Ontario Power Generation

Oil Analysis for Equipment Reliability at OPG Nuclear

Presented by Andrew Sit, P.Eng
andrew.sit@opg.com
Pickering Components & Equipment Engineering
2019 STLE Toronto Spring Workshop
May 15, 2019

ONTARIO POWER GENERATION

Introduction to OPG Nuclear

- Darlington Nuclear: 4 x 878 MW units

- Pickering Nuclear: 6 x 515 MW units

Purpose of Oil Analysis

- Nuclear Safety!
- Chemistry Control
  - Monitor and maintain chemistry parameters within design specifications – turbine fluids
  - Procedural actions if parameters are out-of-spec
- Predictive Maintenance
  - Detect early indications of lubricant or equipment, and prescribe corrective action it becomes a serious problem (operator burden, production loss, safety hazard)

Method for Oil Analysis Program

- OPG Standards, Procedures and limits based on:
  - ASTM D4378, In-Service Monitoring of Mineral Turbine Oils for Steam and Gas Turbines
  - ASTM D6224, In-Service Monitoring of Lubricating Oil for Auxiliary Power Plant Equipment

Designation: D6224 - 16

Standard Practice for
In-Service Monitoring of Lubricating Oil for Auxiliary Power Plant Equipment[1]

INTRODUCTION

A more systematic approach to monitoring auxiliary power plant equipment can help to minimize the high cost of oil changes and unplanned shutdowns. These avoided costs must be balanced against the cost of sampling and laboratory testing.

This practice is designed to help the user evaluate the condition of the lubricant through its life cycle by carrying out a meaningful program of sampling and testing of oils in use. This practice is performed in order to collect data and monitor trends which suggest any signs of lubricant deterioration and to ensure a safe, reliable, and cost-effective operation of the monitored plant equipment.

1. Scope*

1.1 This practice covers the requirements for the effective monitoring of mineral oil and phosphate ester fluid lubricating oils in service auxiliary (non-turbine) equipment used for power generation. Auxiliary equipment covered includes gears, hydraulic systems, diesel engines, pumps, compressors, and electrohydraulic control (EHC) systems. It includes sampling and testing schedules and recommended action steps, as well as information on how oils degrade.

Note 1—Other types of synthetic lubricants are sometimes used but are not addressed in this practice because they represent only a small fraction of the fluids in use. Users of these fluids should consult the manufacturer to determine recommended monitoring practices.

1.2 This practice does not cover the monitoring of lubricating oil for steam and gas turbines. Rather, it is intended to complement Practice D4378.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D92 Test Method for Flash and Fire Points by Cleveland Open Cup Tester

D95 Test Method for Water in Petroleum Products and Bituminous Materials by Distillation

D257 Test Methods for DC Resistance or Conductance of Insulating Materials

D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)

D664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration

D665 Test Method for Rust-Preventing Characteristics of Inhibited Mineral Oil in the Presence of Water

D892 Test Method for Foaming Characteristics of Lubricating Oils

D893 Test Method for Insolubles in Used Lubricating Oils

D943 Test Method for Oxidation Characteristics of Inhibited Mineral Oils

D974 Test Method for Acid and Base Number by Color-Indicator Titration

D1169 Test Method for Specific Resistance (Resistivity) of Electrical Insulating Liquids

D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method

*A Summary of Changes section appears at the end of this standard

Method for Oil Analysis Program

Method	Test Name
ASTM D445	Viscosity
ASTM D6304	Water Content
ASTM D664 or D974	Acid Number
ISO 4406	ISO Cleanliness
ASTM D5185 or D6595	Trace Elements
OPG method / ASTM D1500	Appearances
ASTM D892	Foaming Characteristics
ASTM D1401	Water Separability
ASTM D3427	Air Release
ASTM D2272	RPVOT
ASTM D6971 or D6810	RULER
ASTM D7843	MPC

Oil Analysis Execution

- Routine oil sampling by Operations and Maintenance crews
- Oil Testing:
  - On-site Chemistry Lab
  - Maintenance Oil Testing facility
  - Off-site Analytical Lab (e.g. Kinectrics)
- QC/QA programs in place to ensure accurate and precise results
  - Qualified Personnel
  - Procedures
  - Traceable Standards
  - Traceable Records

Review of Oil Analysis Data

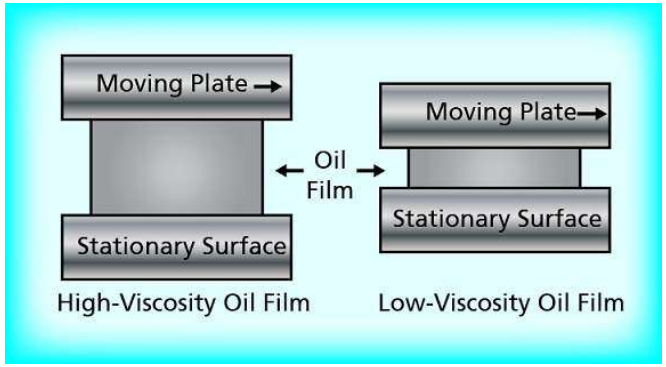
- Crew taking oil sample and performing tests reports abnormal conditions
- Test data is verified and recorded into databases that auto generate notifications of out-of-spec conditions
- Results are reviewed and troubleshooting is conducted by Station Lubrication Engineer, System Engineer and Chemistry Technical Section
- Oversight is provided by the OPGN Corporate Chemistry Program Owner

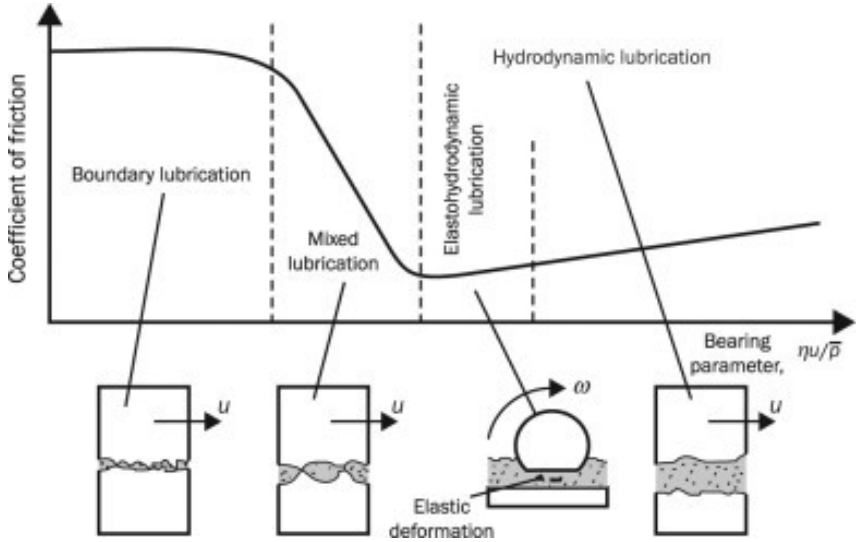
External Assistance

- External Labs - Kinectrics
- Lubricant OEMs – Imperial Oil, Petro-Can, Canoil
- Candu Owners Group (COG) – Bruce Power, New Brunswick Power, CNNO, Cernavoda
- EPRI's Nuclear Maintenance Application Center (NMAC) – mainly North American Utilities, including nuclear and non-nuclear operators

Viscosity

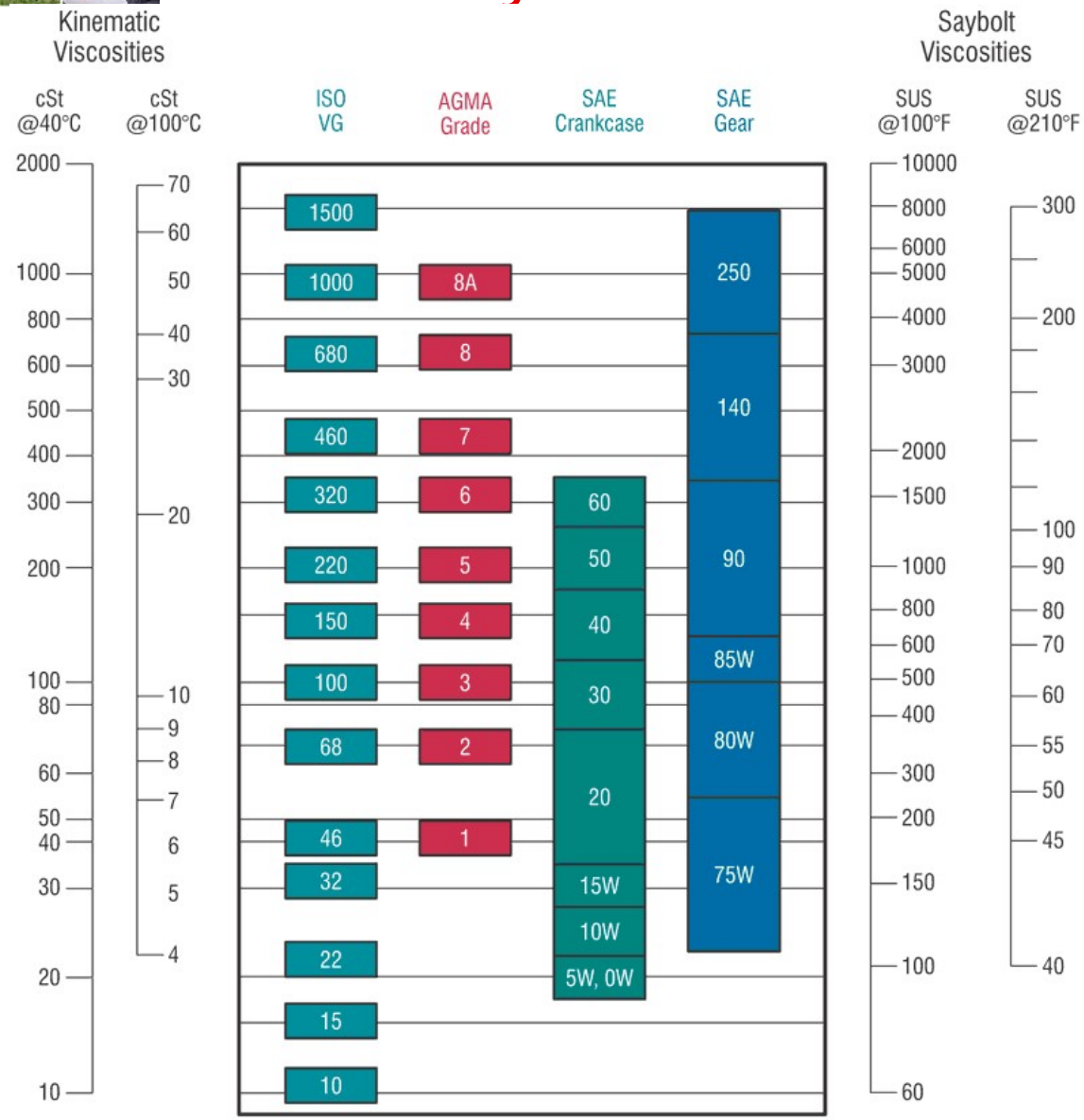
- Fluid's resistance to flow - how thick the oil is
- Most important property for separation of moving parts
- Problems:
  - Too low viscosity will result in boundary lubrication and increased friction/temperature
  - Too high viscosity will result in excessive fluid friction and increased temperature





ONTARIO POWER GENERATION

Viscosity



ONTARIO POWER GENERATION

Viscosity

- Measured by how long it takes to flow through a calibrated opening at a given temperature
- Changes due temperature

Viscosity

- Causes of problems:
  - Contamination (wrong oil, fuel)
  - Fluid degradation (oxidation, molecular shearing)

- Correction:
  - Replace lubricant

Water Content

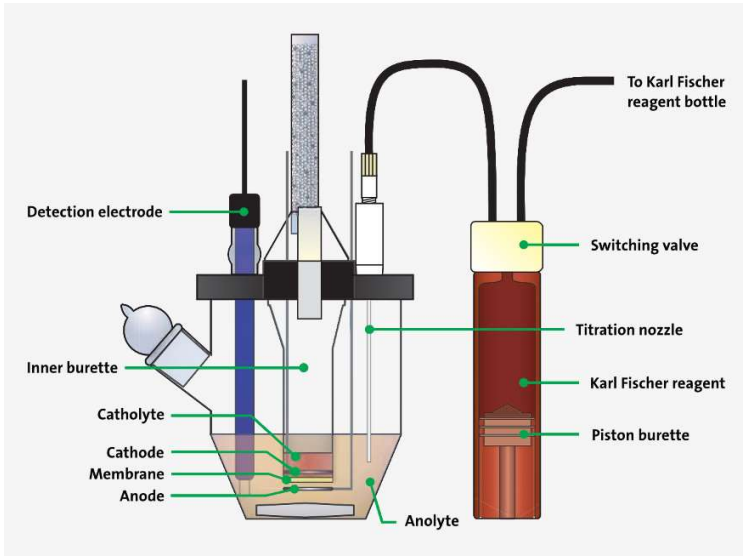
- Water in lubricants is either dissolved or in free state:
  - Dissolved water (50 – 1000+ ppm) is usually not a problem
  - Free water can be emulsion (hazy to milky appearance), droplets and separate layer
- Problems with free water:
  - Reduces lubricant film strength/thickness
  - Causes corrosion
  - Creates sludge
  - Plugs filters
  - Removes additives

ONTARIO POWER GENERATION

Water Content

- Measured by Karl Fischer titration method
  - Water and reagent iodine are consumed in a 1:1 ratio - once all of the water present is consumed, excess iodine is detected voltametrically, and water content is calculated

$$\underset{\text{[alcohol]}}{ROH} + SO_2 + \underset{\text{[base]}}{R'N} \rightarrow \underset{\text{[alkylsulfite salt]}}{[R'NH]SO_3R} + \underset{\text{[water]}}{H_2O} + \underset{\text{[iodine]}}{I_2} + 2R'N \rightarrow \underset{\text{[hydroiodic acid salt]}}{2[R'NH]I} + \underset{\text{[alkylsulfate salt]}}{[R'NH]SO_4R}$$



Water Content

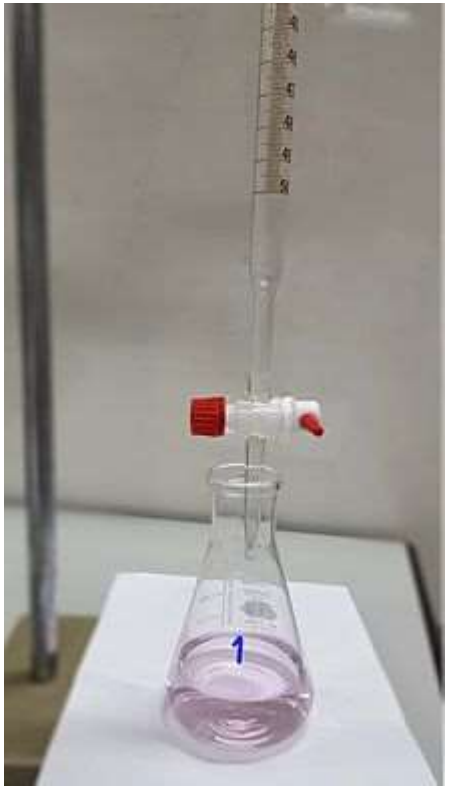
- Causes of problems:
  - Environmental humidity
  - Cooler leaks
  - Steam leaks
  - Other sources of water
- Correction:
  - Control source of water ingress
  - Drain water from bottom of reservoir
  - Filter out water
    - Vacuum dehydration
    - Coalescing or absorption filters
    - Desiccant breathers

Acid Number (AN)

- Acids are produced by lubricant degradation (oxidation)
  Problems:
  - Rapid and significant increase in AN indicates:
    - End of lubricant's useful life
    - Contamination with acidic fluids (e.g. hydraulic oils)
  - Abnormally high AN can:
    - Form sludge and varnish
    - Be highly corrosive, esp. with water contamination
    - Be associated with changing viscosity

Acid Number (AN)

- Measured by potassium hydroxide (KOH) titration to neutralize sample acid in an lubricant sample with a pH indicator



Acid Number (AN)

- Causes of problems:
  - High operating temperature
  - Contamination with water, air entrainment and wear metals (which act as catalysts)
  - Antioxidant additive depletion (end of service life)
- Correction:
  - Replace lubricant
  - Feed and bleed lubricant to replenish antioxidants, if condition is not severe
  - Use acid removal filters (e.g. Fuller's earth, IX resin, active alumina)

ISO Cleanliness

- Measures solid particulates in the lubricant; AKA "Particle Count"

Typical Hydraulic Component Clearances	
Component	**Microns**
Anti-friction bearings	0.5
Vane pump (vane tip to outer ring)	0.5-1
Gear pump (gear to side plate)	0.5-5
Servo valves (spool to sleeve)	1-4
Hydrostatic Bearings	1-25
Piston pump (piston to bore)	5-40
Servo valves flapper wall	18-63
Actuators	50-250
Servo valves orifice	130-450

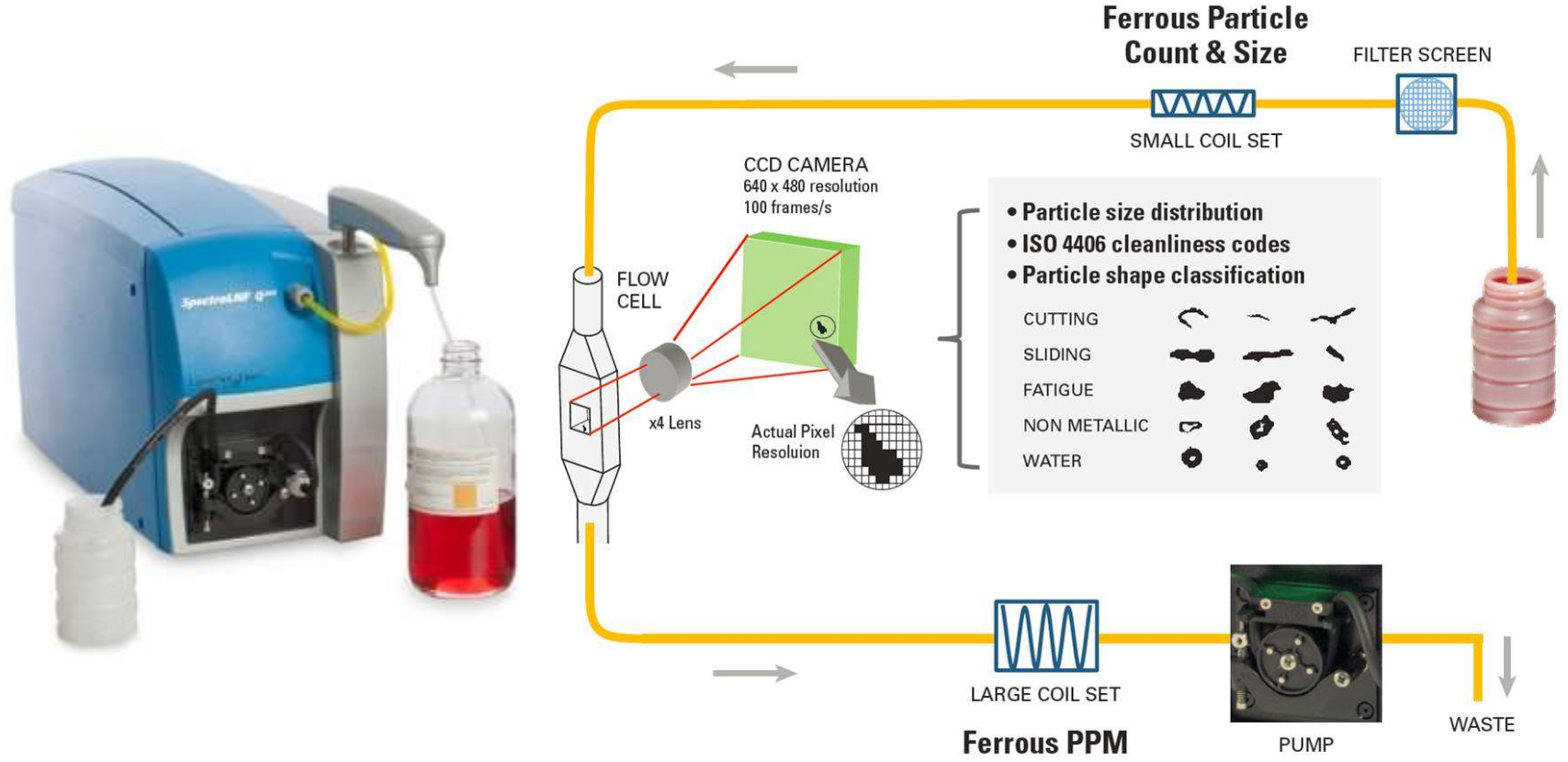
- Problems:
  - Score bearings and gear teeth
  - Plug filters and jam valves
  - Fatigue and spalling of rolling element bearings

ONTARIO POWER GENERATION

ONTARIO POWER GENERATION

ISO Cleanliness

- Optical particle counter



ONTARIO POWER GENERATION

ISO Cleanliness

- Causes of problems:
  - Contaminants in new lubricant
  - External contamination
  - Self generated wear particles

- Correction:
  - Filter the lubricant
  - Prevent foreign material ingress (use filtered breather)
  - Replace component(s) generating wear particles
  - Replace fluid

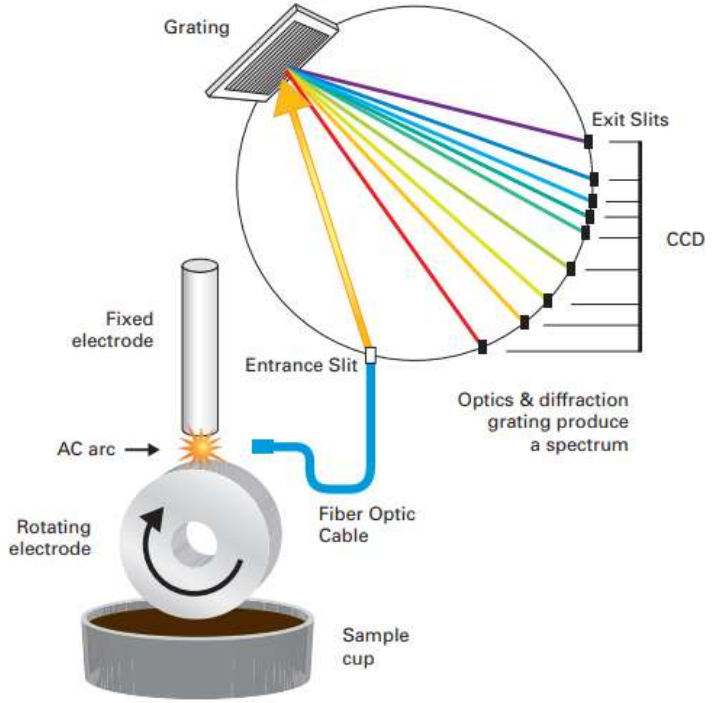
Trace Elements

- Specific metals and elements in the lubricant from:
  - Wear metals
  - Contaminants
  - Additives
- Measures Al, Ba, B, Ca, Cr, Cu, Fe, Pb, Mg, Mo, Ni, P, K, Si, Ag, Na, Sn Ti and Zn in PPM
- Problems:
  - Component wear (e.g. iron, tin bearings, copper from bronze seals)
  - External contaminants (e.g. environmental dirt – silicon, aluminum; cooling water – sodium, magnesium)
  - Additive depletion (e.g. anti-wear zinc, phosphorus)
  - Wrong fluid – different lubricants have characteristic trace element signatures

ONTARIO POWER GENERATION

Trace Elements

- Rotating Disc Electrode Optical Emissions Spectrometer (RDE OES), measures:
  - Al, Ba, B, Ca, Cr, Cu, Fe, Pb, Mg, Mo, Ni, P, K, Si, Ag, Na, Sn, Ti and Zn in ppm



Trace Elements

- Causes of problems:
  - External contamination
  - Self-generated contamination (wear metals)
  - Additives and their depletion
  - Wrong fluid
- Correction:
  - Eliminate source of and filter out contaminants
  - Replace worn components (overhaul)
  - Replenish addivities with partial or full fluid replacement

Appearances

- Measures:
  - Cloudiness
  - Sediment
  - Free water
  - ASTM Color

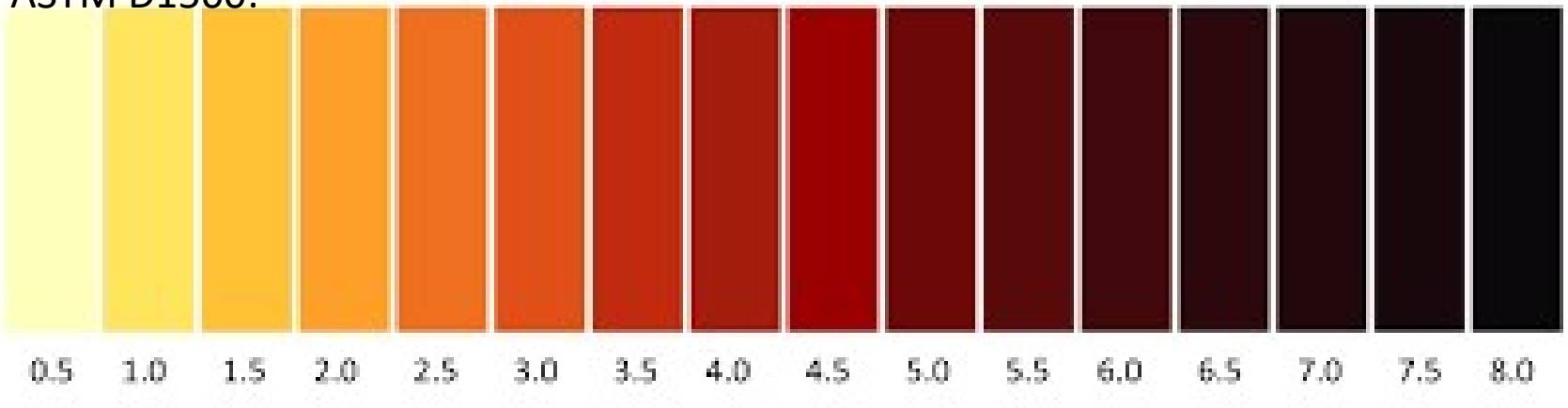
- Problems - various
  - Water
  - Contamination
  - Fluid degradation

ONTARIO POWER GENERATION

Appearances

SCALE	CLOUDINESS	FREE WATER	SEDIMENT
0	Normal	None	None
1	Hazy	Small droplets	A few specs
2	Cloudy	Puddling	Layer
3	Heavy clouding	Layer	Heavy Layer

ASTM D1500:



Appearances

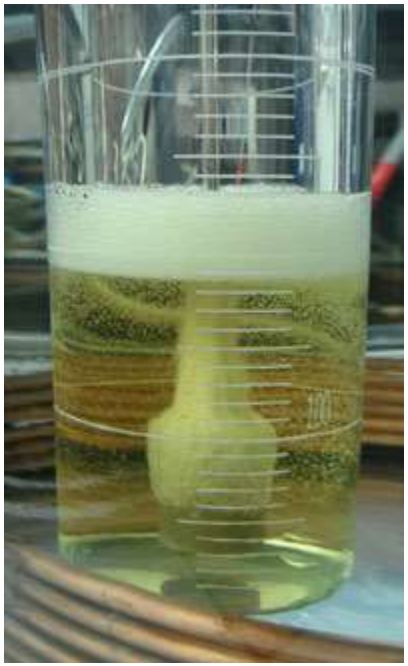
- Causes of problems:
  - Cloudiness – water emulsion or other contamination
  - Sediment – dirt or wear particles
  - Free water – severe water ingress
  - ASTM Color – rapid color change may indicate lubricant degradation or contamination
- Correction: various

Foaming Characteristics

- Measures lubricants foaming tendency and stability
- Problems:
  - Foam and entrained air reduces fluid film strength
  - Foam can cause leaks
  - Loss of fluid level indication
  - Reduced cooling
  - Promotes oxidation
  - Pump cavitation and micro-dieseling

Foaming Characteristics

- Air is blown in oil sample in a graduated cylinder at specified temperature
- Foaming Tendency – maximum foam volume generated
- Foaming Stability – foam volume remaining after 10 minutes standing



Foaming Characteristics

- Causes of problems:
  - Defoamant additive depleted
  - Contamination (water, cleaners)

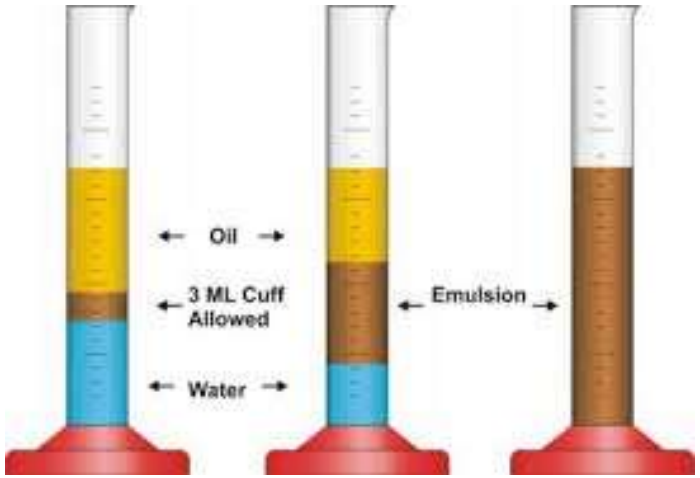
- Correction:
  - Replenish addivities with partial or full fluid replacement

Water Separability

- Measure lubricant's ability to separate free water
- Turbine and circulating oils are designed to separate and drop water to the bottom of the tank
- Engine oils are designed to prevent a water slug from passing through by keeping water in emulsion
- Problems:
  - Loss of water separability from design function risks free, separated water entering into moving parts

Water Separability

- 40 ml of each lubricant and water are stirred for a specified time and temperature in a graduated cylinder. After standing for 20 minutes, oil, water and emulsion volume are measured



Water Separability

- Causes of problems:
  - Contamination – detergents from engine oil can ruin a turbine oils water separation characteristics
  - Degradation – degradation products can acts as an emulsifier
  - Additive depletion – loss of emulsifier or detergents/dispersants additives

- Correction:
  - Partial or full fluid replacement

Air Release

- Measures time required for air to be released from a fluid
- Problems:
  - Reduced fluid film strength
  - Increased fluid volume
  - Promotes oxidation
  - Cavitation and micro-dieseling
  - Spongy or slow hydraulics

Air Release

- Air is blowing into a lubricant sample for specified time and temperature. Air Release is measured as the standing time required for the sample to return to 99.8% initial density.

Air Release

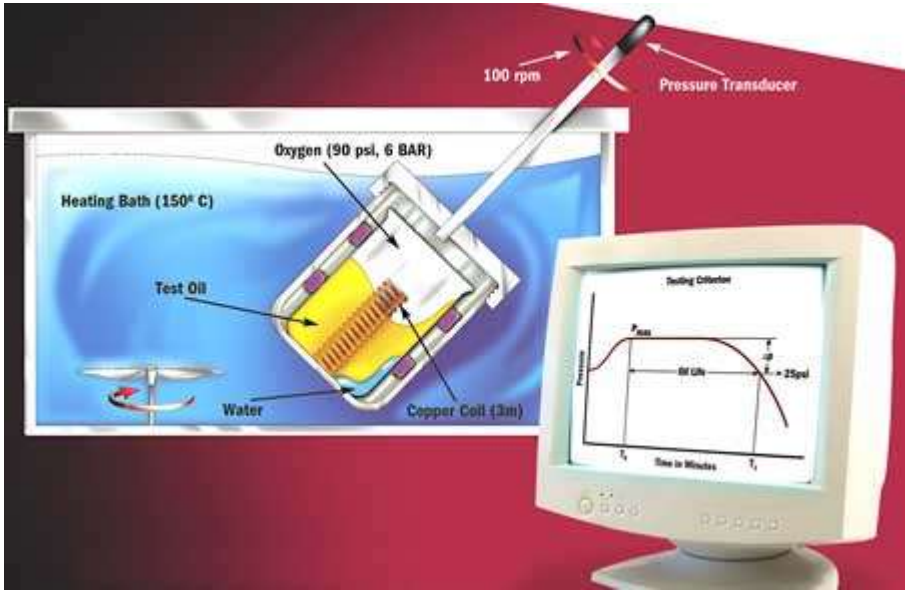
- Causes of problems:
  - Degradation products or external contaminants can increase the Air Release value
- Correction:
  - Partial or full fluid replacement

Rotating Pressure Vessel Oxidation Test (RPVOT)

- Measures oxidation stability of a lubricant
- Oxidation life of modern lubricant formulations is very good due to base oils and antioxidant additives
- Problems:
  - Oxidation is accelerated by high temperature, water, water, air entrainment, radiation
  - Oxidation can
    - Change the viscosity of the lubricant
    - Decrease lubricity
    - Create sludge and varnish

Rotating Pressure Vessel Oxidation Test (RPVOT)

- Oil sample is exposed to pressurized oxygen gas, water and copper catalyst in a rotating pressure vessel. RPVOT results is the time from start to a significant drop in gas pressure.



Rotating Pressure Vessel Oxidation Test (RPVOT)

- Causes of problems:
  - Depletion of antioxidant additive
- Correction:
  - Replenish addivities with partial or full fluid replacement
  - Reduce operating temperature
  - Filter and prevent contaminant ingress

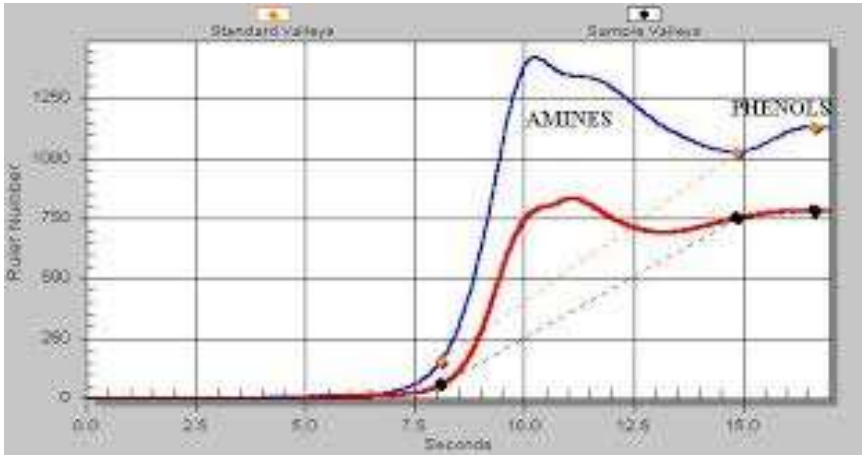
RULER

- Measures “Remaining Useful Life” by measuring the level of remaining antioxidant additives
- Problems:
  - Same as Oxidation in RPVOT

ONTARIO POWER GENERATION

RULER

- Linear sweep voltammetry method
  - Small fluid sample required, fast, cheap
  - Measures levels of hindered phenol and aromatic amine



RULER

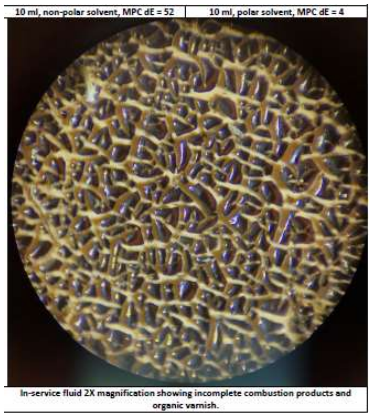
- Causes and correction: same as for RPVOT

Membrane Patch Colorimetry (MPC)

- Measures varnish potential of a lubricant
- Problem:
  - As varnish accumulates, it comes out of solution and deposits in locations of pressure and temperature drops
  - Varnish can deposit in valves, bearings and reservoirs

Membrane Patch Colorimetry (MPC)

- Lubricant is passed through a 0.45 µm cellulose filter patch
- Colorimeter is used to measure Lightness, red/green and yellow/blue values (CIELAB scale)
- Patch weight can be measured
- Microscopic examination of patch



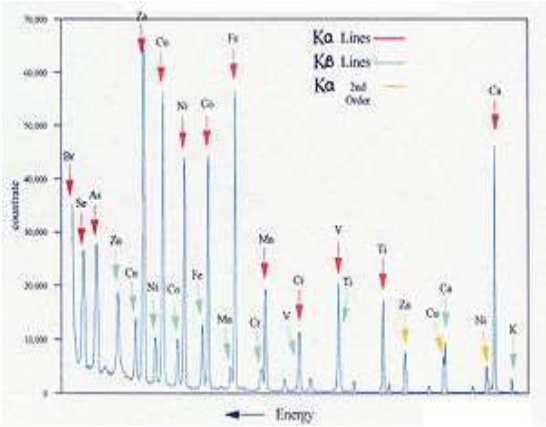
Membrane Patch Colorimetry (MPC)

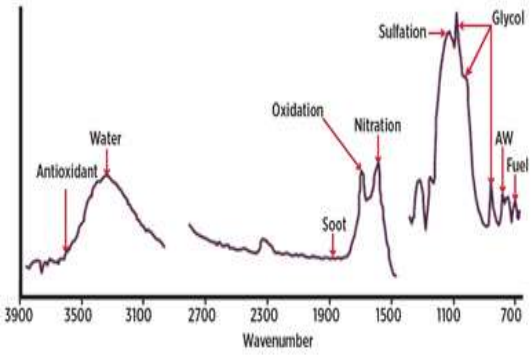
- Causes of problems:
  - As a lubricant ages, it produces varnish from degradation products
- Correction:
  - Partial or full fluid replacement
  - Varnish removal filtration
    - Ion exchange columns
    - Cellulose depth filtration
    - Electrostatic separation

ONTARIO POWER GENERATION

Troubleshooting Methods

- Filter Patch Microscopy
- Analytic Ferrography
- Fourier Transform IR (FTIR)
- X-ray Fluorescence (XRF)
- Others – consult with external labs





ONTARIO POWER GENERATION

Thank You!