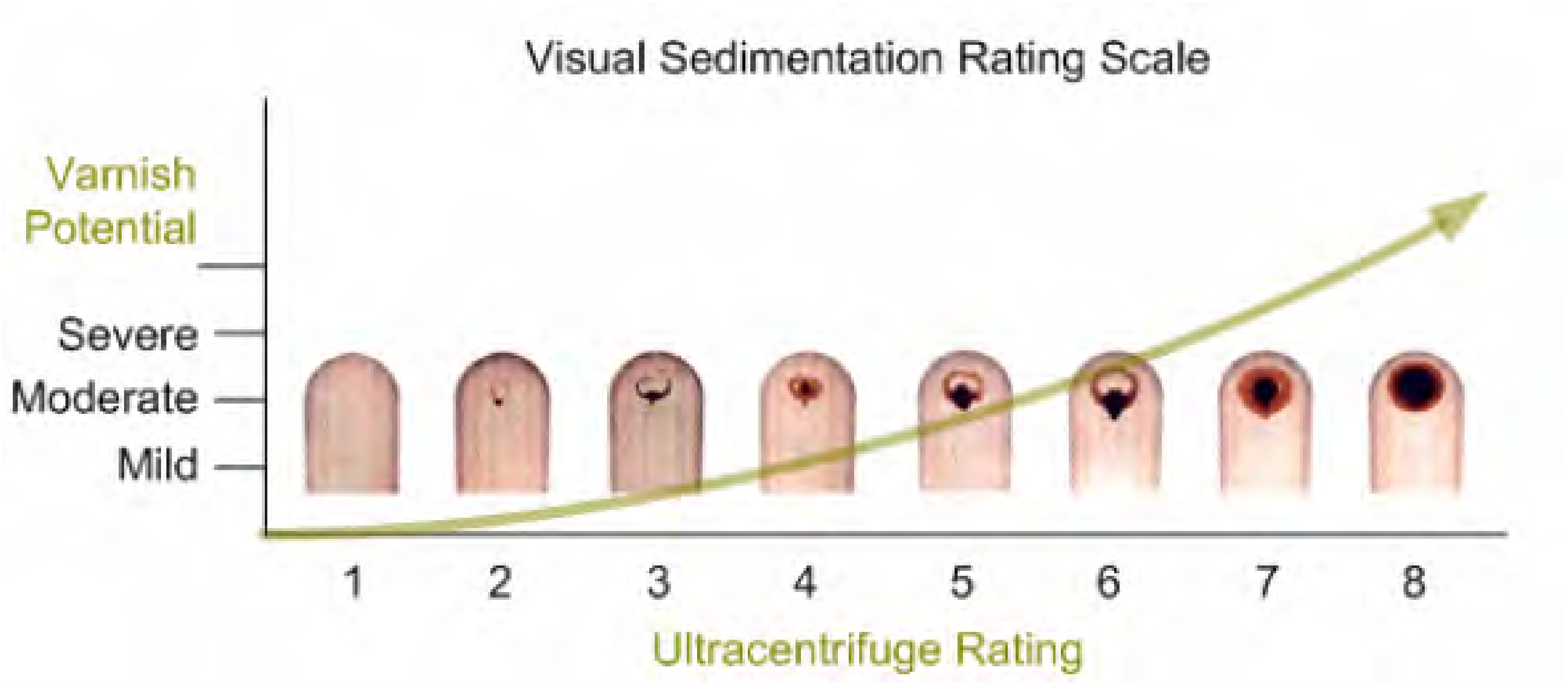
Cause & Effect

- Maintenance Factors
  - Filtration
    - The contamination particles that cause these deposits are too small for traditional filtration to catch
    - Possible electrostatic discharge with fine synthetic media can be a contributing to deposit tendencies
  - Circulate oil and keep it warm
    - Many systems cease oil flow during shut down, and the circulation and hydraulic systems are not heated
    - These factors encourage the oil to drop accumulated contaminants out of suspension
  - Cooling systems
    - When cooling systems are not maintained they lose efficiency, leading to increased heat load on the turbine and the oil - this may lead to accelerated oxidation and deposit formation

Detection

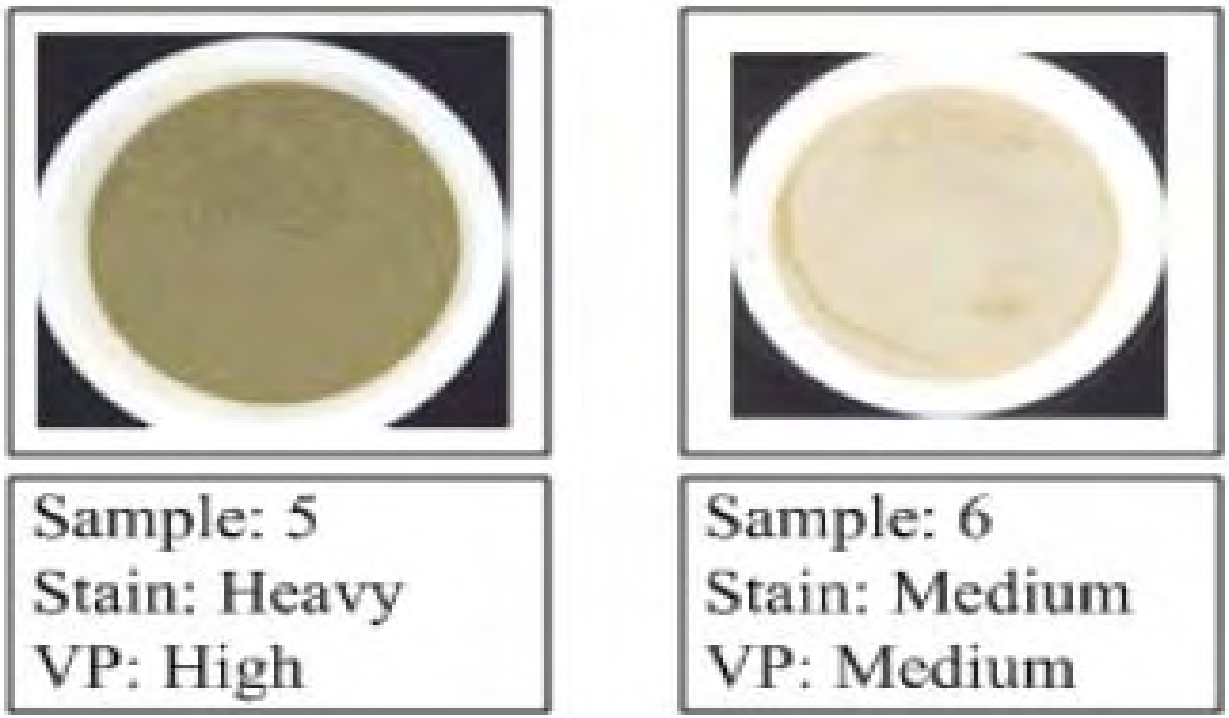
- Traditional used oil analysis (UOA) test methods *do not* catch developing deposit tendency
  - TAN, RPVOT, Oxidation by FTIR, and Viscosity are the typical oxidation indicator tests - they are not effective at detecting deposit tendency
- Several tests have shown varying degrees of additional capability to detect deposit-forming materials
  - Particle Count - focus on 4μ rating *may* provide useful data
  - Ultra-centrifuge - good correlation but not widely available
  - Gravimetric - trends weight of filtrate on fine filter patch
  - Colorimetric - compares color spectra trends of filtrate captured above

Detection



- Ultra Centrifuge Test Developed by ExxonMobil
- Test offered through ExxonMobil Suitability for Continued Service Turbine Oil Testing

Detection



Colorimetric Test Results

Prevention

- Oil Selection
  - Look at the specifications and glassware results

  - AND -

  - Look for work done by the oil manufacturer to evaluate deposit control and overall formulation balance
  - Look for proof of performance in similar units

Property Retention Test - example

- **<u>Proprietary ExxonMobil Property Retention Test</u>: Filter ratings after 2000 hrs**
  - **Scale: 10 = Clean filter   Rating <5 = Unacceptable**

Oil A
2000hrs
rating = 6.7
RPVOT 1,200
TOST >10,000

Oil B
1500hrs
rating = 2.8
RPVOT 2,000
TOST >10,000

Oil C
1500hrs
rating = 2.7
RPVOT 1,700
TOST > 10,000

Oil D
1000hrs
rating = 2.0
RPVOT 3,000
TOST > 10,000

Prevention

- Operation and Maintenance
  - Additional filtration, full flow + kidney loop
    - Electrostatic Precipitation and Balanced Charge Filters do appear to be effective
  - Quarterly UOA, with particle count and varnish detection tests
  - Circulation system on, during shut-down
  - Keep oil above 40°C (F) during shut-down
  - Select and maintain heaters carefully
  - Optimize cooling systems
  - Follow OEM change interval, extend only with experience
  - Flush system when new or changing oil - do not reuse flush oil without full testing and approval by oil manufacturer

Oil Analysis

Oil Analysis

ASTM D4378-97

- ASTM D4378-97, “Standard Practice for In-Service Monitoring of Mineral Turbine Oils for Steam and Gas Turbines” is the recognized standard for the power generation industry, providing lube oil analysis warning limits
- Turbine OEMs and lubricant suppliers also offer test recommendations and warning limits (see GE 32568)
- Important!
  - Base line oil sample result
  - Continuous trending
  - Location and Method of sampling

Typical Oil Analysis Tests

- <u>Physical and Chemical Properties</u>
  - Viscosity (ASTM D445)
  - Water (ASTM D1744)
  - Oxidation (FTIR)
  - Acid Number (ASTM D974)
- <u>Wear Conditions</u>
  - Metals (ICP)
  - PQ INDEX
- <u>Cleanliness of Oil</u>
  - ISO Particle Count

Periodic Oil Analysis Testing

Suitability for Continued Use Testing

- Additional Tests Targeted at the Suitability of Fluid for Continued Service
- Standard Oil Analysis Test Slate Plus:
  - RPVOT (ASTM D2272)
  - Foam (ASTM D892) - If warranted
  - Rust (ASTM D665A) - If water is present
  - Demulsibility (ASTM D1401) - If water is present

Guidelines for Oil Analysis Result Interpretation

- **Viscosity:**
  - + / - 20% of New (ASTM)
  - 25 cSt minimum and 41 cSt maximum (GE)
- **Total Acid Number:***
  - 0.4 mg KOH/gram max (GE)
  - 0.3 to 0.4 mg KOH/gram increase over new oil (ASTM)
- **RPVOT:***
  - 25% of new oil value (GE)
  - 25% of new oil value together with high TAN (ASTM)

  - * RBOT and TAN will be the key indicators of remaining service life

Recommendations

- Assess your current situation - look at operation reliability, conduct in-depth oil analysis including one or more of the tests that indicate deposit tendency - Particle Count, UC Sediment, Colorimetric, Gravimetric

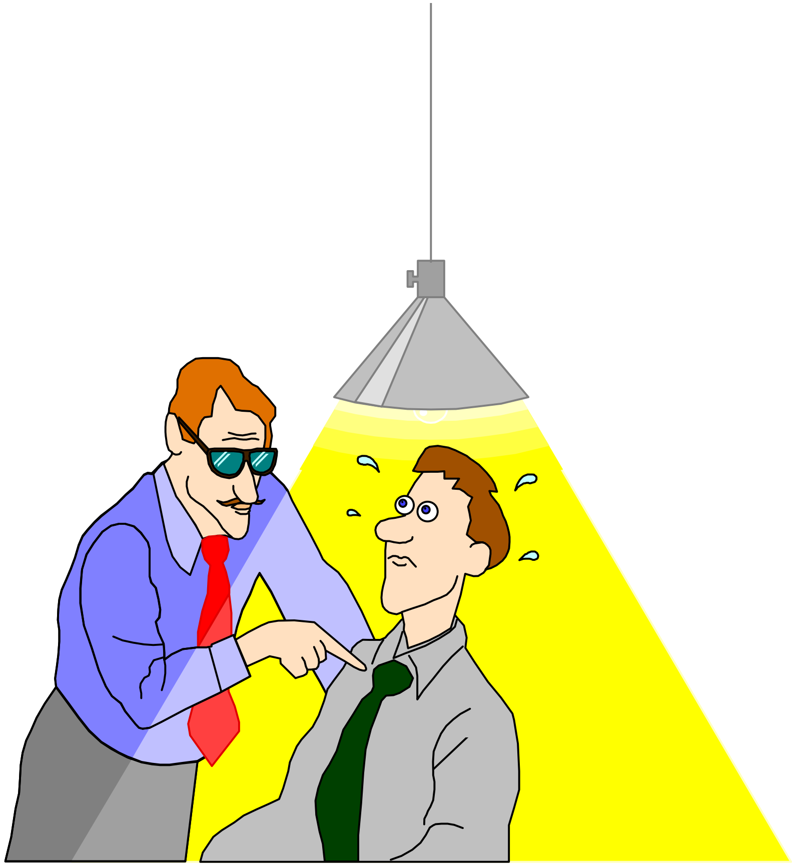
- Determine course of action - work with all resources available to you
  - Work with filter supplier to determine if you have correct filtration
  - Talk with alternative (electrostatic, balanced charge, ion-exchange) filtration suppliers to determine if they would help your situation
  - Discuss flushes or system cleaning with reputable service company to see if they are applicable
  - Work with your oil supplier - but look for product with balanced performance, look beyond the specifications and glassware results, benchmark with others in industry to validate performance
  - Implement any best practice tips from next page that are applicable to your operation

- Be sure to measure baselines so you have a basis to determine total cost of ownership improvement due to your efforts

Best Practice Tips

- Implement ultra-fine filtration, full flow + kidney loop
- Conduct quarterly used oil analysis, with one or more - particle count, ultracentrifuge, colorimetric & gravimetric
- Keep the circulation system on during shut-down
- Keep oil above 40°C during shut-down
- Use kidney-loop system to accomplish two tips above if necessary
- Select and maintain oil heaters carefully
- Optimize cooling systems to insure oil is not overstressed thermally
- Follow OEM change interval on components, extend only with experience
- Run hydraulic control circuits through full range of motion possible - on shut down and prior to start-up - to flush out any debris
- If commissioning a new unit, make sure to conduct a thorough flush, and don't use the flush oil as the initial charge of turbine oil without careful work with your oil supplier

Questions?



Case Study Back Up

Case Study

- Approximately two and a half years after commissioning a GE Combustion Turbine/Generator, it started experiencing hydraulic servo valve sticking. The valves were replaced and spares kept on hand.
- The valve sticking problem occurred several more times, with shorter intervals between events, and more severe deposits observed at each event.
- Routine oil analysis did not indicate any problems with the oil - in fact the oil was rated suitable for continued service.
- Reliability of the unit was decreasing.

Case Study - Routine Oil Analysis

- The unit commissioned in June 1999. Routine oil analysis did not indicate any problems.
  - No wear or contaminant metals
  - Initial Particle Count slightly high, but greatly improved after initial plugging event
  - Water content low - occasional spikes but always below 50 ppm
  - No significant viscosity increase, slight elevation after ~ 4 years
  - No increase in Total Acid Number

Case Study - The First Sticking Event

- In January 2002, the turbine experienced its first event of hydraulic valve sticking. All servos were changed and spares ordered to keep on site.

- Investigative analysis reported the deposits were primarily oxidation by-products of the oil (~ 65%), with some slight contamination (sulfates, phosphates, and in one case, acryloid polymer).

- Additional filtration was performed on the oil, resulting in particle count reduction (15/14 to 14/12).

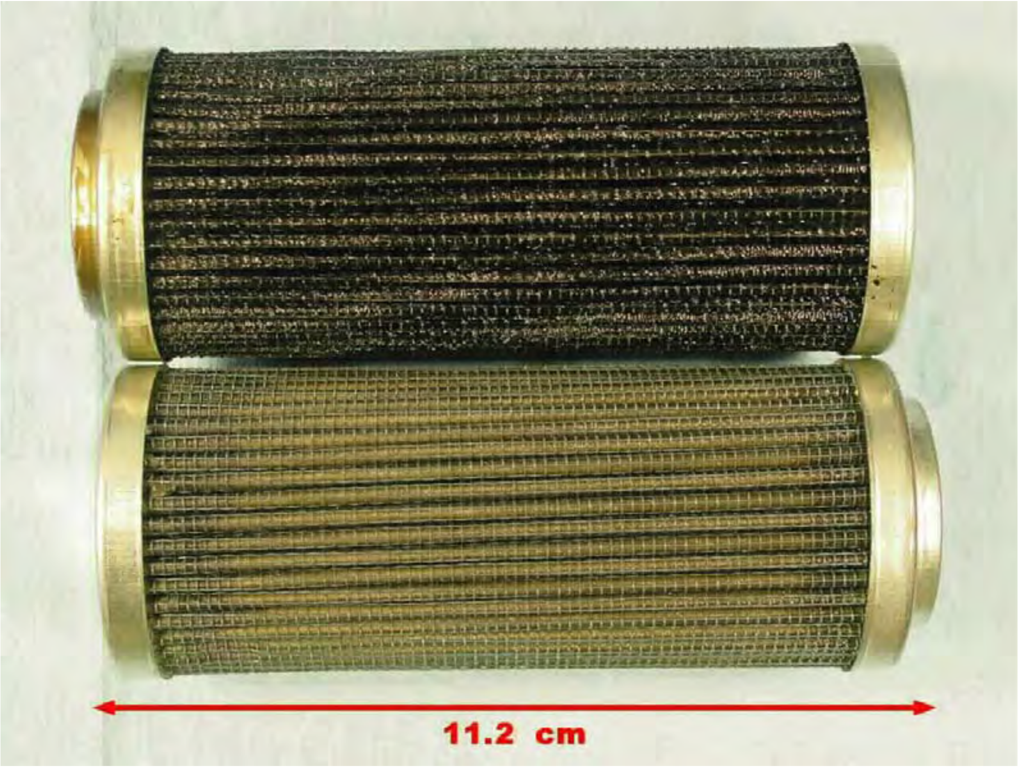
- Filtration was made finer on the unit, leading to a decreasing trend in particle count (typically 12 or 13 / 10 or 11).

- The servo changes and added filtration appeared to have corrected the problem.

Case Study - The Problem Recurs

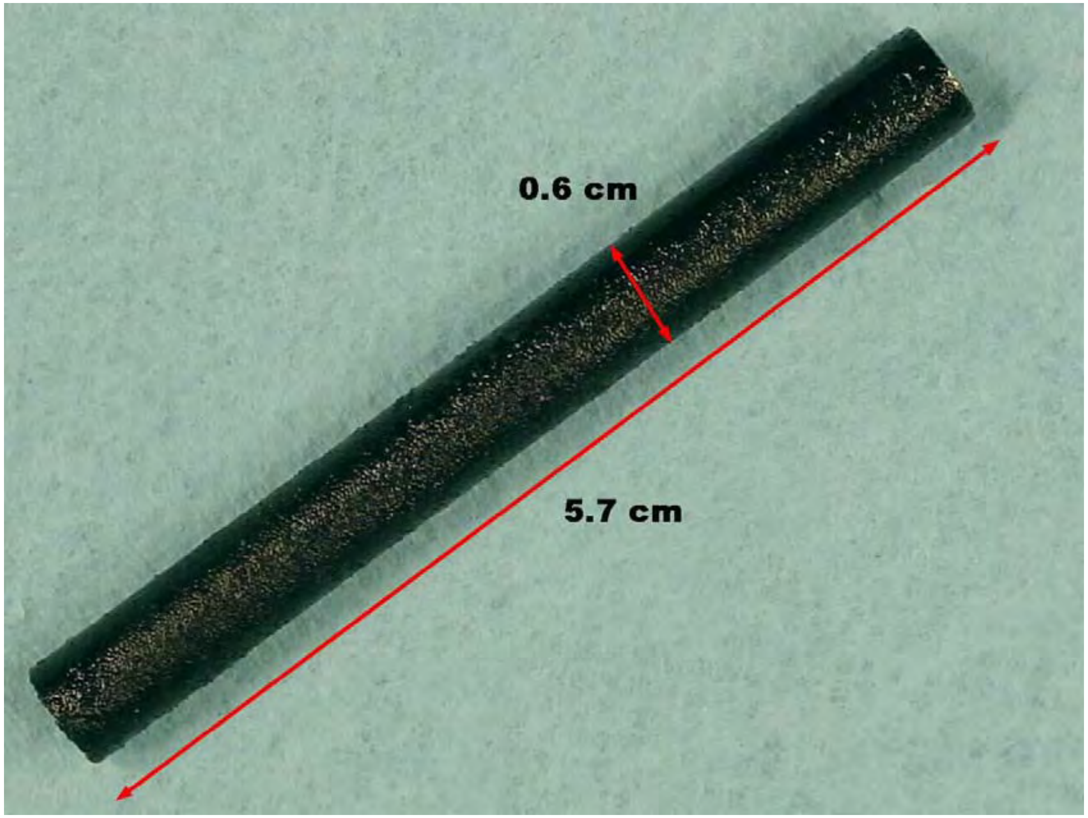
- In September and October 2003, there was severe fuel gas valve sticking, leading to a trip during a load reduction.
- Thorough investigation of the parts showed stuck servos, plugged hydraulic filters, significant varnish on cooler plates, and stuck trip relay pistons. All components replaced with new/refurbished parts.
- A thorough investigation was launched, and the deposits on all parts were analyzed. They were all similar, and comprised mostly of oxidation by-products of the oil, with contaminant sulfates, metals, environmental debris, and slight wear or corrosion metals.
- *The oil analysis still showed no cause for concern on the standard used turbine oil tests.*

Deposit Analysis Photos



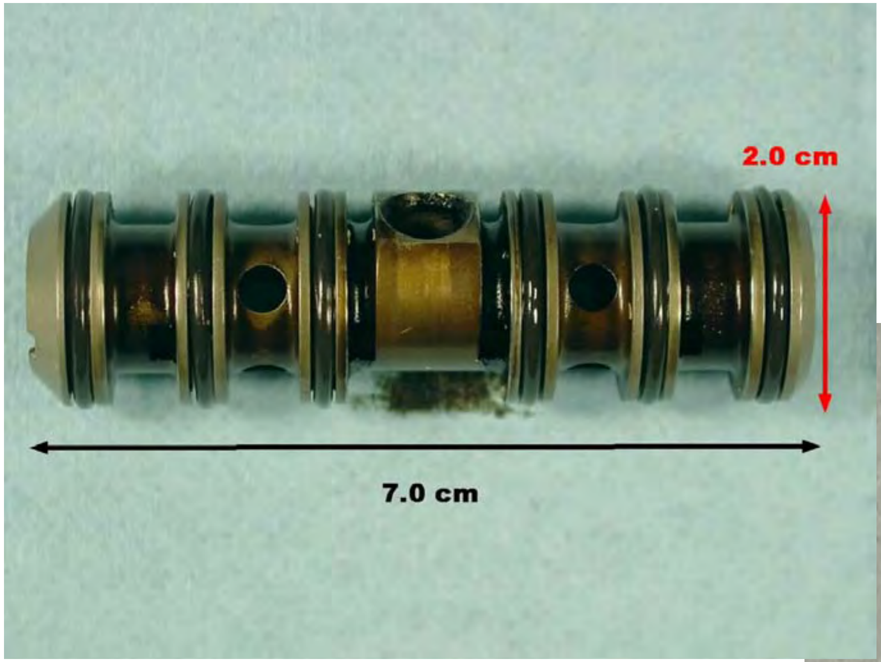
External Servo Filters PM-4 and PM-3 (top and bottom, respectively).

Deposit Analysis Photos



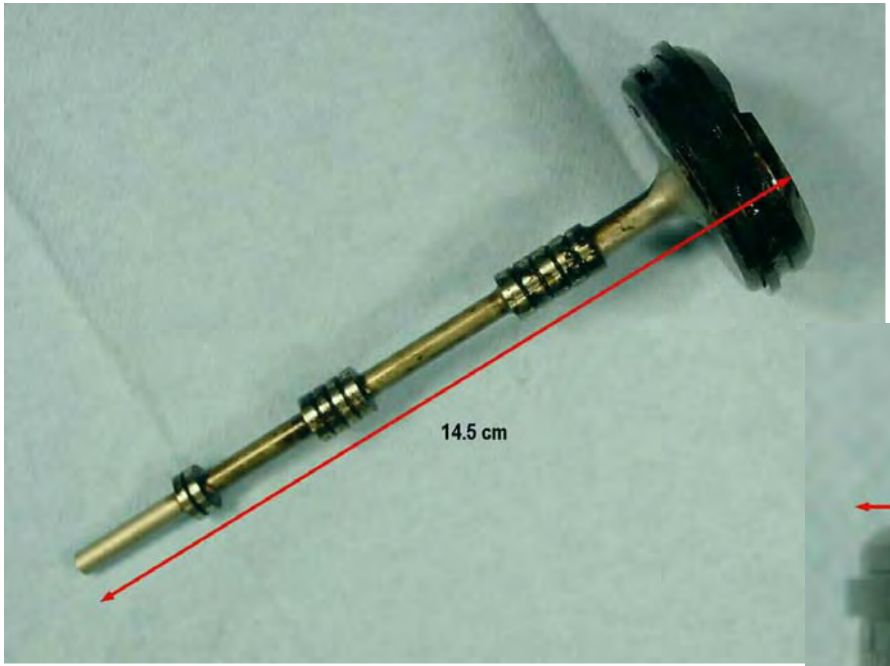
PM-4 Pencil Filter

Deposit Analysis Photos

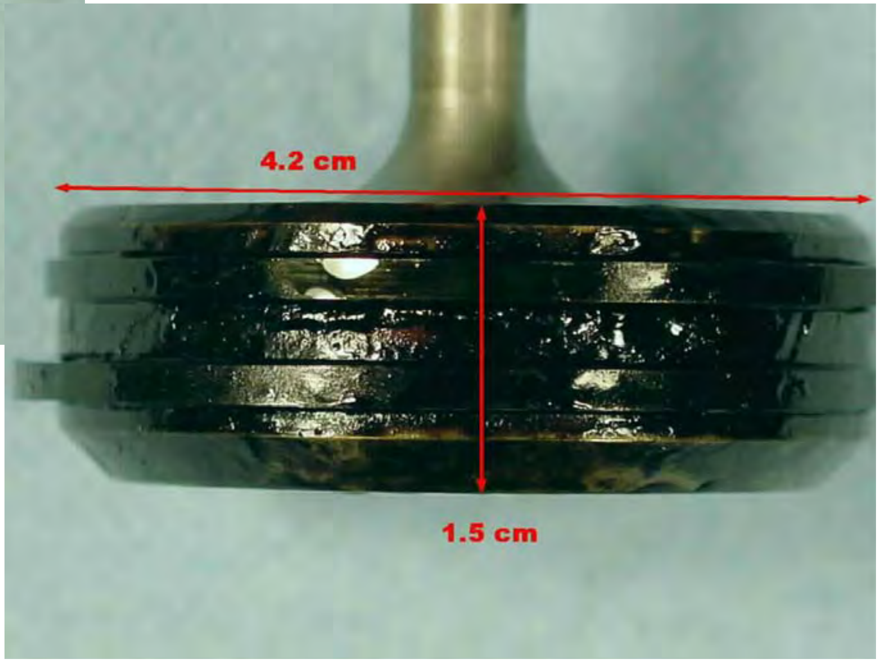


PM-4 Servo Valve Components

Deposit Analysis Photos



Trip Relay Piston



Case Study – Continued Problems and Action Plan

- In February 2004, just four months after the last sticking event, fuel gas valve sticking tendency was detected. The unit was brought down to avoid a trip, and the sticky valves replaced.

- Plant personnel conducted research into gas turbine varnish - literature, filter manufacturers, GE, ExxonMobil Lubes, COT/Puritech, etc.

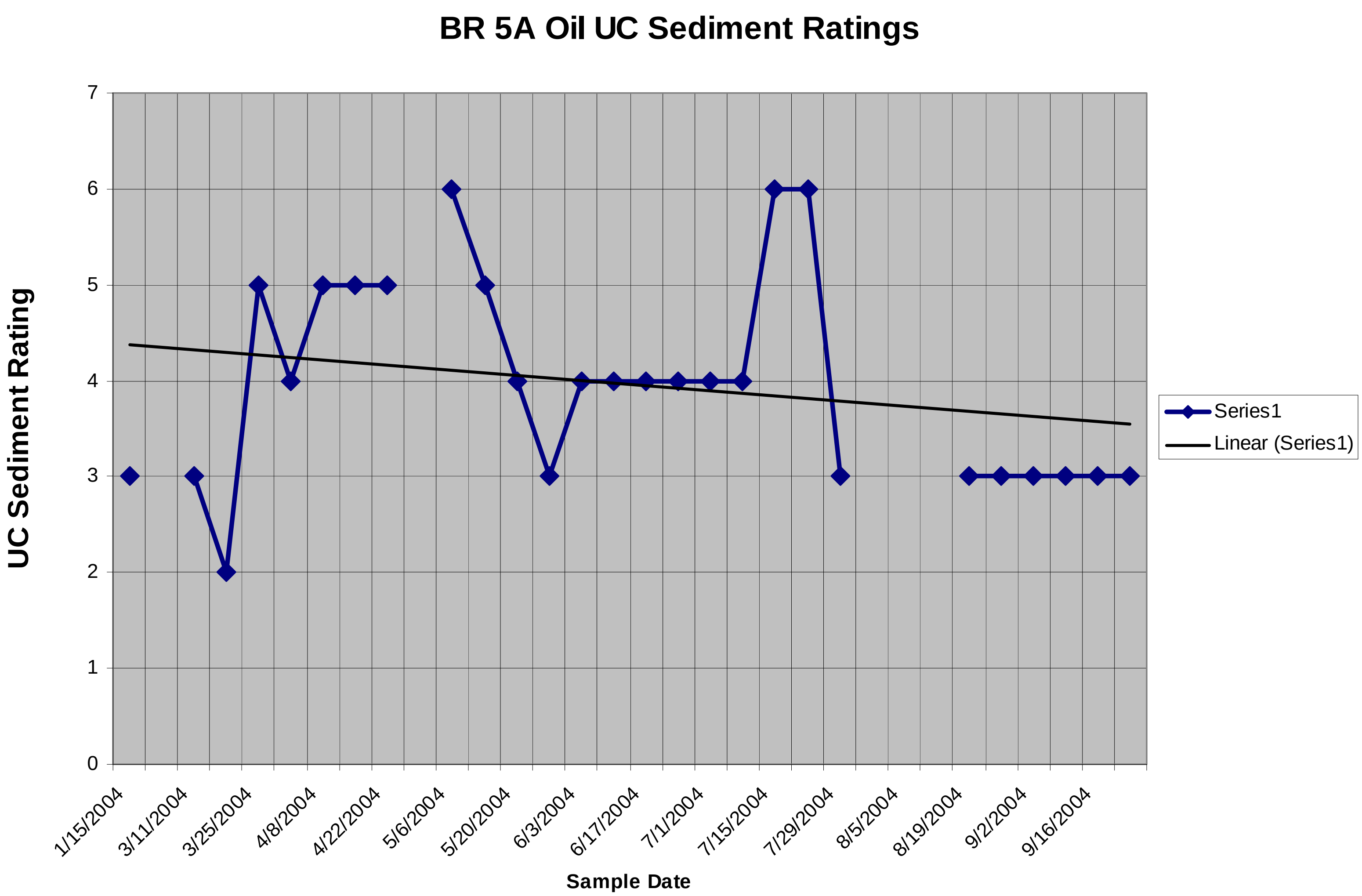
- Course of action determined:
  - "Sweeten" the lube oil by on-line drain/replacement of ~ 30% of system volume (2,100 gallons)
  - Install electrostatic filters (two units originally, additional two added to boost effectiveness)
  - Begin weekly intensive oil analysis, supplementing routine tests with FTIR, RPVOT, Rust, Cu Corrosion, Air Release, Foam, UC Sediment, Colorimetric testing, and Gravimetric testing

- The Goal: Reach planned outage in September, change oil, implement further best practices beyond those listed above

Case Study – Results of Action Plan

- Weekly oil analysis indicated initial drop in values on the “deposit tendency tests” - UC Sediment, Colorimetric, and Gravimetric - due to sweetening of reservoir.
- Subsequent samples showed steady trend down in all categories, with some saw-tooth action - probably related to electrostatic equipment operations and oil solubility/equilibrium/saturation with deposit materials. See following three slides for trends.
- There was no evidence of valve sticking or filter plugging during the seven month period leading to the shut down.
- The unit was shut down in September 2004, for its major inspection, and the fuel gas and IGV valves performed exceptionally well.

UC Sediment Trend



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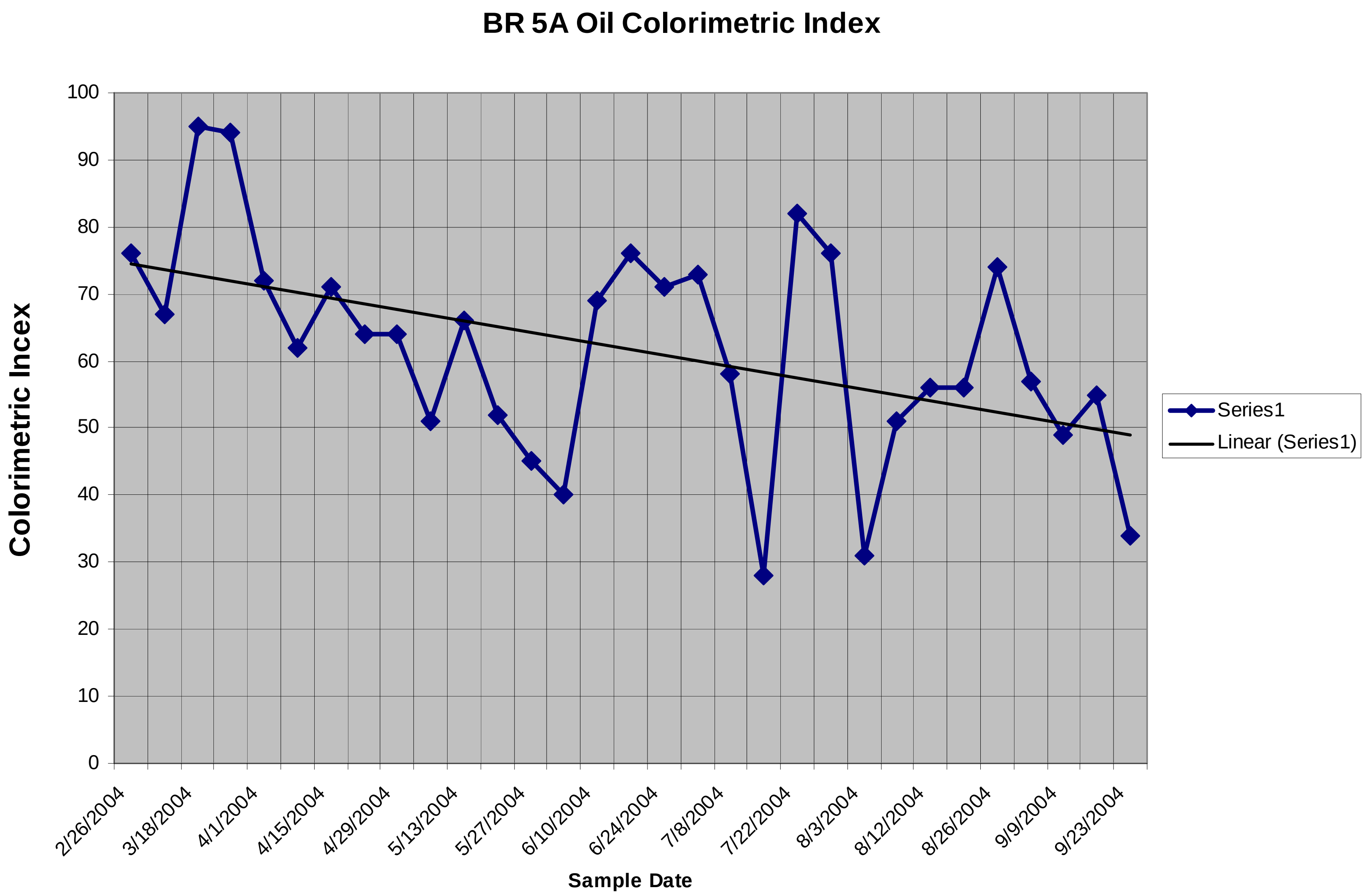
Colorimetric Trend



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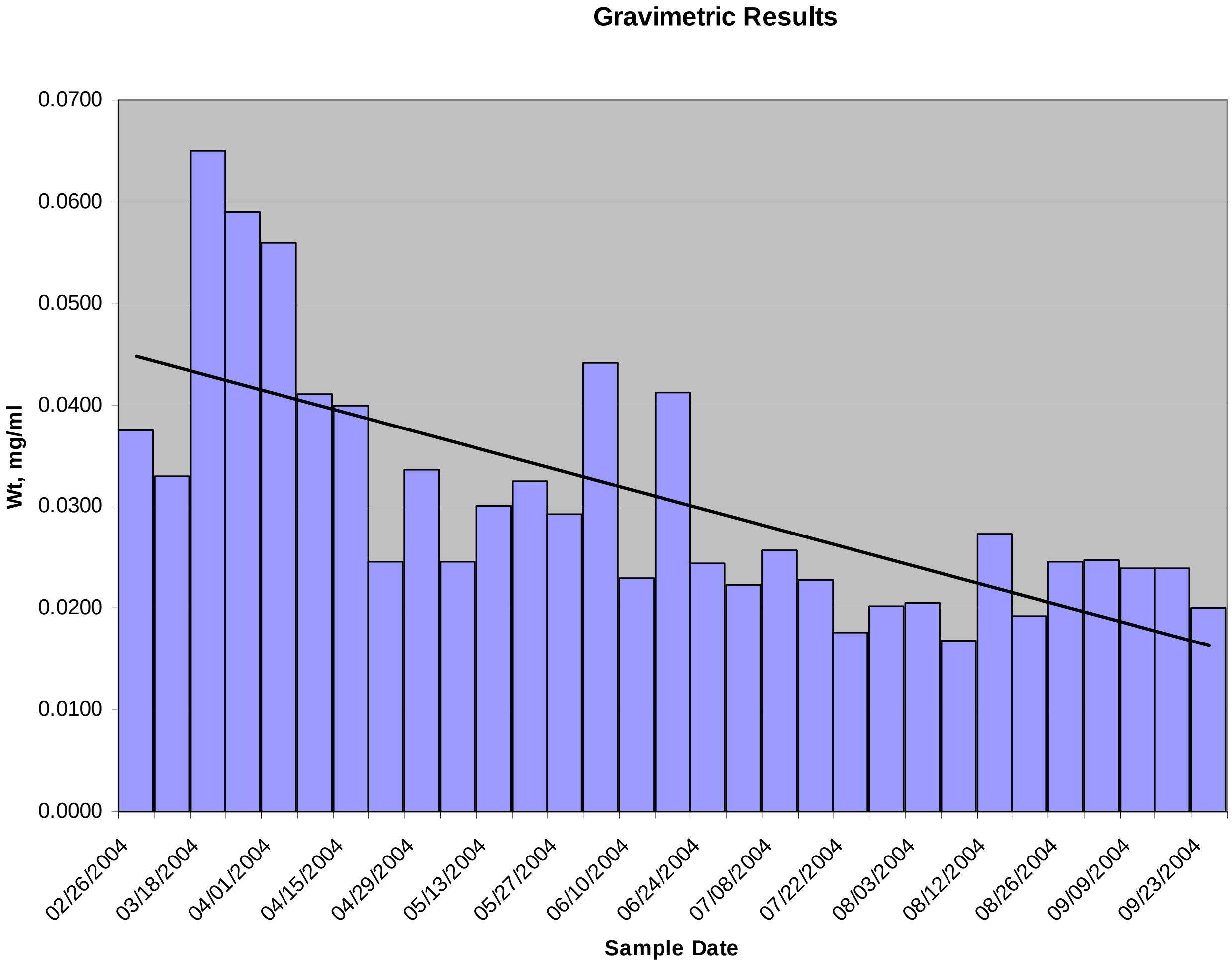
Gravimetric Trend



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Case Study – Action Plan Results

- The servo valves and trip relays were replaced. Hydraulic and pencil filters were inspected and found to be clean.
- A high-velocity flush was performed using an additive designed to help dissolve deposits and keep them in suspension. The reservoir was hand cleaned.
- Reservoir was refilled with new oil (filtered as it was added). The new oil was selected with careful consultation with the lube supplier's engineers. Key criteria were strong oxidation and thermal performance balanced with "keep clean" performance.
- Two of the four electrostatic filter units were returned to service. After a baseline sample, quarterly in-depth analysis will be performed (as outlined previously) to insure effectiveness of all lube system efforts.
- The photos on the following slides show the components inspected after shut down - these components had almost nine months operation with no issues, where the last set of valves had stuck in just four months prior to remediation steps.

Shut Down Component Inspection

Shut Down Component Inspection