Oil Fundamentals

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The Functions of a Lubricant

- Reduce friction and wear
- Remove heat
- Prevent the formation of oxidation product
- Act as anti-rust and anti-corrosion agent
- Act as a seal
- Transport contaminants to the filter for removal
- Power transmission
**Benefit of Oil Analysis**

- Increase maintenance staffs’ general awareness of lubrication related issue.

- Predictive maintenance
  - Up to six month earlier indication of wear related problems
  - Confirm certain problems detected through vibration
  - Most informative for engines, compressors, crushers, pulverizers, presses, and gearboxes.

**Benefit of Oil Analysis**

- Minimize unscheduled downtime:
  - Indication of component failure
  - Identify type of damage (chemical, abrasion, fatigue, or other), and
  - Locations of the damage
  - Fix the problems before it breaks.
**Oil Analysis Provides:**

- Means to access the levels and types of contamination and wear in the oil.
- Lubricant chemical condition - “Is it still fit for use?”
- Failure prediction from data trending.
- Preventive maintenance optimization by effectively define:
  - Sampling schedule
  - Oil/filter change schedule

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**Potential Cost Savings from Oil Analysis**

- Lubricant consolidation
- Extended oil change intervals
- Extended machine life
- Power consumption
- Labor
Starting an Oil Analysis Program

“Technology Champion”
- Develops goals and objectives
- Designs written procedures for:
  - storage and dispensing
  - sampling
- Drives the corrective activities
- Maintains ultimate responsibility for the program
Goals and Objectives

- Some of the goals and objectives include:
  - Reducing unplanned downtime and lubricant related failures
  - Reducing lubricant procurement costs
  - Consolidating lubricant supply
  - Reducing oil disposal costs
  - Extended machine and lubricant life

Storage and Dispensing

- Protect the lubricants in storage from contamination
- Ensure lubricants being added to machines are free from harmful contaminants
- Ensure the correct lubricants are added to machines
- Employ good housekeeping practices
**Identify Machines**

- Start with a *small* group of “critical” machines
  - Critical to production
  - Critical to safety
- Add machines as program progresses
  - Knowledge and experience developed
  - Better understanding of sampling intervals and analysis techniques
  - Experience with establishing Alarms

**Identify Analysis Techniques**

- Free oil analysis
- Commercial oil laboratory analysis
- On-site instrument oil analysis
**Routes and Schedules**

- Begin by sampling “critical” machines monthly to develop trends (3-6 months)
- Design logical “routes” for simplifying sample collection
- Adjust sampling interval based on trend

**Sampling Points**

- Install sampling ports for consistency
  - circulating portion of a reservoir
  - middle of the fluid level
  - prior to the filter
  - in the return line after the last lubricated component (turbulent flow is desirable)
- Sample pump/tubing
**Sampling Procedures**

- Flush valves/ports prior to collecting
- Use new bottles/tubing for each sample
- Collect while the machine is running or no longer than 15 minutes after shutdown
- Don’t collect samples from drain locations - debris and water tend to settle

**Performance Metrics**

- Failure avoidance (unscheduled downtime)
- Reduced procurement (lube consolidation / extended oil change)
- Reduced oil disposal (extended oil change)
- Energy savings
- Labor (reduced overtime / call ins)
Training

- Storage and dispensing
- Sampling
- Contamination control
- Analysis techniques
- On site analysis

Laboratory Analysis Techniques
**Lubricant Analysis Techniques**

- Elemental Analysis
- FT-IR
- Viscosity
- TAN / TBN
- Water - Karl Fischer, Crackle Test
- Particle Counting
- Ferrography - Ferrous Density, Visual WDA
- RBOT

**Elemental Spectrometry**

- Quantifies the amount of inorganic elements in the oil.
- Methods used include:
  - Rotrode Spectroscopy, ICP (AES)
  - Atomic Absorption (AA)
- Results are reported in parts per million (ppm)
- Elements are categorized as wear, additives, and contaminants
- Some particle size limitations - less than 8 microns
  *(depending on the instrument used, the limitation may be much less.)*
**Rotrode Spectroscopy**

Submerged in a 1 ml oil bath, the carbon wheel begins to rotate, carrying the oil to the space between the carbon electrode and wheel where an arc is produced, igniting the oil.

Each element emits precise spectral color when ignited. The spectrometer measures the intensity of the various wavelengths and quantifies the elements present.

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**Inductively Coupled Plasma (ICP)**

This method introduces a sample (or dilution) into an argon plasma.

This method works well for automated analysis.

Reference: www.scimedia.com
**Rotrode Filter Spectroscopy**

Used to measure wear metal levels in the larger particle sizes.

Measures particles larger than 15 microns.

Oil is filtered through the disk, which holds the particles. The oil is then washed away using solvents.

**FT-IR**

Fourier Transform Infrared Spectroscopy

- Used for chemical or molecular analysis as opposed to elemental analysis from SOA
**FT-IR**

Uses infrared light transmitted through a thin lubricant sample. The molecules in the sample absorb some of the infrared light. The wavelengths that are able to pass through are processed into a spectrum which identifies which wavelengths were absorbed. The amount of absorption is directly related to the concentration of that particular molecule.

**Viscosity**

- Viscosity is often referred to as “the single most important property of a lubricant”
- For all lubricants, it is important to measure the 40C, 100C and Viscosity Index
- A change in the 40C viscosity of 15% from “new” oil indicates a problem
**Viscosity**

Viscosity is measured using two capillary viscometers - one is maintained at 40°C, one is maintained at 100°C. A measured amount of oil is deposited into a capillary tube. The tubes are designed to allow the oil to reach “bath” temperature prior to the measurement. As the oil passes the first sensor, a timer starts. When the oil reaches the second sensor, the timer stops and the viscosity is calculated.

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**TAN / TBN**

- Sometimes referred to as Neutralization Numbers
- **TAN - Total Acid Number**
  - Quantity of base required to neutralize all acidic constituents present in 1 gram sample
  - Measured as mg KOH/g (potassium hydroxide)
  - Indicates build up of acidic constituents in the lubricant
  - Applicable to industrial (non-engine) applications
- **TBN - Total Base Number**
  - Measure of the reserve alkalinity of engine oils
  - Reported as mg KOH/g (potassium hydroxide)
Water Tests

Crackle Test

- Used to screen samples for water contamination
- A hotplate is heated to ~ 300 F, a small amount of oil is placed on the heated surface. If the oil "crackles" water is present.
- Lower detection ~ 200 ppm (results depend on additive package of the oil)

Water Tests

Karl Fischer Titration

- Titration method using reagents which react with the water.
- Quantifies the amount of total water, reported in ppm or %
- Lower detection to 30 ppm (depending on procedure)
Particle Counting

- Typically used to monitor the cleanliness of “clean” systems and incoming lubricants
- Used routinely on most systems to monitor:
  - Wear debris
  - Contaminants
  - Filter efficiencies
- Very important test for determining the need for Wear Debris Analysis.
- Can be expanded to include:
  - gearboxes
  - pumps
  - compressors

Particle Counting

- Ability to specify Target Cleanliness Levels for systems, machines, and incoming lubes
- Ability to implement Contamination Control
- Used to determine filtration specifications and efficiencies
- Trending allows early indication of abnormal wear and increases in contaminant levels due to outside influences
Wear Debris Analysis

- Ferrous Density determination is used to measure the amount of ferrous material present in a sample
- Visual wear debris analysis is used to identify:
  - Particle size, shape, color, texture
  - Particle concentration
  - Optical properties of the particle(s)
  - Also referred to as Analytical Ferrography

RBO

- Rotating Bomb Oxidation Test
- Used to determine the oil’s oxidation stability and/or remaining useful life.
- Normally compared to a “reference” oil (i.e., new oil of the same brand and type)
RBOT

A given amount of sample oil, water, and a copper catalyst coil are placed in an oxygen-pressurized bomb (vessel). The bomb is charged with oxygen to a pressure of 90 psi and placed in a constant temperature oil bath at 150°C. The bomb is then rotated axially at 100 rpm at a 30 degree angle. The time, in minutes, required to reach a specific drop in gauge pressure as compared to a reference oil determines the oil’s oxidation stability.

Lubricant Analysis Options
Perception

Lubricant analysis has not lived up to its potential as a predictive maintenance tool.

Lubricant Analysis Options

- Lubricant Analysis Resources: 3 Options
  - Free oil analysis
  - Commercial oil laboratory analysis
  - On-site instrument oil analysis
**Lubricant Analysis Options**

**Free Oil Analysis:**

- Viscosity at 40 °C
- Elemental analysis using Spectro, AA or ICP
- Water content, and sometimes
- Total Acid Number (TAN)

**Advantages:**
- Free
- Good info for lube chemistry

**Disadvantages:**
- Incomplete info for wear and contamination
- Slow turn-around time, up to 2 weeks
- Need to transfer electronic data, if at all possible
- Quality assurance issues of the testing facilities
**Lubricant Analysis Options**  
**Commercial Lab Analysis:**

- Viscosity at 40 and 100 °C and viscosity index
- Elemental analysis using Spectro, AA or ICP
- Water content
- Total acid number (TAN) or total base number (TBN)
- Fourier transform infrared spectroscopy (FTIR)
- Particle counting
- Wear debris analysis (WDA)
- Other specialty tests

**Advantages:**
- Most complete & informative results if the testing package is selected correctly
- Quality data from state of the art instruments
- Capability of performing specialty tests

**Disadvantages:**
- Expensive: from $12 to $200+ per sample
- Turn-around time: 2 to 5+ days without premium
- Need to transfer electronic data, if at all possible
Lubricant Analysis Options
On-site Instrument Analysis:

- Viscosity
- Particle counting
- Ferrous density
- Dielectric measurement
- Crackle test for water
- TAN/TBN kit

Advantages:
- Ownership and control
- Immediate results and re-test when needed
- Tests performed by people who know the machine
- Electronic data with no transfer
- Test more points more often
- Test incoming lubricant
- Find, fix, and verify the problem is fixed
Lubricant Analysis Options
On-site Instrument Analysis:

- Disadvantages:
  - Cost: Got to have the budget to buy the tools
  - Labor: Got to have the personal to do the tests
  - Education: Got to train the personal
  - Still need to send the questionable samples to a commercial lab for in-depth analysis

What do you get from oil analysis?

- Chemistry
- Contamination
- Wear

Need all three information!!
Laser Turn Table

A recent case history involves a laser turntable that operates a robotic welder. Minilab oil analysis showed alarming results...

Notice the extreme wear condition and the alarming contamination condition on the Trivector!
The Shop Microscope Showed
Iron Spheres in Laser Turntable Oil Reservoir

Laser Turntable samples were also collected and sent off to two different labs who provide “Free Oil Analysis.”

The first lab reported, “Analysis indicates component & lubricant conditions are acceptable.”
The second lab reported, “No corrective action required.”

At this point the supervisor asked:

“Why did you write a work order to change the oil in the Laser Turntable when two labs say nothing is wrong?”

Ed said, “Who knows, there may be a mistake” and suggested testing another sample. Ed and the supervisor did this together.
Storage and Handling Practices

Storage of Lubricants

- Drums should be stored:
  - Indoors in a ventilated room
  - On racks off the floor
  - On their sides, not upright

- Outdoors storage (even temporarily)
  - On their sides undercover with openings positioned at 3 and 9 o’clock
  - For maximum protection, the drums should be stood on end with the openings down on a well-drained surface
### Storage of Lubricants

- Separate areas should be provided for:
  - Unopened containers and bulk tanks
  - Opened containers
  - Empty containers
  - Lubrication accessories
- Containers and/or hoses need to be clearly marked to prevent misapplication

### Storage of Lubricants

- Use filters or breathers for drum “vents” to control ingress of solid contaminants.
- Use desiccant breathers for drum “vents” to control moisture ingress in wet locations
Handling of Containers

- Drums should not be bounced off trucks or racks
- Drums should be rolled rather than dragged
- Make sure all transfers take place under clean conditions to avoid contamination
- Containers are kept tightly closed when not in use

Dispensing of Lubricants

- Use the oldest lubricant first
- Test the lubricant before use, if in doubt
- Use drum spigots rather than drum pump to avoid cross contamination. Spigots allow the drums to be stored on their sides.
- Different lubes should never be mixed in dispensing containers or transfer equipment.
Dispensing Equipment

- Containers should be clearly marked
- Always check if the dispensing equipment is clean
- Keep the dispensing containers tightly closed when not in use
- Avoid open-topped containers, like pitchers

Safety Concerns

- Clean up spilled and leaking lubricants
- Oily rags should be disposed of in tightly closed safety containers
- No smoking around lubricant and solvents
- When necessary, shut off machine before lubricating
Storage and Handling Practice: Summary

- Contamination control begins with good storage, handling and dispensing practices
- Use common sense

Sampling Practices
**Sampling Tips**

- The oil samples **must** represent the entire system to have relevance
- Maintain consistency in sample collection
  - Same location
  - Same method
  - Same machine conditions (speed, load, etc.)
- Develop written procedures for collecting samples to maintain consistency

**Sample Point Locations**

- Know the lube system / path and understand the location and scope of what has to be sampled.
- Analysis data should provide information about the oil and machine condition
**Circulating Systems**

- Locate filters (if applicable)
- Sample prior to filter - sampling after the filter will typically provide a “cleaner” sample
- Sample while running (if possible) or no longer than 15 minutes after shutdown

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**Circulating Systems**

- Sample from the return line after the last lubricated component …. or
- In circulating portion of reservoir, at entry end, near the middle of the fluid level
- Use sampling valves or “fixed” sampling points if possible and locate sample port in a turbulent location (elbow, etc.)
**Oil Sampling**

Sample an “active zone”
- Agitated - mixed
- Flowing
- Hot
- After machinery
- Before filter
- Before dilution
- Away from walls
- Before settling
- Clean procedures

**Non-circulating Systems**
- Sample ports will provide the most consistency
- Avoid sampling from drain plugs if possible, contaminants tend to settle out.
- Sample while the machine is running or no longer than 15 minutes after shutdown
- Sample from the middle of the fluid level, not too close to the top or bottom.
- Sample where the oil is turbulent or flowing
Sampling Preparation

- Checklist of necessary items for sampling:
  - Shop towel for cleaning bottles and one’s hands
  - Cleaning solvent for cleaning sample site
  - Flashlight and necessary hand tools
  - Container to catch “flushed” fluid from valves
  - Boxes for carrying samples
  - Bottles and labels
  - Sampling pump and tubing

  Do not reuse the tubing !!!

Sampling “Best Practices”

- Develop written procedures for sampling
- Identify sample point locations on machines
- Label sample bottles prior to sampling
- Clean sample area prior to sampling
- Drain stagnant oil from valve or port
- Use “new” clean sample bottles and tubing
- Ship or analyze samples immediately
**Sampling Frequencies**

- Begin by sampling on a monthly basis to quickly establish trends and identify immediate problems.
- Different machines, different intervals.
- Continue monthly sampling for the first 3 to 6 months.
- Modify sampling intervals based on the historical data collected and/or the criticality of the machine.

**Conclusion**

- Consistency in sample collection method and techniques will provide the best data. Oil analysis depends on trendable results. Care must be exercised when collecting oil samples from machines so as not to contaminate the sample or the lubricant in the machine.
- Sampling frequencies should be based on the actual historical data for best results.
Wear Debris Analysis

M.I.T. Study

Loss of Usefulness

Obsolescence (15%)  Accidents (15%)

Surface Degradation (70%)

Corrosion (20%)  Wear (50%)

ASLE Bearing Workshop
Rabinowicz, 1981
**Definition of Wear Debris Analysis**

Wear debris analysis (WDA) is an attempt to determine the condition of machinery through the examination of the particles generated by wear process.

**Purpose of Wear Debris Analysis**

- To detect potential failures before they occur
- To determine the root cause of failures after they occur
- To detect abnormal machine or lubricant conditions
### Sampling Wear Particles

- Particles are:
  - extracted from oil samples
  - removed from filters
  - removed from magnetic plugs

### Wear Particle Examination

- **White light microscope**
  - The most popular technique used in the oil testing industries
  - The particles are observed and the morphology of the particles are recorded
  - The origin and cause of wear debris and/or contaminant are speculated.
  - Resolutions - about two tenths of a micron
  - Magnification - up to 1000X maximum
  - Material identification is difficult and at best qualitative
**Wear Particle Examination**

- Scanning electron microscope (SEM) with energy dispersive X-ray spectroscopy (EDS)
  - magnification up to 100,000X with a resolution down to 50 Angstroms
  - EDS - determine the chemical composition on the particles of interest

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**Abrasive Wear**

Two-body abrasive wear asperities on the harder surface penetrate the softer surface. The motion causes plowing or gouging, leaving behind a trough and a ribbon shaped particle.

Three-body abrasive wear a hard particle imbedded in the softer surface penetrates the harder surface, producing a trough and a ribbon shaped particle.
**Abrasive Wear, 200X**

![Image of abrasive wear at 200X magnification]

**Abrasive Wear**

![Image of abrasive wear close-up]
**Fatigue Wear**

Repeated deformation in excess of the materials ability to return to its original state causes subsurface cracking.

The cracks eventually become so numerous that the surface begins to come off in large sheets. These sheets are called fatigue platelets and range in size from about 40 microns to several hundred microns (note that the particle size is greatly exaggerated).
Fatigue Wear

Gear teeth in sliding contact can produce fine needle-like particles with an aspect ratio of 10 to 1 or greater and 10 to 40 microns in length.

Fatigue Wear, 100X

[Images of fatigue wear]
Fatigue Wear

- Micro-delamination
- Asperity deformation
- Adhesion

Particles formed:
- Platelets
- Large particles with striations
- Black oxides
- Tempered particles
- Partially melted/fused particles
- Spheres

Boundary Lube Wear

- Includes:
  - Micro-delamination
  - Asperity deformation
  - Adhesion
**Micro-delamination**

Surface deformation by asperity contact causes micro-crack nucleation.

- Motion
- \( \text{log} \)

**Micro-delamination**

Micro-cracks grow with repeated asprity contact.

- Graph showing motion
- Graph showing repeated contact

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**Micro-delamination**

Micro-cracks grow together.

- Diagram showing micro-cracks growing

A small platelet is formed and a pit is left behind.

- Diagram showing platelet formation
- Diagram showing pit formation
**Asperity deformation**

As asperities contact the softer material is smeared in the direction of motion.

Subsequent contact breaks the deformed portion at the weakest point.

**Adhesion**

Contacting asperities form a junction by interacting at the molecular level. Part of one of the asperities is effectively welded to the other asperity and is removed.

Subsequent contact breaks the welded piece loose at the weakest point.
**Boundary Lube Wear**

- Results from:
  - Start up - rotational speed = 0
  - Coast down - rotational speed approaching 0
  - Wrong lube - viscosity too low
  - No lube
  - High temperature - viscosity decreases with increasing temperature

**Normal Rubbing Wear, 500X**
Boundary Lube Wear, 100X

Boundary Lube Wear, 200X
**Corrosion**

- Corrosion is caused by:
  - Corrosive contamination (including water)
  - Additive depletion
- Results in:
  - Very fine (< 1 micron) black powder
  - Red oxide (rust) resulting from water
Corrosion, 1000X

Corrosion - Rust
Fretting Wear

- Caused by:
  - Small cyclic motions
    - between the bearing race and housing
    - between the bearing race and shaft
    - between the contacting surfaces of gear teeth
  - Results in:
    - Very small platelets (< 2 microns)
    - Appear as coarse black powdery substance

Fretting Wear, 500X
Contamination

- Contaminants such as fibers, dust, dirt, sand, bug legs, paint chips, sealant, pieces of gaskets, anti-seize compounds, and Teflon tape are also commonly found while examining samples. Some of these are benign and of no real concern, others are abrasive and cause increased wear. All contaminants have the potential to clog filters, servo valves, and oil journals

Contamination, Fibers and Sand
Contamination, Salt from Sea Water

Contamination, Bugs
**SEM-EDS, a Powerful Tool for Wear Debris Analysis**

Scanning Electron Microscope (SEM) with Energy Dispersive X-Ray Spectroscopy (EDS):

- Higher magnification, better resolution
- Elemental analysis on the particles
- Pin pointing the origin of particles

**SEM-EDS Analysis, A Carbon Steel Sphere**
SEM-EDS Analysis, Glass Fiber

SEM-EDS Analysis, Stainless Steel Chunk
Electron Micrograph of Cutting Wear Ribbon. X-Ray spectrum shows the ribbon is almost pure Iron.

Partially melted aluminum particle