

Submitted via Water Quality Permitting Portal – Permit Submittals application

January 12, 2023

Keith Primm - Water Quality Permit Coordinator
Department of Ecology - Central Regional Office
1250 West Alder Street
Union Gap, WA 98903

RE: **2022 Environmentally Acceptable Lubricants Annual Report for Wanapum and Priest Rapids dams: National Pollutant Discharge Elimination System Permit Nos. WA0991028 and WA0991029 (S10.B)**

Dear Mr. Primm:

Please find enclosed Grant County Public Utility District's (Grant PUD's) Environmentally Acceptable Lubricants (EAL) Annual Report for 2022, consistent with Section S10.B of the National Pollutant Discharge Elimination System Permits (Permits) for both Wanapum and Priest Rapids dams. Please note that per Section S10.B (page 24) of the Permits, we are submitting an updated version (January 12, 2023) of an EAL report that was developed in 2020 and submitted to the Columbia River Keepers on May 28, 2020¹, Pursuant to paragraph 3 of the Order Granting Parties' Motion to Stay and Stipulation (June 24, 2019), *Columbia Riverkeepers v. Grant County Public Utility District*, Case No. 2:19-cv- 00096-RMP.

In the attached EAL Report, Grant PUD reviewed potential use of EALs for in-water components of the dam that have been demonstrated to meet standards for biodegradability, toxicity, and bioaccumulation potential that minimize their likely adverse consequences in the aquatic environment, compared to conventional lubricants. Whether or not the use of EALs is "technically infeasible" was based on consideration of applicable legal requirements; facility operational requirements; costs of conversion; risk of potential damage to equipment; and maintenance and outage schedules. The factors identified within this definition encompasses the factors identified within the Permit's definition of "technically infeasible".

Consistent with Section S10.B of the Permits, we are supplementing the attached EAL report with a list of in-water components that use either conventional or EAL oils/greases for both Wanapum and Priest Rapids dams (Table 1), as well as updated information regarding use of EALs at its fish attraction water pump wicket gates. See below.

¹ A January 14, 2022 update to this same report was filed per the Wanapum Permit on January 14, 2022 and this 2023 update (attached in this filing) is an update to that 2022 updated report.

Table 1 In-water component/equipment list for Wanapum and Priest Rapids dams.

Component/equipment	Location	Type	EAL or Conventional
Spillway Gate Chains and Gears	Wanapum and Priest Rapids	Pyroshield 5180 Open Gear Grease Pyroshield 5182 Open Gear Grease	Conventional
Bulkhead Gate Wire Ropes	Wanapum and Priest Rapids	Monolec LE 2001 Wire Rope Lubricant Almasol LE 2002 Wire Rope Lubricant	Conventional
Turbine Components	Wanapum and Priest Rapids	Shell Turbo T68 Oil	Conventional
Wanapum Fish Bypass	Wanapum	Mobil EAL 224H series hydraulic oil	EAL
Fish Ladder attraction water pump wicket gates	Wanapum	Panolin Biogrease	EAL
Turbine Wicket Gates	Priest Rapids	76 Red Multiplex EP-1	Conventional
Fish Ladder Gravity Intake Gate Wheels	Priest Rapids	Lubrication Engineers Almaplex 1275 Grease	Conventional
Traveling Screen for Priest Rapids Hatchery Siphon Intake	Priest Rapids	Maxtron EP Lithium Complex Grease	Conventional
<i>Note: Table 1 from the 2021 EAL report for Wanapum Dam showed a line item for the Spillway Gate Gearbox; however, upon further review it was determined based on the location of the gearbox it is not an in-water component of the dam and thus was removed from this updated table for the 2022 report.</i>			

As described in Section 4 of the EAL Report, Grant PUD has been testing use of EAL grease (Panolin BioGrease EP 2 and the BioBlend HDS2) at its Wanapum Dam fish attraction water pump wicket gates. This testing was completed in February of 2021, and Panolin Biogrease was selected as the preferred EAL and will remain in the fish pumps instead of the 76 Red Multiplex EP-1. There were issues with viscosity and separation experienced with the BioBlend HDS2, and as such it will not be used as an EAL alternative. Testing plans for introducing Panolin BioGrease EP 2 into the Priest Rapids Dam turbine wicket gates are in progress.

Grant PUD continues to monitor EAL developments via a partnership with The Centre for Energy Advancement through Technological Innovation (CEATI) to continue researching EAL oils and greases. Grant PUD will provide updates to these research efforts in future EAL reports submitted as part of this Permit.

If you have any questions, please contact me at 509-793-1468 or rhendr1@gcpud.org.

Respectfully,

Ross Hendrick

Ross Hendrick
Senior Manager – Environmental Affairs

CC: Mr. Damon Roberts – Ecology CRO
Mr. Erik Van Doren – Ecology CRO

Enclosed: Environmentally Acceptable Lubricant Feasibility and Assessment Report

Environmentally Acceptable Lubricant (EAL):

Annual Report

Wanapum Dam – Permit No. WA0991028
Priest Rapids Dam – Permit No. WA0991029

By
Public Utility District No. 2 of Grant County
P.O Box 878
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January 2023

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List of Abbreviations

CEATI	The Centre for Energy Advancement through Technological Innovation
CWA	Clean Water Act
EAL	Environmentally Acceptable Lubricant
FERC	Federal Energy Regulatory Commission
Grant PUD	Public Utility District No. 2 of Grant County, Washington
NPDES	National Pollutant Discharge Elimination System
WDOE	Washington Department of Ecology
WQC	water quality certification

1.0 Introduction

Public Utility District No. 2 of Grant County, Washington (Grant PUD) owns and operates the Priest Rapids Hydroelectric Project (Project). The Project is licensed as Project No. 2114 by the Federal Energy Regulatory Commission (FERC) and includes the Wanapum and Priest Rapids developments. A Clean Water Act (CWA) Section 401 water quality certification (WQC) for the operation of the Project was issued by the Washington Department of Ecology (WDOE) on April 3, 2007 (WDOE 2007), amended on March 6, 2008, and effective on issuance of the FERC license to operate the Project in April of 2008 (FERC 2008).

In May of 2019, Grant PUD requested coverage under the National Pollutant Discharge Elimination System (NPDES) permit for both Wanapum and Priest Rapids dams to address potential discharges of pollutants, including potential discharges from drainage sumps, unwatering sumps, drains, turbines, wicket gate bearings and other potential lubricant contact points, and discharges of the cooling water systems. Grant PUD received a NPDES permit from the WDOE for Wanapum Dam in October of 2021, with an effective date of December 1, 2021 (WDOE 2021), and for Priest Rapids Dam in July of 2022 (WDOE 2022), with an effective date of September 1, 2022 (hereafter referred to as “Permit or “permits”).

The Project is currently in conformance with all applicable water-quality based, technology based, toxic and pretreatment effluent limitations as provided by the CWA under 33 U.S.C. §§ 1311, 1312, 1313, 1316, and 1317.¹ The WDOE certified the Project is following these provisions by issuing its WQC under the CWA, 33 U.S.C. § 1341 (WDOE 2007).

Pursuant to paragraph 3 of the Order Granting Parties’ Motion to Stay and Stipulation (June 24, 2019), *Columbia Riverkeepers vs Grant County Public Utility District*, Case No. 2:19-cv- 00096-RMP (Stay Order), Grant PUD is providing Columbia Riverkeeper with the following Environmentally Acceptable Lubricant Assessment and Feasibility Report (Report).

Paragraph 3 of the Stay Order states:

No later than June 1, 2020, the PUD shall complete an assessment and report on the feasibility, based upon the considerations identified in this paragraph, of switching lubricants used at the Dams to one or more “Environmentally Acceptable Lubricants” (“EALs”) for in-water components of the Dams that have the potential to contribute to pollution discharges. Thereafter, the PUD shall switch to using EALs where feasible and as soon as practicable in accordance with a projected schedule described in the assessment and report. The assessment of feasibility and the projected schedule will be made at the sole discretion of the PUD, but will take into consideration consistency with meeting: applicable legal requirements; facility operational requirements; costs of conversion; risk of potential damage to the equipment; and maintenance and outage schedules. Nothing in this Stipulated Order shall be deemed to create a legal obligation on the PUD to switch to an EAL or to establish a schedule for a switch to an EAL if the PUD determines in its sole discretion and describes in the assessment and

¹ These provisions are in CWA sections 301, 302, 303, 306, and 307.

report that a switch to an EAL is not feasible. As used in this paragraph, EALs mean those lubricants that have been demonstrated to meet industry standards for biodegradability, toxicity, and bioaccumulation potential that minimize their likely adverse consequences in the aquatic environment compared to conventional lubricants. Upon completion of the assessment and report described in this paragraph, a copy shall be provided to Riverkeeper.

This Report assesses the technical feasibility of switching the grease and oil lubricants used on components at the Dams to Environmentally Acceptable Lubricants (EALs). Although technical feasibility (which includes consideration of facility operational requirements, risk of potential damage to the equipment, and maintenance and outage schedules) was determinative in the Grant PUD's decision-making with respect to switching to an EAL, Grant PUD also considered legal requirements and costs of conversion.

Grant PUD uses oils and greases to lubricate the following list of dam components that may contact the Columbia River: fish ladders, spillway gate chains, turbines, turbine and generator bearings, and wicket gates. This Report evaluates the use of EALs at these dam components:

- Spillway Gate Chain – Grease
- Wicket Gates – Farval – Grease
- Intake Bulkhead Gate Wire Rope – Coating Lubricant
- Columbia River Fish Ladders – Oil
- Turbines – Grease
- Turbine and Generator Bearings – Oil

As stated in paragraph 3 of the Stay Order, EALs means those lubricants that have been demonstrated to meet industry standards for biodegradability, toxicity, and bioaccumulation potential that minimize their likely adverse consequences in the aquatic environment compared to conventional lubricants. EALs are lubricants that are readily biodegradable, which means that the lubricant has the natural ability to biodegrade to their natural state when subjected to sunlight, water, and microbial activity, by at least 60% within 28 days in accordance with OECD 301B protocol.

Grant PUD's assessment of the technical feasibility of switching the greases, oils, and lubricants is ongoing, with multiphase testing of compatibility, long-term viability research, and practicality assessments for each dam component being considered.²

² Due to the extent that lubricants are used at the Dams at Grant PUD, the project for EALs has been divided into two categories, oils and greases. Due to the large scope of the categories, Grant PUD has decided to partner with CEATI (The Centre for Energy Advancement through Technological Innovation) for research into acceptable EAL oils. CEATI is currently working with a contractor to develop a proposal of the scope of testing that must be done in regards to EAL oils, and specifically turbine compatible EAL oils.

2.0 EAL Turbine Oil

The in-water dam components that currently use oil and are being considered for EAL oil include turbine hubs, turbine and generator bearings, and the oil pressure system (Turbine Components). Turbine Components are critical to operation of the plant's production of power. These large and expensive components have an estimated life of 40 years, as does the currently used oil (which does not qualify as EAL). The current oil, once added to the system, is continuously filtered and monitored, and additional oil is rarely added to the system over the life of the Turbine Components. Grant PUD has found no approved testing methods or utility scale research which has been conducted to ensure that currently offered EAL oils are compatible with existing oils and will not significantly increase the maintenance or repair of this critical equipment. Oil compatibility problems in Turbine Components are well documented and Grant PUD has experienced bad results with oil compatibility problems in the past that resulted in expensive repairs. Recognizing the significant adverse consequences related to oil non-compatibility or increases in maintenance or repairs with the Turbine Components, Grant PUD will continue to invest in research through The Centre for Energy Advancement through Technological Innovation (CEATI) and other industry organizations on the use of EAL oil. At this time, and after extensive research and analysis, Grant PUD determined that switching to EAL oil in Turbine Components is not technically feasible for the following reasons.

First, Grant PUD has concluded that changing the currently used non-EAL oil over to EAL oil is not technically feasible because potential compatibility problems between the oils. Voith Hydro, one of the current contractors that Grant PUD is using to rebuild the turbines at Priest Rapids Dam, as well as the supplier of the turbine and most of the associated components, has already stated that they do not plan on changing their shop testing from traditional mineral oil to any of the new EAL oils. Voith Hydro's refusal to change current acceptance testing practices for the Turbine Components means that even with a thorough cleaning of the turbine it is unlikely that it will ever be completely clean of the mineral oils. Thus, it is inevitable that the EAL oil would mix with the already-in-use mineral oil. Mixing EAL oil and mineral oil can cause many different complications inside the system including the swelling of seals and chemical deterioration makes the oil less effective. Because it is not possible to completely clean the Turbine Components of the current non-EAL oil, there is no way to eliminate compatibility issues from introducing a new EAL oil. Thus, at this time, it is not feasible to switch to EALs on existing Turbine Components due to compatibility issues with the previously used oil.

Second, Grant PUD is concerned about the lack of knowledge on the reactions that EAL oils will have with the different components inside the Turbine Components. One component that causes concern is the seals. Certain EAL oils have been known to cause damage when exposed to natural rubber and silicon, making them less effective at keeping the oil contained and preventing spills and contamination. EAL oils have also been known to cause excessive swelling in seals, which can cause premature failures in the seals. These premature failures can cause cascading problems, including massive oil leaks, which could cause the oil to enter the water and create an environmental incident, even with EAL oil, as well as costly plant outages due to the difficulty in accessing the locations of the seals in the Turbine Components.

Third, the use of EALs on Turbine Components is not technically feasible because of the risk that new chemicals in the EAL oils that could cause a reaction inside the turbine hubs' protective

coating. Turbine hubs have a protective coating to help prevent corrosion and wear. Introduction of new chemicals in EAL oils could cause a reaction inside the turbine hubs with the protective coating. Because the reaction between the potential EAL oil and the protective coating is unknown there is a concern that introducing a new EAL oil could cause the turbine to breakdown, which would be a catastrophic impact on the operation of the Dams and could cost millions to fix.

Fourth, the use of EAL oil on Turbine Components is not technically feasible because of the risks associated with water contamination in the turbine hub. The process with the current mineral oil in the turbine hub is that the ‘dirty’ oil is piped to the ‘dirty oil tanks’ located in the Oil Storage Room. Once there, the oil is processed through a purification filter and a dehydration unit to remove contaminants and water. The resulting clean oil is then stored in the clean oil tanks for use in the turbine and generator equipment. When used in the units, the oil is pumped through a totalizer flow meter into the clean oil header which services all the oil storage locations in the dam. Each of the turbine and generator units receiving oil from the clean oil header has the oil pass through a strainer and a totalizing flow meter with a local manual read-out, that can be individually valved to supply the oil to the turbine guide bearings, the upper generator guide bearings, the lower generator guide bearings, the thrust bearings, the oil head static head, and the governor sump. The turbine guide bearings, the upper generator guide bearings, and the lower generator guide bearings have a pump circulating the oil through a filter and a water-cooled plate heat exchanger with an additional dual-cartridge filter system. The governor sump is the oil supply source for the governor system, which is used to control the turbine blade positions and the wicket gate positions inside the turbines. The governor sump is equipped with a Kidney Loop Filter system, so that the sump is able to maintain the prescribed turbine oil purity requirements.

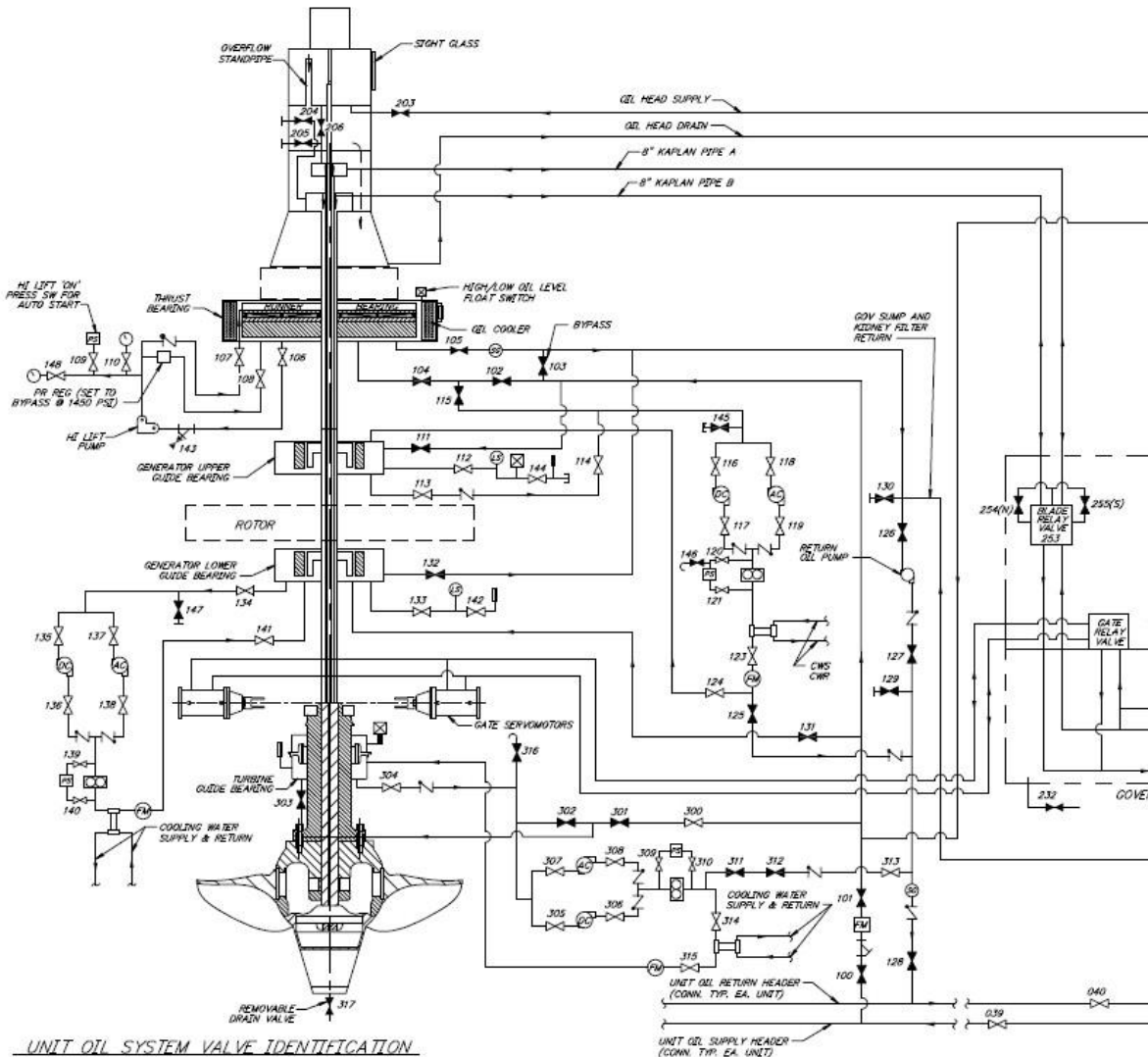


Figure 1 Drawing of the Turbine Oil System.

With the current mineral oil used inside of the turbine hubs, slight water contamination in the oil is not a large concern, because the oil does not absorb the water. Instead, the oil lets the water sit on top until it has been filtered out, not causing any problems with the oil or the components within the turbine hubs. By contrast, with EAL oil, this is not the case. As soon as water is introduced to EAL oil the oil begins to break down. This oil breakdown causes it to reduce its ability to lubricate efficiently and decrease its viscosity, which causes higher friction rates in the components.

An inevitable water contamination in the EAL oil will also make it so that the oil will break down at a faster rate and will have to be replaced on a more regular basis. With the cost of EAL oil being 2-3 times that of the cost of traditional mineral oil, this is not a cost-effective solution. It is also a more labor-intensive solution with a larger potential for accidental spills, as once the oil begins to break down it must be replaced to prevent damage, introducing the potential for human error and accidents. Even with the oil filtration system with a purification filter and a

dehydration unit for contaminants and water removal, once the EAL oil has become contaminated with water, it can cause corrosion due to the oil breaking down and creating a type of acidic water.

After extensive research, Grant PUD has been unable to find approved testing methods or utility-scale research that shows that available EAL oil is compatible with existing oils and will not significantly increase the maintenance or repair of this critical component. Oil compatibility problems in these types of systems are well documented (Shugarman 2001, Le Pera 2002) and Grant PU has encountered oil compatibility problems in the past that resulted in expensive repairs. As such, Grant PUD determined that using EAL oils for Turbine Components is not technically feasible at this time.

3.0 Current Use of EALs and Alternatives

Grant PUD has been introducing EAL lubricants into the dam's lubrication processes as they have become available and can meet the performance and compatibility requirements of the existing equipment. One such location where this has been successful is in the Wanapum Fish Bypass, where Grant PUD converted to using Mobil EAL 224H series hydraulic oil, which allows for juvenile fish to safely pass through from upstream of the dam to downstream.



Figure 2 The Wanapum Dam Fish Bypass was finished in 2008 and was the first equipment at Grant PUD to use Environmentally Acceptable Lubrication.

Use of EALs in submerged applications, such as chains and wire ropes, have been shown to not be technically feasible: “By design, EALs will biodegrade rapidly when exposed to an environment, such as the river, that contains organisms that will initiate biodegradation. The biodegradation is so efficient that the lubricant is not serviceable after 1 month of exposure.” (Hydroelectric Design Center, 2017).

The U.S. Army Corps of Engineers, Portland District tested EAL grease for submerged applications in conjunction with the Hydroelectric Design Center. The test results demonstrated that there was a significant increase in maintenance intervals needed, as well as a large increase in the potential risk of a lack of lubrication, as the lubricant cannot function as needed to prevent damage. This lack of lubrication also can result in catastrophic failures, loss of generation, and costly repairs on a short timeline.

Grant PUD is actively researching EAL grease substitutes for the most commonly used grease at the Dams, 76 Multiplex Red EP-1 Grease. This is the grease that is used at Priest Rapids Dam for the turbine wicket gates which are currently in the process of being replaced. Therefore, there is opportunity to introduce EAL grease in new wicket gates as a trial without fear of cross-contamination issues. The Wanapum Dam wicket gates have previously been replaced with all greaseless composite bushings and therefore don’t require any lubrication. During the planning stage of the Priest Rapids turbine and generator replacement project it was determined that greaseless composite bushings were not feasible in all the locations at the Priest Rapids Dam. The new units at Priest Rapids include composite greaseless bushings in 70% of the locations, which replaced the original greased bushings.

4.0 EAL Grease

The following sections outline Grant PUD’s pilot research program on finding a compatible EAL grease to use at the Dams.

4.1 Researching EAL Grease

Grant PUD began researching currently available EAL grease by contacting other hydro facilities working on the conversion from traditional grease to an EAL formula. Grant PUD contacted and received feedback from the Bureau of Reclamation, specifically Hungry Horse Dam, that is using Huskey LVI and Lube Seal grease. The U.S. Army Corps of Engineers, working with the dams on the Lower Columbia River, who are currently using Panolin Biogrease EP2 grease. Portland General Electric also shared that it is currently using Chevron Clarity Synthetic EA grease but is looking at technically feasible ways of transitioning to EAL grease. Grant PUD also communicated with other companies, such as BioBlend, that are working to create EAL grease.

After creating a comprehensive list of potentially compatible EAL greases, Grant PUD sent samples of the EAL greases to Oil Analysis Lab Inc. in Spokane, Washington. To ensure that the test facility was up to Grant PUD standards for testing, three mechanical engineers conducted an onsite visit of the facility and found the staff to be incredibly knowledgeable and well-versed in the types of requested testing.

The testing was to determine if the potential EAL greases are compatible with the currently used 76 Multiplex Red EP-1 grease. An incompatible mixed-grease consistency can turn the grease to a liquid consistency or make the grease too firm for proper penetration. To ensure that the

greases are compatible, the Oil Analysis Lab Inc. conducted two separate compatibility tests, the cone penetration test and the dropping point test.

First, to perform the cone penetration test, Oil Analysis Lab Inc. mixed the EAL greases and the current 76 Multiplex Red EP-1 using 60 strokes at three different percentages: (1) 10% EAL, 90% Red; (2) 90% EAL, 10% Red; and (3) 50% EAL, 50% Red. A stroke is when the cone is forced into the mixed grease semi-continuously in a ‘start-stop’ manner, simulating the conditions inside of the equipment. After completely purging the used grease lines of the Red Grease, there was still no guarantee that all the old non-EAL grease would be completely removed. Oil Analysis Lab Inc. determined that the test was most effective when they did not to completely purge the old grease but added the new EAL grease as the old grease settled and had to be replaced anyway.

Second, Oil Analysis Lab Inc. tested for compatibility using the dropping point test. “The dropping point of a grease is the temperature at which it passes from a semi-solid to a liquid state. The dropping point test determines the cohesiveness of the oil and thickener of a grease.” (Lubricant Testing 101 - Dropping Point). The dropping point test is used in compatibility testing to ensure that the old grease and the new grease have the same melting point and can withstand high temperatures even when mixed together. By combining the greases at the above-stated three different mixtures, the dropping point test ensures that the grease will not melt at a lower temperature, making it unusable for high-temperature situations.

The results of the two tests identified two potential EAL greases that met the compatibility requirements. These two EALs, Panolin Biogrease EP2 and BioBlend HDS2, had satisfactory compatibility results in the 98th percentile and above in both the cone penetration and drop-point tests. See Appendix B of this Report for more information.

4.2 In-House Testing of Compatible EAL Grease

Grant PUD was then able to perform in-house testing on the two identified potentially compatible EAL greases. Grant PUD decided to only conduct further testing on the EAL greases identified as most likely to be compatible, those greases that met the 98th percentile and above requirement. This high requirement was set, as the testing was to be performed on the Wanapum Dam fish attraction water pump wicket gates. Wicket gates, also known as guide vanes, are a component of turbines that are used to control the flow of water into the turbine itself. The wider open the wicket gates are, the more water flows into the turbine runners, resulting in higher power output, which runs the water pumps for the fish attraction. The Wanapum Dam fish attraction water pump wicket gates were selected for the testing, due to there being two systems, one as the main system, and one as the backup. A problem that did come up with using the Wanapum Dam fish attraction water pump wicket gates being used for the small-scale testing is that they are important components in the fish bypass system that cannot be out of service for the majority of the year and are required for the Project permitting. Additionally, this is also the reason that the two highest scoring EAL greases were tested a year apart. That way, if something went wrong with the first EAL grease test and the system had to go down, there was a back-up system that could still run while the first was being fixed.



Figure 3 The Wanapum Dam fish attraction water pumps are being used for in-house testing of the two EAL greases that met the compatibility tests qualifications. Due to their small size, and the yearly maintenance, Grant PUD decided that testing on the fish attraction water pumps was the best course of action to identify any wear issues or compatibility problems.

Grant PUD first tested the Panolin Biogrease EP2, a fully synthetic grease that has a wide temperature range and good mechanical stability that passed all the compatibility tests with scores of either good or adequate. Grant PUD started testing the Panolin Biogrease EP2 testing in February 2019 and completed testing in February 2020. The testing results demonstrated that this grease is compatible with the non-EAL grease and had such a successful run that even once the testing was complete the EAL Panolin Biogrease EP2 continued to be used. In the testing, and in figure 4, full penetration of the grease can be seen in the #1 fish attraction water pump wicket gate piping. The Panolin Biogrease EP 2 has a distinct taupe brown color that highly contrasts with 76 Red Multiplex EP-1 grease, even when mixed, creating a light maroon shade. This manner of testing also provided a visual indication for when the grease had completely penetrated the system of the fish attraction water pump wicket gates that Grant PUD used for small-scale testing for the wicket gates.



Figure 4 The complete penetration of the Panolin Biogrease EP2 in the Fish Attraction Water Pump #1, into the above water fittings for the wicket gates. The taupe brown colored grease can be seen covering the red colored grease.

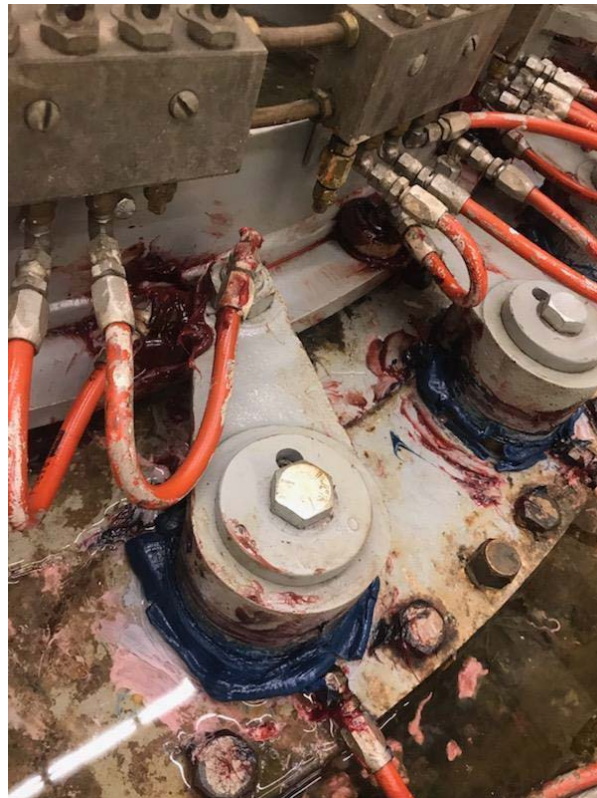


Figure 5 The complete penetration of the BioBlend HDS 2 in the Fish Attraction Water Pump #2, into the above water fittings for the wicket gates. The blue grease completely covering the red grease.

In February 2020, Grant PUD then began testing the second selected grease, the BioBlend HDS2, a synthetic lithium complex grease, and completed the testing in February 2021. BioBlend HDS 2 has excellent anti-wear capabilities, as well as a high viscosity, which creates a better protection against friction. The BioBlend HDS 2 grease has a distinct blue color, that overtook the red grease, making full permeation easily identified. Although the results of the Panolin Biogrease EP2 had been acceptable, the BioBlend HDS 2 grease tested even higher in the satisfactory percentiles of the compatibility testing with the current 76 Red Multiplex EP-1 grease based on the Oil Analysis Lab Inc testing. This compatibility between the old grease and the new grease creates an even smaller chance of a potential problem when mixing the two. In the end it was not the compatibility that ended up being the problem with the BioBlend HDS2, it was this high viscosity that ultimately made the grease fail the testing and be concluded as not an option for wider use at the Dams.

It was discovered by a mechanic on a review of the system that the BioBlend grease was too viscous and created an airgap in the Farval system when the grease did not settle and the Farval system not having enough power to push the grease through the lines. A temporary solution was put together by the mechanics by strapping the plunger of the Farval system reservoir down and tightening it when the system needed more grease. The conclusion that the mechanical engineer came to is that the grease at the bottom of the Farval reservoir, next to the piping mechanism was able to be pulled into the system, but this created an air gap between the bottom of the reservoir and the grease. The grease was so viscous that it didn't settle in a normal manner, the solution for this problem was to create a temporary vice system connected to the plunger to manually push down the lever at the top of the reservoir forcing the grease into the air gap.



Figure 6 The temporary solution of strapping the plunger down to the reservoir, that was created to compensate for the thick viscosity of the BioBlend HDS2 EAL grease.

This temporary solution turned into a more permanent solution as the Coronavirus epidemic went on and access to the plants became even more stringent to help protect the operators and ensure no interruptions to the production of power.

Furthermore, in June 2022 further issues with the use of the Bioblend HDS2 grease were experienced. The Farval stopped pumping grease, and investigation found that the oil in the grease seemed to be separating from thickener, leading to the grease drying out and clogging the Farval pump. At this point the BioBlend grease was removed and replaced with the Panolin Biogrease.

4.3 Conclusions of In-House Testing of Compatible EAL Grease

Once the testing was complete for both the Panolin BioGrease EP 2 and the BioBlend HDS2 EAL greases in February 2021, Grant PUD decided that the Panolin BioGrease 2 was the best option of EAL for the District due to the viscosity and separation issues experienced with the BioBlend HDS2. Testing plans for introducing Panolin BioGrease EP 2 into the Priest Rapids Dam turbine wicket gates are in progress.

5.0 Conclusion

This Report summarizes Grant PUD's extensive assessment of the technical feasibility of switching the grease and oil lubricants used on components at the Dams to EALs. Grant PUD made the following determinations on the current technical feasibility of using EALs on the following components:

- Spillway Gate Chain – It is not currently technically feasible to use EALs in submerged applications, such as chains. This assessment is in Section 3.
- Wicket Gates – Panolin BioGrease EP2 will be tested in this application, as explained in Section 4.3.
- Intake Bulkhead Gate Wire Rope – It is not currently technically feasible to use EALs in submerged applications, such as rope. This assessment is explained in Section 3.
- Columbia River Fish Ladders – Grant PUD already uses EAL oil at the Wanapum Dam Fish Bypass.
- Turbines – It is not currently technically feasible to use EALs in turbines, as explained in Section 2.
- Turbine and Generator Bearings – It is not currently technically feasible to use EALs in turbine and generator bearings, as explained in Section 2.

Grant PUD will continue to monitor EAL developments in the industry and will continue looking into an EAL oil replacement. For this reason, Grant PUD decided to partner with The Centre for Energy Advancement through Technological Innovation (CEATI) to research EAL oils. CEATI is collaborating with a contractor to develop a proposal of the scope of testing that must be done regarding EAL oils, specifically turbine compatible EAL oils. Grant PUD will assess the results of this testing when it is complete.

Literature Cited

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Appendix A

Compatibility Test Results

Oil Analysis Lab Inc

Solving Problems Through Science

Website: www.oillab.com

Grease Compatibility Testing per ASTM D6185

Customer: Grant County

Dropping Point (Degrees F)

Base Sample	Mix Sample	Pass Min		90:10 Mix	50:50 Mix	10:90 Mix	Pass/Fail
Multiplex Red	Huskey LVI	475		380	-	-	Fail
Multiplex Red	Huskey Lube Seal	475		>400	300	-	Fail
Multiplex Red	Panolin	319		384	>400	370	Pass

Cone Penetration - 60 Strokes

Base Sample	Mix Sample	Pass Min	Pass Max	90:10 Mix	50:50 Mix	10:90 Mix	Pass/Fail
Multiplex Red	Huskey LVI	NT	NT	NT	NT	NT	Fail
Multiplex Red	Huskey Lube Seal	NT	NT	NT	NT	NT	Fail
Multiplex Red	Panolin	312	334	324	334	330	Pass 10:90 & 90:10

High Temp Storage - Cone Penetration 60 Strokes After Oven at 120C

Base Sample	Mix Sample	Pass Min	Pass Max	90:10 Mix	50:50 Mix	10:90 Mix	Pass/Fail
Multiplex Red	Huskey LVI	NT	NT	NT	NT	NT	Fail
Multiplex Red	Huskey Lube Seal	NT	NT	NT	NT	NT	Fail
Multiplex Red	Panolin	236	330	278	182	232	Pass 90:10

Observations

Panolin appears to be compatible with the Multiplex at a 90% Panolin 10% Multiplex mixture. 50:50 Mixture is not compatible. The 10:90 mixture was close but failed on after being in the oven.

Neither Huskey product appeared to be compatible with Multiplex

Oil Analysis Lab Inc

Solving Problems Through Science

Website: www.oillab.com

Grease Compatibility Testing per ASTM D6185

Customer: Grant County

Dropping Point (Degrees F)

Base Sample	Mix Sample	Pass Min		90:10 Mix	50:50 Mix	10:90 Mix	Pass/Fail
Multiplex Red	Chevron Clarity	>400		>400	>400	290	Fail 10:90
Multiplex Red	BioBlend	>400		>400	>400	>400	Pass

Cone Penetration - 60 Strokes

Base Sample	Mix Sample	Pass Min	Pass Max	90:10 Mix	50:50 Mix	10:90 Mix	Pass/Fail
Multiplex Red	Chevron Clarity	276	334	314	317	304	Pass
Multiplex Red	BioBlend	252	334	316	296	280	Pass

High Temp Storage - Cone Penetration 60 Strokes After Oven at 120C

Base Sample	Mix Sample	Pass Min	Pass Max	90:10 Mix	50:50 Mix	10:90 Mix	Pass/Fail
Multiplex Red	Chevron Clarity	250	330	327	304	259	Pass
Multiplex Red	BioBlend	234	330	294	265	260	Pass

Observations

Chevron Clarity failed the Dropping point at 10:90 (10 Parts Multiplex 90 Parts Clarity). It also was a borderline pass on the 90:10 high temp storage. Bio Blend passed for compatibility on testing ran.

Appendix B
CEATI EA Oils Test Plan

Report for

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HYDRAULIC PLANT LIFE INTEREST GROUP (HPLIG)

CEATI REPORT No. T182700-03/103

TESTING PLAN FOR ENVIRONMENTALLY ACCEPTABLE HYDRO PLANT OILS

Prepared by **Kinectrics
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Sponsored by
The 2018 Participants of the Hydraulic Plant Life Interest Group (HPLIG)

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April 2019
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ABSTRACT

The objective of this document was to produce a set of standardized tests (i.e., a test plan) for CEATI members to use for the evaluation of potential candidates to replace incumbent oils with environmentally acceptable (EA) oils suitable for use in various applications within power plants.

With a focus on turbine oils (also seal oils and certain hydraulic fluids) and insulating oils, this test plan was designed to compare the performance of the fluids based on their physical, chemical and environmental properties. Certain products would also be tested for their dielectric and electrical properties, where applicable.

Keywords:

Biodegradability

Environment(ally) acceptable

Transformer fluid (insulating oil)

Turbine oil

Transformer

Turbine

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Algonquin Power and Utilities		USA
Ameren Corporation	IL	USA
American Electric Power	OH	USA
Avista Utilities	WA	USA
BC Hydro	BC	Canada
Bonneville Power Administration	OR	USA
Brookfield Renewable Power	QC	Canada
California Department of Water Resources	CA	USA
Chelan County Power	WA	USA
CMS Energy	MI	USA
Columbia Power Corporation	BC	Canada
Douglas County PUD	WA	USA
Duke Energy		USA
Eagle Creek Renewable Energy		USA
Electricité de France		France
Electricity Supply Board		Ireland
Enel Green Power	MA	USA
EnergyKeepers	MT	USA
Eugene Water & Electric Board	OR	USA
Exelon	IL	USA
FirstLight Hydro Generating Company	MA	USA
FortisBC Inc.	BC	Canada
Fortum Sverige AB		Sweden
Grant County Public Utility District	WA	USA
Great River Hydro	NH	USA
Hetch Hetchy Water & Power	CA	USA
Hydro Tasmania		Australia
Hydro-Quebec	QC	Canada
Idaho Falls Power	ID	USA
Idaho Power	ID	USA
Korea Hydro & Nuclear Power Co., Ltd		Korea
Landsvirkjun		Iceland
Lewis County PUD	WA	USA
Manitoba Hydro	MB	Canada
Mercury Energy		New Zealand
Minnesota Power	MN	USA

Nalcor Energy	NL	Canada
New Brunswick Power	NB	Canada
New York Power Authority	NY	USA
Newfoundland and Labrador Hydro	NL	Canada
Northern California Power Agency	CA	USA
Northwest Territories Power Corporation	NT	Canada
NorthWestern Energy	MT	USA
Nova Scotia Power Inc.	NS	Canada
Ontario Power Generation	ON	Canada
Pacific Gas & Electric Company	CA	USA
PacifiCorp		USA
Placer County Water Agency	CA	USA
Portland General Electric	OR	USA
Puget Sound Energy	WA	USA
Rio Tinto Alcan	QC	Canada
Sacramento Municipal Utility District	CA	USA
Salt River Project	AZ	USA
SaskPower	SK	Canada
Seattle City Light	WA	USA
SHEM Société Hydro Électrique du Midi		France
Snohomish PUD	WA	USA
Snowy Hydro Limited		Australia
Southern California Edison	CA	USA
Southern Company Services	GA	USA
Tacoma Power	WA	USA
Tennessee Valley Authority	TN	USA
TransAlta	AB	Canada
Uniper		Sweden
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EXECUTIVE SUMMARY

1. Background:

The objective of this test plan was to produce a set of standardized tests for the evaluation of potential candidates for environmentally acceptable (EA) oils suitable for use in various electricity generation power plants in a variety of applications. CEATI and its members wanted to get ahead of potential governmental legislation and identify the testing required to deem a fluid as EA. An EA oil is defined as friendly to the environment and eventually biodegradable in soil or ground water.

2. Summary:

The test data generated from the plan is to be used in order to identify characteristics and parameters to evaluate fluids (turbine & seal oils, certain hydraulic fluids and insulating oils) and deem them as EA acceptable or not; to evaluate environmental risks of new and existing fluids used for turbine and insulating oils (electrical use) applications, and for the fluids themselves to be marketed as 'EA'. The performance of the fluid within the application was also discussed, and an evaluation matrix scorecard was designed based on the EA rating and the performance of the fluid for the specific application.

3. Conclusions:

This test plan is designed so that fluid manufacturers and utilities or governmental bodies, can request that specific suppliers or utilities test their fluids to a certain standard in order to deem them as EA. The implication is that the spill of an EA fluid is easier to remediate in the event of a leak or spill.

4. Recommendations:

The authors recommend choosing a few applications with the largest impact (number of assets affected and the best economic value) such as turbine oils, insulating oils and hydraulic applications in vehicles servicing electrical utilities and performing the testing outlined in this test plan for EA and performance. After the results have been compiled, assuming a suitable candidate oil is found, a lifecycle economic assessment should be undertaken to evaluate the feasibility of replacing the existing fluid.

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1.0 INTRODUCTION

Mineral oils are widely used in electricity generation plant equipment for various applications, such as transformer oils, fuels and lubricants for varying functionality. Mineral oils are typically distillates of crude petroleum and possess poor biodegradability, biocompatibility and toxicity compared to vegetable oils. Biodegradable oils are convenient for applications wherever lubricants might come encounter the environment.

With increasing environmental awareness and determination to eliminate potential negative environmental impacts which could be a consequence of the need to lubricate plant assets, the electricity generation industry is increasing its efforts to identify oils that will meet minimum acceptable lubrication and environmental acceptance criteria.

Before switching fluids to a biodegradable lubricant, it is prudent to consider the lubricating system's design and operational characteristics. Parameters such as operating temperature, environment/atmosphere, pressures, flow rates, sealing materials or transfer materials used (i.e. hoses), the potential for contamination (such as water, dust or dirt) and whether the existing filtration system is sufficient for the new biodegradable lubricant should all be weighed. Another very important consideration is whether the new biodegradable fluid is compatible with the application's existing lubricant. Symptoms of an incompatible fluid include severe foaming, leaking seals, plugged filters, higher-than-normal wear on some components (such as the pumps), and

increased operating temperatures.

The purpose of this project is to provide an oil testing guideline for the Centre for Energy Advancement through Technological Innovation (CEATI) Hydraulic Plant Life Interest Group (HPLIG) participants that will identify and confirm the properties of varied marketed environmentally acceptable (EA) oil products to encourage their potential use in plants. For the purpose of this manuscript, EA oil is defined as friendly to the environment and eventually biodegradable.

Two types of broad applications will be generally introduced. For the purpose of this test plan, hydraulic oils and gear oils will be excluded as the scope of this test plan is quite large.

1.1 Turbines

There are several types of turbines depending on the source of energy.

Hydro-electric plants typically use potential energy stored as a water reservoir behind a dam. The potential energy is converted to kinetic energy when water is allowed to flow down the penstock from the dam and the kinetic energy is used to turn a turbine. The falling water strikes a series of blades attached to the turbine shaft which converts the kinetic energy to mechanical energy. The rotating turbine drives the generator through magnetic coils, thereby converting the turbine's mechanical energy into electric energy. The generator is connected to a rotor which also spins. The rotor spins around rolls of copper wire (called the stator), that generates a flow of electrons (electricity) that can be stepped up in voltage using a transformer.

There are two main types of turbines for hydroelectric power; impulse and reaction [1]. The height of the water pool (referred to as 'head'), and the moving volume of water (flow) determine the type of hydropower. Other contributing factors regarding the type of hydroelectric power include the depth of the turbine and its efficiency, and the cost [2].

An impulse turbine is driven by high speed of water or steam through nozzles that moves the runner arms and discharges to atmospheric pressure. The resulting impulse spins the turbine generating the kinetic energy from the water flow to the runner. The water from the nozzle streams hit each runner, and the water flows out the bottom of the turbine housing after hitting the runner [1]. An impulse turbine is usually suitable for high head and low flow applications. A pelton wheel is an impulse water turbine, that extracts kinetic energy from the impulse of the moving water and has at least one free jet discharging water into an aerated space and impinging on the buckets of a runner. A Turgo wheel is a derivative of the Pelton [1]. The Turgo turbine is an impulse water turbine whose runner is a cast iron or steel wheel whose shape generally resembles a fan blade that is closed on the outer edges. The water or steam is driven to one side, travels across the blades and exits on the other side. A cross-flow turbine is drum-shaped and uses an elongated nozzle directed against curved vanes on a cylindrically shaped runner [1]. The fabrication of the cross-flow turbine allows the water to flow through the blades twice; the first pass is when the water flows from the outside to the inside, and the second pass is from the inside back out. The cross-flow was developed to

accommodate larger water volume flow and lower heads as an alternative to the Pelton turbine [1].

A reaction turbine generates power from the impulse of steam and the change in momentum (from the expansion and acceleration of steam), acting as a nozzle. The runner is placed directly in a water stream flowing over the blades (stationary guide vanes). Reaction turbines are generally used for sites with lower water heads compared with the impulse turbines. A propeller turbine generally has a runner with three to six blades where the water contacts all of the blades continuously [1]; its moving part (the propeller) resembles a ship or sub-marine propeller. This turbine works best with

high flow rates. [1].

There are several different types of propeller turbines:

Bulb turbine - The turbine and generator are in a sealed unit situated directly in water.

Tube Turbine - The penstock bends near the runner, allowing a straight connection to the generator.

Straflo - The generator is attached directly to the turbine.

Kaplan – Both the blades and the wicket gates are adjustable, allowing for a wide operability range. Francis - A Francis turbine has a runner with fixed vanes inside a spiral casing. Water strikes the edge of the runner (pushing the blades), and then flows towards the axis of the turbine [3].

Kinetic – Free-flow turbines (i.e. kinetic energy turbines), generate electricity from the kinetic energy present in moving water rather than the potential energy (from the head). Kinetic energy turbines sometimes operate in moving waters (ex. rivers, channels, tidal waters, etc.) using the natural path of the water stream. These specific turbines typically do not require a diversion of water such as manmade channels, dams, riverbeds, etc. Kinetic systems do not require large infrastructural civil works; however, they have been known to utilize existing structures such as bridges, or tailraces [3].

Nuclear plants have a different source of energy. In CANada Deuterium Uranium (CANDU) reactors (Canadian nuclear stations), natural uranium is used with heavy water (D₂O) as the moderator. In non-CANDU reactors (ex. India, China, Japan, Russia, UK, US nuclear stations, etc.), enriched uranium is used and light (regular) water (H₂O) is used as the moderator. In both types of nuclear stations, the heated moderator water is circulated through a boiler, which converts regular water into steam in a boiler. Through various flow paths (each station may have a different set-up), the steam passes through a turbine converting steam energy into mechanical energy. Some stations have high-pressure and low-pressure turbines, and varying degrees of water ‘dryness’, which will not be discussed further.

Each turbine and generator have its own rotor/shaft that is supported at each end by journal bearings. The journal bearings get hot due to friction and heat conduction along the shaft from the hot parts of the turbine.

The turbine oil’s job is to prevent metal-to-metal contact and dissipate any high temperature, which extends the life of the bearings and reduces the chances of catastrophic failure. A bearing failure from the turbine-generator would be considered a severe failure. For this reason, it is important to have sufficient oil flow through the bearings for lubrication and cooling purposes.

Some HPLIG member stations have jacking oil systems, which is used to 'prime' the turbine shaft (low RPM of the turbine). These oils are typically the same as those used in turbines, and thus will be discussed further simply as turbine oils.

Some stations also utilize governing oils. Many of the HPLIG members use turbine oil as their governor fluids. These oils are typically the same as those used in turbines, and thus will be discussed further simply as turbine oils. For the purpose of this manuscript, only new oils are considered. Once the fluid is in-service, the oils should never be mixed due to different contamination limits and application use. Both Canadian and American nuclear stations use a fire resistant fluid (FRF), such as phosphate esters, as their hydraulic fluid. FRF fluids will not be discussed further.

1.2 Insulating oils

Electrical insulating oils (also known as transformer oils or insulating oils) are another class of oils used by HPLIG members. Insulating oils are typically naphthenic base oils, which are believed to have lower oxidation stability than paraffinic and are suitable for outdoor use [4]. Naphthenic oils can be used because insulating oils do not operate under high temperature conditions. Silicone oils have been used as insulating oils for newer electrical equipment, particularly to replace the discontinued polychlorinated biphenyls (PCBs) that were once used from the 1960s-2000s.

Insulating oils have a dual purpose; one to cool by dissipating heat from the windings to the outside air; and two, to act as insulation between different parts within the transformer. Typically, insulating oils are not usually formulated with any additives; they just contain mixtures of base stocks.

Mineral oil specifications are typically dictated by the following North American standards: American Society for Testing and Materials (ASTM) D3487, Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus or the Institute of Electrical and Electronics Engineers (IEEE) C57.106, Guide for Acceptance and Maintenance of Insulating Mineral Oil in Electrical Equipment.

These standards covers new mineral insulating oil specifications of petroleum origin for use as an insulating and cooling medium in new, existing power generation and distribution electrical apparatus including transformers, circuit breakers, switchgears, reactors, etc.

It is also possible to fill transformers with vegetable-based oils (mainly esters). The claimed benefits include less risk of a fire, better moisture adsorption and environmental friendliness. Currently the vegetable-based oils cost more than mineral oil, so it is usually available as a "special request", and is not the default mineral oil choice.

1.3 Lubricant additives

The primary attribute desired by most end users from their lubricant is that it protects their asset from wear; thereby increasing the asset's reliability and useful lifespan. Turbine oils have been used for more than 100 years. Steam turbines are rotating elements driven by motors that transform the energy of steam (from various sources) into mechanical work using one or more stages. Turbine oils are typically 96-99 % base stock with 1-4% additive packages. Additives can vary, but are typically made of anti-wear (AW), extreme pressure (EP) additives, silicone-free anti-foaming agents (ex. poly(ethylene glycols-polyethers) and pour point depressants (ex. alkylated naphthalenes, polyalkyl methacrylates) [5].

The additives are usually proprietary to each oil supplier and are responsible for several factors, including; circulation and heating in the presence of air, contamination suppression, load-carrying ability, oxidation stability, protection against rust, water separability, foam resistance and rapid entrained air release [6].

The special lubricity required for hydraulic oils typically fall into two categories; rust and oxidation (referred to as R&O), and antiwear and R&O. Hydraulic oils are also base stock and a special additive package blended together to achieve the desired results (EP, wear protection, aging stability, viscosity-temperature, foaming, etc.).

Currently, the most important antiwear and antioxidant additive is a class of molecules called zinc dialkyl dithiophosphates (ZDDPs) [7, 8]. Antiwear films generated from ZDDPs are known to protect moving surfaces, acting as sacrificial films that are constantly regenerated in various environments [8-12]. Studies have shown that the breakdown products of ZDDPs, and not the ZDDPs itself, provides the antiwear protection needed to lubricate sliding

steel surfaces within a simulated and actual engine environment. Several studies show that ZDDPs decomposes upon rubbing to form a protective film (tribofilm or antiwear film), however thermal decomposition has also been the accepted major mechanism of the antiwear film formation [7-11]. It is well known that these films are comprised of an amorphous polyphosphate glass structure.

The environmental implications of using ZDDPs have been well studied [7], and the necessity to use more environmentally friendly oil additives has become ever more apparent. The industry trend is constantly moving towards ashless (free of metals) AW and EP additives.

Rust and corrosion inhibitors (sometime metal deactivators) are additives (e.g., sulfonates, carboxylic acid derivatives, amine esters, and vapour phase corrosion inhibitors) that reduce or eliminate internal rust and corrosion by neutralizing acids and forming a chemical passivation barrier to repel moisture from metal surfaces. Some of these inhibitors are specific to protecting certain metallic surfaces. Therefore, formulated oils may contain several corrosion inhibitors. They are common in almost every oil and grease.

Viscosity index (VI) improvers are large polymers added to oil that prevent the oil from thinning out (losing viscosity) as the temperature increases. This isn't used as frequently for turbine oils, but can be used for hydraulic oils. Viscosity index improvers are also responsible for better oil flow at low temperatures, resulting in reduction in wear. Furthermore, VI improvers are sometimes used to achieve high-VI hydraulic or gear oils for accelerated start-up and lubrication at sub-zero temperatures.

Detergents and dispersants are added to oil for two functions; to keep the metallic surfaces clean from deposits and to neutralize the acids that are formed. Dispersants keep particles dispersed or suspended in the oil. These additives are typically not present, or are used in very small quantities when added, in turbine oils, but are used in hydraulic

Antifoam additives create a lower interfacial force (tension), which weakens the oil-water interface and allows the foam bubbles to disperse (burst) more readily. They have an indirect effect on oxidation by a reduction of the amount of air-oil surface area contact. Some of the anti-foaming applications.

additives are oil-insoluble silicone materials that are not dissolved but rather dispersed finely in the lubricating oil. Only very low concentrations are usually required and if too much anti-foaming additive is added, it can have a reverse effect and promote further foaming and air entrainment.

Friction modifiers are typically used as sacrificial layers to lower the coefficient of friction, thereby minimizing the interaction of the metallic surfaces with each other. These additives are typically not used in turbine oils, and may be used in hydraulic applications.

The pour point of an oil is the lowest temperature at which an oil will remain fluid. Paraffinic mineral oil crystallizes to become semi-solid and eventually solid at low temperatures, by first forming wax crystals. The wax crystals form a lattice that prevents the remaining liquid from flowing through it. Certain additives are added to fully formulated oils to reduce the amount of wax being formed allowing the oil to continue to behave as a liquid at low temperatures.

Emulsions are stable oil-water mixtures. Demulsifier additives are molecules that change the interfacial tension of the oil so that water will coalesce and separate from the oil, preventing formation of emulsions. This is vital for lubricants exposed to lots of steam or water, so that free water can be drained once settled out through a tap. In contrast, an emulsifier additive is used in water dilutable metalworking fluids and some fire-resistant fluids (mainly water glycol fluids) to help create stable oil and water emulsions. The emulsifier additive can be thought of as a binder sticking oil and water together, because normally they would separate from each other due to interfacial

forces and different specific gravity.

Biocides are often added to water facing lubricants to limit the growth of bacteria and fungus.

Fire resistant fluids are used in the electrohydraulic governor control systems of large turbines. The fluids used are either phosphate esters or blends of phosphate esters. These systems are extremely critical and susceptible to moisture, particulates, varnish and acidity. Phosphate esters are beyond the scope of EA applicability for at least this test plan. Consideration should be given in the future to an EA replacement.

Due to the degradation of lubricant additives and contamination, most commercial oils cannot be reused. Some users try to recycle or reuse spent lubricants with limited success. Rather than dumping the fuel oil into a landfill, a 'greener' approach is to use spent lubricants as an energy source by burning the oil. A recycling program where the water and solids are removed from the used oil is considered re-refining, which is a similar process to refining crude oil. After filtration, (i.e. processing), the base oil can have equal or better quality to virgin base oils. These base oils can be used to produce new lubricants, starting the cycle over again [13].

1.4 Biodegradability Requirements

In recent years, pollution and environmental health aspects have become increasingly important as public issues [14]. The lubrication industry has been focused on lubricants lost to the environment; as spills or leaks would contaminate water and soil directly, while the immediate and surrounding air is affected by volatile organic compounds. The need to find alternatives is the primary driving force for new technological developments. Therefore biodegradable synthetic lubricants used in environmentally sensitive areas have been of recent interest [14].

Generally, three types of base oils are used for biodegradable, environmentally friendly lubricants. These are vegetable, synthetic and mineral oils. One specific type of mineral oil is biodegradable because it is prepared from sugar cane.

Vegetable oils are a biodegradable, renewable alternative to petroleum oils. They are generally considered less toxic, reduce the overall dependency on petroleum-based products, and lubricants and greases made from certain vegetables can help reduce surpluses and help stabilize prices for farmers. Using vegetable-based products offer positive public relations benefits and can generate support towards rural agricultural communities. However, without additives, vegetable oils in their natural form lack sufficient oxidative stability for normal lubricant use. Vegetable oils typically have poor oxidation stability (i.e. they will oxidize rather quickly during use) and become thick and polymerize into a plastic-like gooey material. Chemical modification through the addition of additives can help reduce this oxidative behaviour but can significantly impact the cost. Some of the chemical modification might include partial hydrogenation. The challenge with hydrogenation is to determine at what point the process is to halt. Full hydrogenation of a vegetable oil can lead to margarine-like substances. Depending on the lubrication needs and pour point range required, optimum hydrogenation is required. Recent advances in biotechnology have led to the development of genetically enhanced oilseeds that have better oxidation stability and do not require chemical modification and/or use of antioxidants [15].

Synthetic oils generally fall under three classes; Polyalphaolefins (PAOs), Diesters/Polyol Esters and Polyalkylene Glycols (also known as Polyglycols or PAGs). PAOs are the most common major synthetic base oil used in industrial and automotive applications [16]. PAOs are a synthetic hydrocarbon that mirror the hydrocarbon backbone structure found in mineral oils. Polyalphaolefins are fully saturated, such that they do not contain ring structures, double bonds, sulphur, nitrogen components or waxy hydrocarbons. Because of the lack of several organic functional groups, this organic group of class of molecules (PAOs) result in very non-polar base oils with a high viscosity index, excellent low-temperature flow properties, pour-points, good oxidation stability and compatibility with mineral oils, paints and seals commonly found in lubricating systems. Due to the controlled fabrication process, PAOs can be manufactured without lighter, more volatile (smaller) chains. This in turn, reduces the potential for harmful emissions, and thus raises the flash point. PAOs, however, do have some disadvantages, which include poor solubility of common oil additives and the tendency to shrink seals. Therefore, PAOs are sometimes blended with organic esters to form a semi-synthetic base oil blend that has lesser negative characteristics. PAOs are also known to have poor fire resistance and biodegradability [17].

Diesters (dibasic acid esters) are manufactured through a reaction of dibasic acid with alcohol. The resulting performance properties can be adjusted based on the types of dibasic acid and alcohol used [16]. Polyol esters are manufactured through a reaction of a carboxylic acid with a polyol. In a similar manner to diesters, the resulting performance properties can be adjusted based on the types of carboxylic acids and polyols used. Ester-based synthetics, such as diesters and polyol esters, have advantages when it comes to biodegradability and miscibility with other oils. In fact, it is common for diesters and polyol esters to be mixed with PAOs during additive blending to help the oil accept more significant additive packages. Diesters and polyol esters are often deployed as the base oil for compressor fluids, high-temperature grease applications and even bearing or gear oils. Because they are known to perform well at higher

temperatures polyol esters have also been widely used for jet engine oils. However, the price is prohibitive for very high volume lubrication environments (such as power generation). Ester-based fluids readily pull moisture from the environment (acting hygroscopic). As a lubricant becomes contaminated with water, the stability of the fluid related to the water content becomes a factor. The ability of a lubricant and its additives to resist chemical decomposition in the presence of water is known as the lubricant's hydrolytic stability, which is a major concern for ester based hydraulic fluids. For these fluids, ASTM D2619-09(2014), Standard Test Method for Hydrolytic Stability of Hydraulic Fluids (Beverage Bottle Method), is recommended. It is often referred to as the Coke bottle test, as it employs a pressure-type soda bottle that is capped during the testing process.

PAGs are copolymers of ethylene- and propylene-oxide. They can be both water soluble (higher concentration of ethylene oxide), and water insoluble (higher concentration of propylene oxide). Water soluble PAGs are ideally suited for fire-resistant lubricant applications. One disadvantage of PAGs is their tendency to emulsify in equipment such as gear boxes. This is detrimental because of foaming, sludge and corrosion. A major disadvantage of both PAOs and PAGs is their poor additive solubility. Because the additives must also be biodegradable to be considered biodegradable, the additives selected are limited to formulate effective biodegradable lubricants from PAOs and PAGs [16]. Today, some manufacturers are blending diesters and polyol esters with PAOs to form base oils which are biodegradable, have good solubility, resist oxidation and have good temperature viscosity characteristics. Other manufacturers are blending synthetic diesters and polyol esters to boost the performance of vegetable oils such as canola oil while maintaining good biodegradability.

At the time of writing this manuscript, the authors are only aware of one mineral oil alternative that is biodegradable. It is a Group III base oil that is manufactured from sugar cane by a proprietary process. Please refer to Novvi (www.novvi.com) for further information.

Crude oil is the source for mineral oil and is a distribution of different types of hydrocarbons, while synthetic oil is manufactured through chemical combinations of low molecular weight molecules, acting as building blocks, to form higher molecular weight compounds. The molecular structure can be fine-tuned to the desired properties, unlike mineral oils, whose performance characteristics are somewhat static. Plant-based (vegetable) oils are structurally similar to synthetic esters but are primarily based on triglycerides [18].

Currently, the authors are aware of six biodegradable base stocks [14], including;

- Highly unsaturated or high oleic vegetable oils (HOVOs);
- Low viscosity polyalphaolefins (PAOs);
- Polyalkylene glycols (PAGs);
- Dibasic acid esters (DEs); and
- Polyol esters (PEs)
- Group III base oil from Novvi

In the United States, the discharge of oil or free oil into surface waters, including lakes, rivers, streams, wetlands, and coastal areas is regulated by the Clean Waters Act (title 40: Protection of the Environment PART 435). Spills on land are still to be reported to the US Environmental Protection Agency (EPA).

In Canada, spills are handled at the provincial level. The discharger is to notify the Ministry of the Environment (or equivalent) for that specific province and follow through with the due diligence of that provincial requirement for spills.

1.5 US BioPreferred Program

The goal of the US' BioPreferred program managed by the U.S. Department of Agriculture (USDA) is to increase the purchase and use of bio-based products. The BioPreferred program was created in 2002 with the intent of reducing the US' reliance on petroleum, increase the use of renewable agricultural resources, and to contribute to reducing adverse environmental and health impacts.

Biobased products are an alternative choice to conventional petroleum products, that are derivatives from plants and other renewable agricultural, marine, and forestry materials. Biobased products include diverse categories such as lubricants, cleaning supplies, inks, fertilizers, and plastics, etc. For the BioPreferred program, bio-based products do not include food, animal feedstock, or fuels. Companies wanting to use the label 'BioPreferred' will have their products tested as part of a

certification process based on ASTM D6866 [19].

The US BioPreferred program has a category known as turbine drip oils. These lubricants are used in drip lubrication systems for water well line shaft bearings, and water turbine bearings for irrigation pumps. To meet the US BioPreferred requirement, turbine drip oils must have a minimum biobased content of 87%.

If this manuscript applies to a US utility supplier, please refer to current information on how to obtain BioPreferred status, if applicable.

Currently, there are five products which are registered in this category. Three products are from Renewable Lubricants Inc. (Ohio), and one each from Archer Petroleum Corporation (now Atlas Engineered Products – Nanaimo, British Columbia) and Greenland Corporation (Calgary).

1.6 US Vessel General Permit Regulation & 40 CFR 112

The Vessel General Permit (VGP), 2008, which expired in 2018, has been replaced by the Vessel Incidental Discharge Act (VIDA). Established in 2018, the VIDA regulates certain types of discharges from vessels into U.S. waters [13, 20]. This regulation mandates that all vessels greater than 79 feet (~24 m) in length must use environmentally acceptable lubricants in all water facing interfaces, unless technically infeasible. According to the EPA, environmentally acceptable lubricants are biodegradable, non-toxic and not bioaccumulative [13, 20]. This regulation provides no performance criteria or guideline.

The regulated discharge sources are very diverse, consisting of tankers, freighters, barges, cruise ships and other passenger vessels, and commercial fishing vessels.

Each type of vessel has potentially different discharges, entitled aquatic nuisance species (ANS); which include metals, pollutants, pathogens, oil and grease, and toxic chemical compounds. Each discharge can potentially affect aquatic species and possibly human health. The general principal behind the permit is minimizing ANS into waterways and oceans by reducing the vessel discharge, and thereby ultimately enhanced environmental quality [21].

The VGP is the standard that must be enforced with regard to turbine oils that meet the definition of Environmentally Acceptable Lubricants, and plays a significant role as the standard that must be enforced for any power transformers in place on the waters of North America.

For releases or leaks at facilities with above-ground storage tanks storing oil products, the US EPA enacted 40 CFR 112 [22], which sets in place routine inspections and measures that would prevent oil spills from entering waterways such as streams, lakes, rivers, etc. This sub-set of the act (40 CFR 112) applies to reservoirs, storage tanks, and equipment that stores oil.

1.7 European Union (EU) Ecolabel

In 2011, and updated in 2018, the European Union (EU) published the criteria for establishing an EU Ecolabel [23].

The EU Ecolabel label, once established, guarantees that oil suppliers meet minimum requirements for performance, show limited toxicity to aquatic organisms, have high biodegradability and a low potential for bioaccumulation, and contain a high fraction of renewable raw materials.

For products with concentrations higher than 0.1% of oil by weight, aerobic biodegradation data is mandatory for all substances wanting to use an EU Ecolabel and bioaccumulation data is required for substances that are deemed non-biodegradable. For any individual substances accounting for more than 5% oil by weight of the total product, aquatic

toxicity data is mandatory for all components. The EU Ecolabel applicant must also provide data on the acute aquatic toxicity of each individual substance present in the product at concentrations between 0.1% and 5% by weight [24].

The EU Ecolabel has divided lubricants into three categories:

- Total loss (lubricants physically exposed to the surroundings, and its entry into environment is unavoidable and they are irretrievable); or
- Partial loss; or
- Accidental loss (lubricants used in confined systems which are susceptible to accidental losses).

The types of lubricants that have been designated for an EU Ecolabel include:

- 1) Hydraulic fluids and tractor transmission oils,
- 2) Greases and stern tube greases
- 3) Chainsaw oils concrete release agents, wire rope lubricants, stern tube oils and total loss lubricants,
- 4) Two-stroke oils, and
- 5) Industrial and marine gear oils

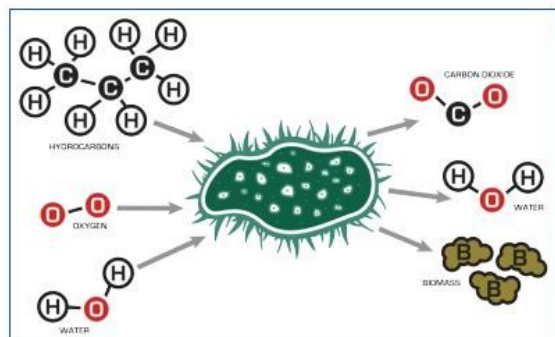
During the EU Ecolabel application process [24] the oil suppliers, manufacturers, service providers, retailers, etc., must compile the relevant documentation and conduct certified testing through an accredited International Organization for Standardization (e.g., ISO 17025) facility.

Current or future CEATI members from Europe are encouraged to comply with the EU Ecolabel in addition to specific tests outlined below in order to be considered EA oil.

1.8 Biodegradability, Ecotoxicity and Bioaccumulation

Biodegradability is the measure of persistence, or breakdown rate, of a substance through a biological process in the natural environment. Figure 1 shows a schematic of biodegradability through a conversion of the lubricant from a hydrocarbon to a more basic molecule (e.g., CO_2), through the metabolism and respiration of microorganisms, such as bacteria [13].

Figure 1: Biodegradability



Taken from [13].

A product can be classified as 'inherently biodegradable', if it breaks down when subjected to sunlight, water, and microbial activity, when the biodegradation is between 20-60% within 28 days according to the Organization for Economic Co-operation and Development (OECD) 301B protocol [13]. Products often made with highly refined virgin base oil can fall into this category of

‘inherently biodegradable’ if they are fabricated with plant or synthetic base material. These fluids also utilize additive chemistry which are ashless (free heavy metals, ex. Zn), as metal containing additives are known to have considerable environmental persistence. Environmentally sensitive or environmentally friendly is a category of lubricants that are ‘inherently biodegradable’ and are quite subjective to the end users’ interpretation.

If a 301B lubricant fluid spill were to occur, the fluid would degrade over time under normal circumstances, and there would be minimal environmental persistence, if any. The overall environmental impact would be considerably less compared with a mineral oil based lubricant designed for similar performance [25].

Ecotoxicity is a measure of the toxicity of a substance to organisms and the environment. The tests listed in Table 1 employ species that are used to provide indications of whether a chemical is either acutely or chronically toxic to the environment [13].

Table 1: Common considerations Standards for Lubricants

Biodegradability	Toxicity	Bioaccumulation
ASTM 6006: Assessing Biodegradability of hydraulic fluids	ASTM D6081: Aquatic toxicity testing	OECD 107: Partition coefficient, shake flask method
ASTM 5864: Determining Aerobic Aquatic Biodegradation/OECD 301B: Freshwater Modified Strum test	OECD 201: Freshwater algae and cyanobacteria, growth inhibition test	OECD 117: Partition coefficient, HPLC method
ASTM D6139: Determining aerobic aquatic biodegradation, Gledhill Shake Flask/ OECD 301D: Freshwater Closed Bottle Test	OECD 202: Daphnia sp., acute immobilization and reproduction test	-
ASTM D6731: Determining Aerobic, Aquatic Biodegradability, Closed Respirometer/OECD 301E: Modified biodegradation test	OECD 203: Fish, acute toxicity test	-
ASTM D7373: Predicting Biodegradability, Biokinetic model	OECD 210: Fish, early-life stage	-
OECD 301C: Modified MITI test	OECD 211: Daphnia Magna reproduction test	-

Taken from [13].

Although the list in Table 1 contains almost exclusively marine organisms, there are also tests that use plants, bacteria and various other organisms. These values are typically reported as an effective concentration (EC) value or lethal concentration (LC) value.

Bioaccumulation is the process through which substances are taken up by organisms either directly through exposure to a contaminated environment or by consumption of food containing the substance. For bioaccumulation, the principle route of movement appears to be dietary ingestion rather than bioconcentration from water because these substances typically have low water solubility and tend to concentrate in the lipid fractions of biological tissues [13]. Therefore, the testing involves the evaluation of the partition coefficient, or the tendency of a compound to separate from water. These tests evaluate a separation into octanol or water. The compounds that prefer octanol have a likelihood of accumulation in the fat of organisms and bioaccumulate.

1.9 Non-Toxic Oils and Lubricants

According to the United Nations Globally Harmonized System (GHS) criteria [25], a lubricant may be classified as ‘non-toxic’ or ‘not environmentally toxic’ if it has passed tests confirming it is not acutely toxic to fish, daphnia, or algae. Some fluids may also meet GHS non-toxic criteria and are classified as readily or inherently biodegradable. In applications or in operations near fresh water, or where such fluids may be at risk of exposure to people, non-toxic oil

and lubricants are typically specified. The terms ‘readily biodegradable’, ‘inherently biodegradable’, ‘environmentally acceptable’ and ‘non-toxic’ mean different things and in some cases choosing the incorrect lubricant may have serious environmental implications should there be a spill or environmental exposure. Users of lubricating oils are encouraged to make informed decisions, considering the application, the environmental impact and their specific business objectives [25].

2.0 TEST PLAN

The following sections are broken up into environmental acceptability and performance testing. The performance testing has further sub-categories which include turbine oils (hydraulics, seal, governor) or insulating oils.

It is strongly recommended to review testing requirements with the appropriate regulatory agencies prior to testing to determine the acceptable biodegradation test method that is required for assessment. The tests below should supplement any additional regulatory testing requirements (such as US BioPreferred program, the US Vessel General Permit Regulation, the EU Ecolabel, etc.

2.1 Test plan for EA acceptability

The biodegradation of materials, such as plastics, lubricants, and other chemicals which will eventually end up scattered throughout the environment after use, is of great importance. Therefore, certification of bio-based materials that may end up as waste in fresh water, with respect to their biodegradation behavior, is necessary. Standard testing methods for measuring biodegradation in fresh water are described in the OECD guidelines [26, 27], ASTM standards, or ISO standards. The OECD was established in 1961 as a forum for governments to share experiences and seek solutions to common economic and social problems. Today, approximately 50 industrialised and emerging economy countries have joined the OECD as members or adherents.

The most practiced tests in evaluating biodegradation of chemicals in aerobic aqueous media are OECD 301 and OECD 310 for readily biodegradable testing, and OECD 302 for inherent biodegradability testing, respectively [26, 27]. Similarly, the international standards ISO 7827, ISO 9408, ISO 9439, ISO 10707, ISO 10708, and ISO 14593 determine the biodegradability of organic compounds in an aerobic aqueous environment. The ISO tests are equivalent to OECD 301 and OECD 310. Test methods comparable to OECD 302 (inherent biodegradability) were also developed at the international (ISO) level (ISO 9887, ISO 9888).

The American standards ASTM D 5271 (plastics) and ASTM D 5864, ASTM D 6139 and ASTM D 6731 (lubricants) address the biodegradability of final products which are soluble to insoluble in water. Despite the availability of various testing methods for determining biodegradability in fresh water, further research and a global standardized test method is required.

The relevant techniques will be briefly introduced. The OECD and ASTM methods are similar; however different inoculum and media are prescribed.

Unfortunately, there is no single standard test method recommended for evaluating the biodegradability of a lubricant. All of the tests listed in this report can be used; however, the test methods do have their intrinsic limitations.

2.1.1 OECD 301

OECD 301B [26-28] is an aerobic biodegradation test that introduces a material to an inoculum in a closed system and measures CO₂ evolution over a minimum of 28 days.

The OECD 301B test method can be used for highly-to-poorly soluble products, and even for materials with certain concentrations known to be insoluble in water. Common materials tested with OECD 301B include fuels, lubricants, oil, personal care products, surfactants, greases etc.

To be classified as readily biodegradable, a product must meet the ready biodegradability requirements specified by the OECD 301B method.

There are a variety of OECD 301 [28] ready biodegradability methods, including OECD 301A-F. The designation between the sub-classes is related to the solubility, volatility and the absorbing power. For oils, or products that are potential oil replacements, method 301B applies and method 301C or 301F may apply.

Method 301C employs oxygen uptake of the test substance in a mineral medium, inoculated with specially grown micro-organisms. The evolved CO₂ is measured in the sample over a period of 28 days. Biodegradation is expressed as the (corrected) percentage oxygen uptake of the theoretical uptake (ThOD). The percentage of primary biodegradation is also calculated from supplemental specific chemical analysis made at the beginning and end of incubation, and optionally ultimate biodegradation by dissolved organic carbon (DOC) analysis.

Method 301F employs the sample as the nominal sole source of organic carbon. The consumption of oxygen is determined either by measuring the quantity of oxygen (produced electrolytically) required to maintain constant gas volume in a flask, or from the change in volume or pressure (or a combination of the two) in the test vessel. The evolved carbon dioxide is absorbed (in a solution of KOH or another suitable absorbent). The amount of oxygen taken up by the microbes during biodegradation of the test material is reported as a percentage of ThOD or, chemical oxygen demand (COD). Primary biodegradation may also be calculated from supplemental specific chemical analysis made at the beginning and end of incubation, and total biodegradation by DOC analysis.

2.1.2 OECD 310

In the OECD 310 test method [26, 27, 29], the CO₂ evolution resulting from the ultimate aerobic biodegradation of the test substance is determined by measuring the inorganic carbon produced in sealed test bottles of the sample. Standard testing for OECD 310 is 28 days, similar to other ready biodegradability test methods. OECD 310 is applicable to water-soluble and insoluble test substances (oils), however, good dispersion of the substance must be ensured.

Environmental Fate Analysis is important to perform for biodegradability testing on different types of products. To gain market acceptance, suppliers would request biodegradability, toxicity and bioaccumulation testing simultaneously to meet regulatory requirements. The EU Ecolabel for Lubricants requires data for biodegradability, toxicity and bioaccumulation and lists OECD 306 [30], and OECD 310 [29], as the recommended biodegradability tests. It is recommended to review testing requirements with the appropriate agency and local legislation prior to testing to determine which biodegradation method is required for product labeling and regulatory acceptance.

In order to calculate the degradation (percentage), it is important to know the organic carbon content of the test sample prior to testing. In addition, in order to select an appropriate test concentration and to assist with interpretation of poor biodegradability results, information on the material toxicity is supportive.

The sample is incubated (for 28 days) in a sealed bottle with aerobic condition containing a buffer ' ' using mineral salts which has been inoculated with a mixed population of micro-organisms [29]. In order to verify the procedure, a reference substance (aniline, sodium benzoate or ethylene glycol and 1-octanol, etc.) of known biodegradability is tested in parallel. It is recommended that this test be run in triplicate to remove any bias.

At least five test samples (test vessels, blank controls, and vessels with the reference substance) are analysed at the end of the test to enable confidence intervals to be calculated for the mean percentage biodegradation [29]. The CO₂ evolution resulting from the total aerobic biodegradation of the test sample is measured by the inorganic carbon (IC) content produced in the vessels in excess of that produced in blank samples. The measured biodegradation is compared to the theoretical maximum IC production (ThIC), based on the initial sample quantity [29] .

Biodegradation >60% ThIC within less than 10 days validates that the test substance is readily biodegradable under aerobic conditions.

2.1.3 OECD 302B

OECD 302B [26, 27, 31] is an inherent aerobic biodegradation test used for determining the biodegradability of a solution that is not readily biodegradable, known to be insoluble or does not meet the requirements of OECD 301 [28].

For OECD 302B, the determination of DOC monitors the biodegradation process; however, COD can also be used. Standard testing for OECD 302B is 28 days; however can be extended up to 60 days [28].

When performing this biodegradation test, it is important to know the properties of the test material including water solubility, volatility, and vapor pressure.

2.1.4 OECD 201

OECD 201 [26, 27, 32] is frequently used for marine applications to determine the effects of a product on the growth of freshwater algae or cyanobacteria in aquatic systems. Over a period of 72 hours, test organisms are exponentially grown by being exposed to the test product in cultures. The effects over several generations can be assessed, despite a brief test duration. The system response is the reduction of growth of algal cultures exposed to the test product. At least three replicates at each test concentration should be used.

The measurement is a function of the concentration compared with the average growth of control cultures. The cultures are allowed unrestricted growth under sufficient nutrient conditions and continuous illumination. As a function of time, growth and growth inhibition are quantified from measurements of the algal biomass.

2.1.5 OECD 306

OECD 306 [26, 27, 30] is a biodegradation test that measures how products degrade in seawater. OECD 306 is very similar to the OECD 301 test; however, OECD 306 requires the use of seawater and is often used with OECD 301/302 (Sludge Inoculum protocol) testing results. Testing runs for 30 days to 60 days. Similar to OECD 301 test methods, OECD 306 can evaluate ready or total biodegradation.

Lubricants, personal care products can come into contact with aquatic environments. This is generally observed with lubricants used for ships that experience potential leakage, discharge, or accidental spills.

2.2 North American standards

ASTM has developed three different standard test methods for the determination of the aerobic aquatic biodegradation of lubricants (ASTM D 5864, ASTM D 6139, and ASTM D 6731), and one method for predicting the biodegradability of lubricants using a bio-kinetic model (ASTM D 7373). Test methods ASTM D5864 and ASTM D6139 are not intended for volatile lubricants, while test method ASTM D6731 is suitable for evaluating the biodegradation of non-volatile components as well as volatile components of lubricants. Two ASTM tests have been developed to determine biodegradation of plastics in water-based environments (ASTM D5271 and ASTM D6340). Different inoculum options are prescribed, depending on the origin, such as activated sludge from a waste water-treatment plant, secondary effluent, surface water, soil extract, or a mixture of sources.

Certain criteria exist regarding the quantity of micro-organisms in the given inoculum.

2.2.1 Guideline for Determining Biodegradability of Hydraulic Fluids (ASTM D6006)

The ASTM standard D6006, the Standard Guide for Assessing Biodegradability of Hydraulic Fluids [26, 27, 33] guide discusses ways to assess the likelihood that a hydraulic fluid will undergo biodegradation if it enters an environment that

is known to support biodegradation of some substances, for example the material used as the positive control in the test. The information can be used in making or assessing claims of biodegradability of a fluid formula.

This guideline refers to ASTM methods D5864 [34], OECD 301B [35] and OECD 301F[35].

2.2.2 Determining Aquatic Toxicity Testing of Lubricants (ASTM D6081)

ASTM D6081, the Standard Practice for Aquatic Toxicity Testing of Lubricants: Sample Preparation and Results Interpretation [26, 27, 36], is a test method for toxicity testing of poor water soluble lubricants or their components under acute or chronic exposure conditions with fish, large invertebrates, or algae.

Most lubricants and lubricant components are difficult to evaluate in toxicity tests because they are mixtures of chemical compounds with varying and usually poor solubility in water. Lubricants are not usually added directly to aquatic systems for toxicity testing because the addition procedure will have a large effect on the results of the toxicity test.

The toxicity of mixtures of poorly soluble components cannot be expressed in the usual terms of lethal concentration (or the similar terms of effect concentration or inhibition concentration) because the mixtures may not be completely soluble at treat levels that lead to toxic effects. The test material preparation techniques given in this practice lead to test results expressed in terms of loading rate, which is practical and a meaningful concept for expressing the toxicity of this type of material.

2.2.3 Determining Aerobic Aquatic Biodegradation of Lubricants of Their Components (ASTM D5864)

This recommended test, ASTM D5864, Standard Test Method for Determining Aerobic Aquatic Biodegradation of Lubricants of Their Components, was designed to determine the degree of aerobic aquatic biodegradation of lubricants on exposure under laboratory conditions [26, 27, 34].

The biodegradation is measured by collecting and measuring the CO₂ produced when a lubricant is exposed to microorganisms (not specified which microorganisms) under controlled aerobic aquatic conditions. This value is compared to the theoretical amount of CO₂ which could be generated if all the carbon in the test material is converted to CO₂. CO₂ is quantified by trapping it in Barium hydroxide (Ba(OH)₂) solution and titrating the solution to calculate the amount of CO₂ absorbed.

The theoretical CO₂ is calculated from either a direct measurement of carbon content[37] present, or an equivalent method. Biodegradability is expressed as a percentage of the theoretical CO₂ production.

Test substances with a high degree of biodegradation in this test may be assumed to easily biodegrade in many aerobic aquatic environments. There are many conditions regarding this testing, so caution should be taken when performing this test. It is best to find a lab that specializes in this analysis to avoid errors in testing, set-up or interpretation.

The testing takes ~4-12 weeks of test time, so proper consideration should be allotted for shipment, analysis and interpretation. As with all specialized testing, it is best to perform replicate, if not triplicate analyses.

2.2.4 Determining the Aerobic Aquatic Biodegradation of Lubricants or Their Components Using the Gledhill Shake Flask (ASTM D6139)

This recommended test, ASTM D6139 [26, 27, 38], Standard Test Method for Determining the Aerobic Aquatic Biodegradation of Lubricants or Their Components Using the Gledhill Shake Flask, was designed within the confines of a controlled laboratory setting, the degree of ultimate aerobic aquatic biodegradability of a lubricant or components of a lubricant. Test materials which achieve a high degree of biodegradation in this test method may be assumed to easily biodegrade in many aerobic aquatic environments.

This test is very similar to ASTM D5864 [34] with exception to the agitating solution.

The test was designed to agitate the test solution and the CO₂ is collected using a Gledhill Shake Flask system. In this test, 60% or above, of biodegradability is considered readily biodegradable. However, this test requires a long test time (28 days), knowledge of micro-organisms, and experienced staff. In addition, this test has poor precision due to the various and multiple sources of inocula.

2.2.5 Determining Aerobic, Aquatic Biodegradability of Lubricants or Lubricant Components in a Closed Respirometer (ASTM D6731)

This recommended test, ASTM D6731, Standard Test Method for Determining Aerobic, Aquatic Biodegradability of Lubricants or Lubricant Components in a Closed Respirometer, was designed to determine the biodegradation that measures oxygen demand in a closed respirometer [26, 27, 39].

The biodegradation of a lubricant or lubricant components is determined by measuring the oxygen consumed when the lubricant or lubricant component is exposed to microorganisms (not specified which ones) under controlled aerobic aquatic conditions. This value is compared to the theoretical amount of O₂ which could be generated if all elements (carbon, hydrogen, nitrogen, sulphur, etc.) in that sample are oxidized. This test mixes the sample with aerobic microorganisms in a closed respirometer containing defined aquatic medium and measures the biodegradation of the test material following the decrease in oxygen in the respirometer. A control sample is usually run along-side the test sample.

The amount of oxygen utilized is expressed as a percentage of the theoretical oxygen demand. The test duration is dependent on the length of time required for the rate of test material biodegradation to achieve a plateau.

There are many set-up conditions regarding this testing, so caution should be taken when performing this test. It is best to find a lab that specializes in this analysis to minimize errors in testing, set-up or interpretation. The testing takes ~4 to 6 weeks of test time, so proper consideration should be allotted for shipment, analysis and interpretation. As with all specialized testing, it is best to perform replicate, if not triplicate analyses.

2.2.6 Predicting Biodegradability of Lubricants Using a Bio-kinetic Model (ASTM D7373)

This test is added in order to predict biodegradability of lubricants and oils using a bio-kinetic model based on ASTM D7373 [26, 27, 40].

A (known) weighted sample is charged (placed) in a chromatographic column packed with activated bauxite and silica gel.

Non-aromatics are eluted first and N-pentane is added to the column. When all the non-aromatics are eluted, non-polar aromatics fractions are eluted by additions of an equal mixture of toluene and n-pentane. The ester fraction is eluted by additions of di-ethyl ether. Finally, the polar-aromatics are eluted by chloroform and ethyl alcohol.

The solvents are removed by evaporation, and the residual materials are weighed and calculated as the non-aromatics, non-polar aromatics, ester fractions and polar aromatics of the sample. Each fraction yields a calculated value of 'effective composition to biodegradation (ECB)'.

The purpose of this test is to predict the biodegradability of lubricants within a day without dealing with microorganisms.

The nonpolar aromatics and polar aromatics fractions, and nonaromatic and ester fractions are calculated as follows:

Non-aromatics, wt% = [(a/total recovered)] X 100

Non-polar aromatics, wt% = [(b/total recovered)] X 100

Ester fraction, wt% = [(c/total recovered)] X 100

Polar aromatics, wt% = [(d/total recovered)] X 100

Where;

a = weight of non-aromatics recovered by n-pentane

b = weight of non-polar aromatics recovered by a 50:50 mixture of toluene and n-pentane c = weight of ester fraction recovered by diethyl ether, and b = weight of polar aromatics recovered by chloroform and ethyl alcohol; and the total recovered is the sum of a, b, c and d. The calculated value of ECB is provided by:

$$ECB = \sum_n (\varepsilon_a C_a + \varepsilon_e C_e)$$

Whereby;

\square = ECB coefficient from the ASTM (ASTM D7373)

C_a = fraction of non-aromatics

C_e = fraction of esters

Table 2: ECB coefficients for oils

Lubricant	\square = ECB coefficient
Mineral oil	0.3
PAO 2 ^Δ	0.8
PAO 4 ^Δ	0.6
PAO 6 ^Δ or higher	0.4
Natural esters	1
Renewable based diester and polyol ester	0.8
Petroleum based ester types	0.01

Δ = viscosity grade for polyalphaolefin (PAO)

The biodegradability of an oil using the bio-kinetics model is as follows:

$$B(t) = B(1) + \frac{0.49}{\ln(6.8 \times ECB^{-2.38})} \ln t$$

Whereby; t =

time, hours

$B(t)$ = biodegradability of a lubricant with time, and

$B(1)$ = 0.01

This test is considerably easier and cheaper than the previous two mentioned above (ASTM 5864 & D6731). It is best to find a lab that specializes in this type of analysis, to prevent errors in testing, set-up or interpretation. The testing takes considerably less test time (than the previous test methods discussed, ASTM D5864 & 6731), however proper consideration should be allotted for shipment, analysis and interpretation. As with all specialized testing, it is best to perform replicate, if not triplicate analysis.

2.3 Performance testing

The following sections describe additional testing for the performance of the oils depending on its application. In addition to the tests outlined in section 2.1 above, the tests below are recommended (each utility's application may be different, therefore the testing below is suggested). The types have oils have been separated based on the application. The value of each testing parameter will be briefly discussed. For the specific methodology, please refer to the references provided and equivalent standards may be substituted with justification.

2.3.1 Shared Performance testing

2.3.1.1 Flash point & Fire point

The flash point of oil is specified for safety reasons.

There are typically two methods associated with this method, the Cleveland open cup (COC) [41] and the Pensky Marten (PM) closed cup [42]. The COC method is usually used for less volatile oil, while the PM method is usually used for

more volatile oil samples. The flashpoint is an indication of the presence of volatile components in oil and it is the temperature to which the oil must be heated under specified conditions to give off adequate vapours to form a mixture that will ignite in the presence of an open flame. The fire point is the temperature to which the oil sample must be heated to cause the vapour/air mixture to burn continuously on ignition. These tests are useful to provide an indication of the volatility of the oil and data is significant in high-temperature operations.

The flash point in oils is typically measured via ASTM D92, D93, D56 or D3941 [41-44]. The fire point in oils is typically measured via ASTM D92, D1310 or D4206 [41, 45, 46].

2.3.1.2 Pour point

Typically, oils have a wide range of components present do not have a sharp freezing point, and they behave as semi-solids when cooled to low temperatures. The pour point is a guideline based on the lowest temperature at which the oil will cease to flow from a gravity-fed system.

The significance of the pour point is to allow the end-user to know when low temperature environments can influence low oil flow. The pour point in oils is typically measured via ASTM D97 [47].

2.3.1.3 Viscosity

Viscosity or flow properties are key parameters for lubrication efficiency and the proper application of lubrication. The measure of internal friction (or more simplistically, a given fluids' resistance to flow) is defined as the fluid viscosity.

A fluid with a high viscosity resists motion because its molecular make-up gives a lot of internal friction when in motion. A fluid with low viscosity flows easily because its molecular make-up results in lower friction when it's in motion.

The viscosity index (VI) describes the viscosity-temperature relationship [5]. The kinematic viscosity in oils is typically measured via ASTM D445 [48].

2.3.1.4 Moisture

The water absorption of oil depends on the temperature and amount of polar molecules present.

For lubricating oils, which are typically in equipment stored indoors at ambient conditions, the temperature is usually fixed. The internal humidity of the operating conditions can sometimes play a role in the oil moisture levels.

High water content in lubricating oils (>100ppm) can cause detrimental irreversible effects including; leaching additives from the lubricant oils, lead to oil oxidation reactions, varnish production, changes in oil viscosity, promote emulsions, promote foaming, enhance corrosion of metallic surfaces and in severe cases, displace the lubricating oil film, causing bearing damage. Water may be present as dissolved, suspended or free. Water in lubricating oils is measured typically via ASTM D6304 [49].

Insulating oils however are stored in various climates, and highly correlated on the external climate. It is very difficult to maintain a low water content in oils that are stored in areas where temperature and humidity are high. Usually for this reason, transformer oils are heated to drive off free water as water solubility increases with temperature. During the manufacturing of electrical equipment, considerable attention is given to the 'dryness' appropriate to the voltage class of the particular equipment. Water is formed as a by-product during oil oxidation. The residual water redistributes itself between the cellulose insulation and oil as the temperature changes during operation and the water saturation varies with temperature. Water is the primary degradation product of cellulose paper and pressboard insulating during ageing. Water can be absorbed from moisture air through leaks or in free-breathing equipment. Regardless of the source, water will cycle between paper and oil as the temperature fluctuates. A typical value of 50 ppm of water in oils is normal at 20°C, and

800-1000 ppm at 100°C [50]. Water is detrimental to the dielectric properties of the oil due to the attraction of more polar molecules. Water in insulating oils is typically measured via ASTM D1533 [51].

2.3.1.5 Colour

The determination of the color for oils is typically used for trending purposes and is an important manufacturing quality characteristic, since color can be readily observed by the end-user.

When a product has a known color range, a drastic change may indicate possible contamination with another product. Color is not a reliable guide to product quality and should only be used as a tool.

The colour measurement should not be used to discriminate product specifications.

The colour of oils is measured when a sample of oil is placed in a standardized container and the colour of transmitted light is compared to a series of standards. Colour in oils is typically measured via ASTM D1500 [52].

2.3.1.6 Acid number

Acid Number (AN) is an indicator of oil's serviceability.

In lubricating oils, it is useful to monitor the acid buildup in oils due to the depletion of antioxidants. Oil oxidation causes acidic by-products and high acid levels can indicate excessive oil oxidation or depletion of the oil additives which can lead to corrosion of the internal components. By monitoring the acid level the oil can be changed before any damage occurs.

In insulating oils, this testing is sometimes called the neutralization number, which is a measure of the acidic compounds present in the oil. The acid number increases with age and oxidation. Acids in insulating oils can cause premature corrosion of metal parts or sludge formation.

The acid number in oils is typically measured via ASTM D974 [53] or D664 [54]. Consistency is important regarding this measurement and once one method is adopted, it is suggested to continue with that method for historical cross referencing and trending purposes.

2.3.1.7 Copper corrosion

Sulfur is found in many construction materials of transformers including paper insulation, copper contamination, insulation materials, gaskets and oil. Not all sulfur is corrosive or reactive but the tendency to operate transformers at higher temperatures (or high voltages) can aggravate already present sulfur or convert stable compounds into reactive ones that can potentially cause damage.

Elemental sulfur and sulfur compounds in concentrations up to 20% [55] are present in crude oil ' ' refined to make transformer oil. There are five basic groups of sulfur and sulfur compounds found in crude oil (see **Table 3**) [55].

Table 3: Sulfur and Sulfur Compounds Found in Crude Oil

GROUP	CHEMICAL	FORMULA REACTIVITY
Elemental (Free) Sulfur	S	Very Reactive
Mercaptans (thiols)	R-SH	Very Reactive
Sulfides (thio-ethers)	R-S-R ₁	Reactive
Disulfides	R-S • S-R	Stable
Thiopenes	Five-membered ring containing sulfur	Very Stable

R=paraffin with straight or branched chain hydrocarbon or cyclic hydrocarbon

As shown in Table 3, elemental sulfur and mercaptans are very reactive followed by sulfides, disulfides and thiophenes. Reactive sulfur is mainly in organic sulfur compounds where sulfur is attached at the terminal of an organic molecule. When the molecule is more complex, (ex. the S is hindered or surrounded by protecting groups) the compounds tend to be more stable and less reactive (ex. R-S•S-R). Thiophenes are the most stable of all the sulfur compounds listed in Table 3. Some sulfur compounds function as antioxidants and can assist in oxidation stability of transformer oil and may also act as metal passivators or deactivators reducing the catalytic effect on oil oxidation. The objective of refining the oil is to repurpose the oil by either removal of the contaminants, or conversion of the corrosive and reactive sulfur species (i.e. elemental sulfur, mercaptans, and sulfides) to more stable compounds such as thiophenes or disulfides. The refining process includes atmospheric distillation, vacuum distillation, catalytic reaction, and hydro-treating and hydro-generation [55].

The refining process is not always successful. Incomplete refining may leave small quantities of mercaptans present in the oil or the hydrogenation process may produce elemental sulfur instead of hydrogen sulfide.

Corrosive sulfur is defined as all organic-sulfur compounds that will react with metals (such as mercury - present in older transformers) to form sulfides, such as mercaptans. Elemental (free) sulfur is very reactive and tends to form corrosive acids. It has been suggested that low elemental sulfur levels (low ppm range) can cause a corrosive sulphur condition [55].

There are many tests that can be done for corrosive sulphur. At the bare minimum, ASTM D130 [56] for lubricating oils or D1275 for insulating oils [57], should be conducted.

2.4 Turbine oils

The following tests are recommended if the EA oils are mineral or synthetic based for turbine, hydraulic, governor, or seal oil applications.

2.4.1 Foam

Foaming occurs when the release of air is greater than the speed at which bubbles at the surface of the fluid collapse (e.g., more bubbles form than collapse) [5]. This foam is dangerous if it makes its way into pumps or into venting systems. De-foaming additives are typically used to reduce the surface tension of the foam, thus collapsing the bubbles. De-foaming agents can adversely affect the air release properties of the fluid. Defoamers can progressively decline as a result of fluid ageing, or metal passivation.

Foam is measured via ASTM D892 [58]. The foam tendency of an oil is conducted by aerating a fixed volume of oil at a prescribed flow rate of air through a gas diffuser submerged in oil for a fixed amount of time. The volume of foam after 5 minutes of aeration and the volume of foam after 10 minutes of settling are measured. Sequence I, II and III are performed at 24°C, 93.5°C and 24°C respectively.

After the foam collapses from sequence II, the same oil aliquot is tested for sequence III. This is done to address testing concerns associated with agitation, dispersion from anti-foaming agents, and possible presence of volatiles. High temperature foaming is conducted by ASTM D 6082 [59].

2.4.2 Air release

The flow of fluids back into tanks can drag air into the fluid. In addition, turbulence has a tendency to promote the formation of bubbles in the fluid, and partial vacuums or leaks can draw air bubbles into the system.

The oil must be able to separate the surface of the fluid from the air or the air could be drawn into a pump or other system component causing severe damage.

The air release (C) is a mathematical relationship provided by the following [5];

$$C = \frac{(\rho_{FL} - \rho_L) \cdot X}{n}$$

Where ρ_{FL} is the density of the fluid, ρ_L is the density of the air, n is the dynamic viscosity and X is the constant which depends on the density and viscosity of the fluid.

Proper system design prevents the ingress of air into the fluid and assists with the release of any trapped air bubbles. Additives typically do not affect air release properties. Surface-active components (defoamers) and contaminants (corrosion prevention) detrimentally affect the air release properties of oils. The air release of mineral based fluids is generally better than fire-resistant fluids.

Air release is described by ASTM D3427 [60], where tiny air bubbles may become entrained during use, which in turn may decrease the fluid's viscosity, thermal conductivity and increase its cavitation, compressibility and rate of oxidation, lessening its effectiveness and putting components at an increased risk of thermal, chemical and mechanical damage. Once air becomes entrained, air release is the measure of how quickly it will dissipate out of the fluid. The more rapidly the air releases, the quicker the fluids properties will return to normal. This test measures the time it takes for a fluid to

release entrained air at 25°C, 50°C or 75°C.

The sample is heated to the prescribed test temperature and the density is measured. Compressed air is bubbled through the oil for the test duration. The time it takes for the sample to return to within

0.2% of the initial density is reported.

2.4.3 Oxidation TOST

The turbine oil stability test (TOST) is an ageing test for mineral and synthetic oils used to assess the oxidation stability of inhibited steam turbine oils [5]. The ageing of a lubricant is characterized by an increase in the acid number and the amount of sludge present after the oil has been exposed to oxygen, water, steel and copper after 1000 hours at 95°C. The maximum permissible acid number is 2.0 mg KOH/g of sample. The time taken to reach this threshold is the 'oxidation lifetime' of the oil.

This test is described in ASTM D943 [61].

2.4.4 RPVOT

The rotating pressure vessel oxidation test (RPVOT), is another oxidation stability test. The oil is exposed to oxygen, water, heat (150°C) and a metallic catalyst at 90psi (620 kPa). The time for the pressure to drop 25 psi is recorded as the oxidation stability.

This test method is described in ASTM D 2272 [62].

2.4.5 Water separation

The water separation or demulsification is the capacity of oil to repel ingressed water. Water ingress can occur through many avenues, including leaks, condensation changes, poor seals, etc. Water can promote corrosion, cavitation in pumps, increase friction and wear, and accelerate the decay of polymers, plastics and elastomers [5]. Free water, if any, should be removed as soon as possible.

Ideally, a lubricating (turbine, governor, or seal) oil should rapidly and completely repel ingressed water. Demulsification is the time taken to separate an oil-water mixture under standard conditions. This test is based on ASTM D 1401 [63].

2.4.6 Particle counts

Oil cleanliness involves counting particles in 100 mL of oil. Particle counting is typically conducted via light blocking, pore blocking or more modern, by light scattering. A sample within a measuring cell interferes with the normal passage of light. A source of light, i.e., a laser is interrupted by the particles, producing a scattering of light. Various photocell diode detectors measure the intensity of the scattering and translate the scattering to a sphere through mathematical relationships. Care must be taken with measuring oils as air bubbles, water droplets or very dark fluids sometimes contribute to erroneously higher particulate counts (which shouldn't be a problem for new fluids).

The ISO 4406 [64] standard defines particles in categories of $>4 \mu\text{m}$, $> 6 \mu\text{m}$, and $> 14 \mu\text{m}$. The most well-known standards for larger particles are ASTM D 6786 [65] or ISO 4406 [64].

2.4.7 Varnish potential

Varnish is an insoluble film that coats the internal components of power generation equipment and can really hinder operations. Varnish deposits are sub-micron in nature and cannot accurately be measured using standard oil analysis tests. Varnish itself is an insoluble film composed mainly of organic residue that coats the internal components of lubrication systems. It is often comprised of degradation, oxidation or thermal degradation products that are very small in size ($< 1\mu\text{m}$). All new oils should not have any varnish potential.

Although MPC testing has already been globally adopted as the most common methodology for testing the varnish potential of turbine oils and lubricants, this test [66] does promote consistency amongst laboratories for comparison.

2.4.8 Rust prevention

The rust prevention test, ASTM D 665 [67], was designed to measure the ability of a lubricant to prevent rusting under water contamination conditions. A sample of the oil is mixed with water and placed in a tempered bath. A polished steel rod is submerged in the oil and water mixture for a prescribed length of time. The test rod is then subjectively inspected for signs of rust.

A lubricant's ability to prevent rust is crucial for applications that have significant exposure to potential water contamination. Testing a lubricant to determine its rust prevention is important for maintaining the health of ferrous components within electrical equipment. In addition, rust particles can act as catalysts and can cause abrasive wear in journal bearings.

2.5 Insulating oils

The following tests are recommended if the EA oils are mineral or synthetic based for insulating applications.

2.5.1.1 Dielectric testing

The dielectric breakdown voltage is the ability of insulating oil to withstand electrical stress. This value is the voltage at which the oil stops behaving as an insulator and starts behaving as a metal. This value depends on the particulates and water content of the oil.

In this test, the oil covers two electrodes that face each other at a prescribed distance. The electrodes have prescribed geometry and the voltage is increased at a specified rate until insulation breaks down. In new oil or after the removal of particles and water a breakdown voltage of $> 70 \text{ kV}$ is typical. This test can be carried out using ASTM D877 [68] or ASTM D1816 [69].

2.5.1.2 Power/Dissipation factor

The power factor (dissipation factor), which is related to $\tan \delta$ /power factor/loss angle is associated to the dielectric losses in an insulating fluid when used in an alternating current (AC) electric field [70]. The permittivity is represented as:

$$\epsilon^* = \epsilon' - j\epsilon''$$

where ϵ^* is the complex permittivity, ϵ' is the real or measured permittivity, and ϵ'' is the imaginary permittivity [71]. In an alternating field a capacitance and resistive currents are formed orthogonal out of phase with respect to each other. The vector sum of the two currents represent the total current and the angle between the capacitance current vector and the resultant vector is defined as the loss angle, δ [71]. The ratio of the imaginary to the real part of the permittivity is equal to $\tan \delta$; i.e. $\tan \delta = \epsilon'' / \epsilon'$ [71]. The factor, $\tan \delta$ is the dissipation factor, D , that represents the dielectric losses in insulating fluids. The power factor, P , is $\cos \delta$. The relationship between D and P is the following, $D^2 + P^2 = 1$, therefore if one knows one value, the other can be calculated. Furthermore, for minimal values of δ $\tan \delta \sim \sin \delta$, thus for values of $\tan \delta$ up to 0.05 the power factor and the dissipation factor are almost the same.

The test method is outlined in ASTM D 924 [71]. The measurements are made in cells that are machined to precise dimensions. The measurements are typically done at usually 25°C and 100°C. The measurement is comparing the capacitance of the cell filled with the insulating fluid creating an electronic bridge circuit. The result is expressed as a percentage for the dissipation factor or power factor.

2.5.1.3 Interfacial tension

The interfacial tension of an insulating fluid is related to the deterioration of the oil. Insulating fluids are non polar saturated hydrocarbons, and when the mineral oil undergoes oxidative degradation oxygenated molecules are formed, such as carboxylic acids, which are hydrophilic. The introduction of hydrophilic materials in insulating oils can affect the fluid's acidity (chemical properties), dielectric strength (electrical characteristics), and interfacial tension (physical properties) of the fluid. In the interfacial force test [72], the surface tension of the oil against water, is measured. The closer the two liquids are in their polarity the lower the value of the surface tension of the mixture between them. The higher the percentage of hydrophilic materials in the insulating fluid, the lower the interfacial tension of the oil measured against water will be. There are several test methods that can be used to evaluate the interfacial tension of an oil against water however the ring method (ASTM D971)[72] is recommended for higher accuracy and precision.

2.5.1.4 Oxidation stability

Testing by ASTM D2440 [73] measures the oxidation stability of mineral oils under accelerated aging conditions. Oxidation stability is evaluated by the ability of oils to form sludge and generate acidic products during oxidation. Good oxidation stability is necessary in order to prolong the life of insulating oil by minimizing the evolution of sludge and acid. Oils that meet the requirements [74] tend to minimize electrical conduction, ensure acceptable heat transfer, and preserve system life. There is no proven correlation between test performance and transformer service performance, since the test does not model the transformer (oil, paper, enamel, wiring). However, the test can be used as a tool for evaluating the oil's oxidation and to check the consistency of the production of oils.

2.5.1.5 Inhibitor content

Insulating fluids undergo oxidative degradation to form a number of oxidation products. The final oxidation products are acidic materials that can affect the characteristics of the insulating fluid and can cause damage to the metallic components of the transformer (electrical parts). Reactions of the oxidative process can be complex as oxygen is a di-radical species, and the reactions sometimes involve free radical reactions. One way to avert these types of oxidative reactions are to incorporate an (oxidation) inhibitor that will interrupt and stop the propagation of the free radical process of oxidation. Phenolic materials are quite good for this purpose, and the most common currently used inhibitors are 2,6-di-tertiary-butylphenol (DBP) and 2,6-di-tertiary-butyl-4-methylphenol or 2,6-di-tertiary-butyl-para-cresol (DBPC).

New normally refined (mineral based) insulating oil contains small amounts of compounds that act as inherent oxidation inhibitors. These naturally occurring molecules discourage oil oxidation until they are fully spent. The rate at which the natural inhibitors are used up in the oil is dependent upon the amount of oxygen available, the rate at which the oxygen can attack, the soluble contaminants in the oil, the catalytic agents in the oil, and the temperature of the oil [75]. In modern transformers, they are either sealed (excluding air and moisture) or protected by an inert atmosphere (Ar or N₂ are sparged), the benefits of the natural or additive oxidation inhibitors can be extended over many years. As the inhibitors are spent, the rate of oxidation and the deterioration of the oil will increase.

Reclaiming processes, such as acid removal by clay treating and filtering, can restore the oil to +90% of its original characteristics. However, there would be no effect upon restoring the usefulness of the natural inhibitors present in the original oil. Both Fuller's earth and activated alumina (typical reprocessing mechanisms) remove the natural inhibitors and the reclaimed oil would as a result have limited resistance to oxidation. To overcome this hurdle, synthetic oxidation inhibitors can be used to extend the life of the reclaimed oil.

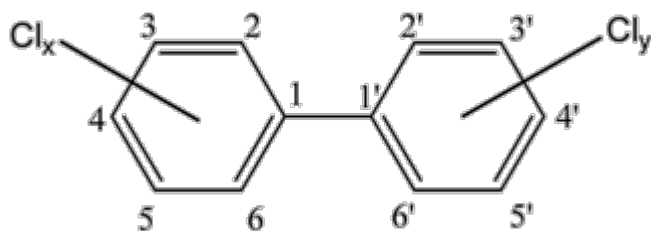
The presence of synthetic inhibitors in the oil will increase the life of the oil with respect to oxidative degradation. As the oil is exposed to this type of oxidative degradation process, the oil will be protected as long as there is inhibitor present. However, as the inhibitor gets consumed and eventually depleted, the oil will begin to degrade at an elevated rate. The determination of inhibitor present can be employed to approximate the useful life of the oil. As the inhibitor is used up its concentration can be measured and additional inhibitor can be added as needed to maintain a desired concentration in the electrical equipment. Typical values for fresh oil are in the range of 0.25 to 0.35 % for DBP or DBPC by weight.

There are 3 methods to determine the amount of inhibitor present in the sample, infrared spectroscopy [76], gas chromatography (GC) [77], and high performance liquid chromatography (HPLC).

2.5.1.6 PCBs

Polychlorinated biphenyls (PCBs) are a class of 209 congeners, in which one to ten chlorine atoms are attached to a biphenyl (see Figure 2).

Figure 2: Molecular schematic of Polychlorinated bi-phenyl (PCBs)



PCBs are synthetic molecules which were heavily used until the 1970's. They are no longer manufactured or heavily used, but are still persistent in the environment and some electrical equipment. PCBs were used as coolants and heat transferring fluids in transformers, capacitors, and other electrical equipment because they are excellent insulators and do not easily catch on fire. The manufacturing and sales of PCBs has been banned since the 1970's, however evidence of PCBs are still found in live service equipment today. PCBs are chemically very stable and because so, they are known to accumulate in the environment, produce, animals and humans [78]. It is a legal requirement to report the release and numerical value of PCBs into the environment in accordance

with published, industry standard reference methods [79, 80].

2.6 Other factors to consider

Fluids (oils) that may be mixed with no negative equipment effects are referred to as compatible. And those fluids or oils that cannot be mixed without potential problems are termed incompatible.

Compatibility is a major factor to consider should an EA alternative or another supplier be chosen to replace the incumbent product. Tier 2 per ASTM D7155 should be applied and assessed accordingly.

Utilities or users of this test plan must ensure proper testing of the fluid's physical and chemical properties and testing on the intended application. For example, mixing lubricants that have widely different base stocks such as a diesel fuel oil with a mineral oil would represent an application incompatibility as well as a fluid incompatibility. Other factors to consider include additive incompatibility (synergistic or agonistic characteristics), base stock reactions, internal machine

metallurgy and also the interaction with other components such as seals, gaskets, etc.

2.7 Report card/scoring system

The rationale provided in this section for the ranking of EA fluids is a guideline suggestion. Each utility may have their own method of scoring lubricants. As long as the scoring and marks allocated are consistent, then the report card should be valid.

A description of the tests was provided in section 2.0.

The significance category is separated into 4 sub-categories;

- 1- Low significance
- 2- Medium significance
- 3- High significance
- 4- Required (very high significance)

The weight category is separated into 4 sub-categories;

- 0- zero

1- low importance

2- medium importance

3- high importance

All EA parameters have been allocated an automatic significance ranking of '4' and a '3' for the weight category. The highest potential score per parameter is 12. See **Table 4: EA scorecard ranking** Table 4.

A simplistic model to score the individual test ranking is calculated by multiplying the weight (W) by the significance (S).

$$\text{Individual parameter ranking} = W \times S$$

Table 4: EA scorecard ranking

Test	Category	Weight	Significance
OECD 301	EA	3	4
OECD 310	EA	3	4
OECD 302B	EA	3	4
OECD 201	EA	3	4
OECD 306	EA	3	4
ASTM D6006	EA	3	4
ASTM D6081	EA	3	4
ASTM D5864	EA	3	4
ASTM D6139	EA	3	4
ASTM D6731	EA	3	4
ASTM D7373	EA	3	4

A failure of any EA test is deemed an automatic zero for that weight parameter. A pass of the EA portion of the testing is considered a pass with full ranking marks. The pass/fail criteria will (should) be provided by the contract laboratory conducting the testing.

The importance for individual tests ranking is provided in

Table 5. The importance is subjective and provided by the authors, however best efforts have been made to estimate the importance of oxidation, wear, additive depletion, contamination, moisture, etc. Each individual test may carry different weights or significance based on the specific application.

Furthermore, additional testing, or less testing may be required, depending on the specific application.

Table 5: Score card for performance testing for EA acceptability

Test	Category	Weight	Ranking	Ranking importance
Flash point	Lube, Insulating oil (IO)	TBD*	2	The higher the flashpoint, the less volatile and safer the equipment is to be around, especially when operational.
Fire point	Lube, IO	TBD*	2	The higher the fire point, the less volatile and safer the equipment is to be around, especially when operational.
Pour point	Lube, IO	TBD*	2	The lower the pour point, the better the fluid behaves in cold temperatures.

Viscosity	Lube, IO	TBD*	4	The closer this value is to the published oil viscosity, the better the fluid and equipment will function.
Moisture	Lube, IO	TBD*	4	The lower the value, the less deterioration due to moisture.
Colour	Lube, IO	TBD*	1	The lower the colour, the less contamination and by-products.
Acid number	Lube, IO	TBD*	4	The lower the acid number, the more anti-oxidants are present and less the acidic components.

Copper corrosion	Lube, IO	TBD*	2	The lower the number, the lesser the impact on Cu parts.
Foam	Lube	TBD*	2	The lower the foam, the better the oil is at dispersing the air.
Air release	Lube	TBD*	2	The lower the number, the better the oil at removing entrained air.
TOST oxidation test	Lube	TBD*	4	The lower the sludge and acid number after 1000 hours, the better the oil will behave in-service.
RPVOT	Lube	TBD*	4	The higher the RPVOT value, the more resistant the oil is to oxidation.
Water separation	Lube	TBD*	3	The less the emulsification, the better suited the oil is with separating water out.
Particle counts	Lube, IO	TBD*	4	The lower the particle counts, generally the better the oil condition is. This depends on the application.

Varnish potential	Lube	TBD*	4	This test provides information about the potential for valve sticking in critical applications. The lower the value, the less potential a failure will be due to varnish.
Rust	Lube	TBD*	1	This is a pass/fail test. The weight may be increased by the user if this application is on a sea vessel.
Dielectric testing	IO	TBD*	3	The higher the dielectric breakdown, the better the oil is at providing insulation
Power factor	IO	TBD*	3	The higher the power factor, the more contaminated the oil is.
Interfacial tension	IO	TBD*	2	Provides information about contaminants present.
Oxidation stability	IO	TBD*	2	Gives an indication of resistance to oxidation.
Inhibitor content	IO	TBD*	3	Gives an indication of remaining oxidation strength and useful life.
PCBs	IO	TBD*	1	PCBs are either present or they are not.

TBD* = To be determined by end user choosing the (EA) alternative oil.

From the end user's perspective, choosing the weight is arbitrary based on the test results. As long as the end user is consistent, the method in going about assigning the individual weightings can be conducted in several different fashions.

The final EA lubricant ranking is the sum of all the rankings.

$$\text{Overall EA ranking} = \sum_{i=0}^n W \times S$$

The end user is encouraged to evaluate the oil with the sum of the highest ranking. This report card structure does not choose the supplier or product on behalf of the utility. Each parameter must be evaluated wholly and consider the holistic view of the station, power plant and/or equipment. This ranking is applicable to other parameters including; price, timing, availability, compatibility, customer support & service, etc., as all have to be considered when switch one oil supplier and/or product with another.

Depending on the location of the proposed application; in addition to the scoring outlined above, the EA alternative must be compliant with the following criteria:

1. Local laws and regulations;
2. Meet or exceed EPA requirements or alternatives, without any interpretations.

Including;

- a. It has been officially represented to be VGP-compliant by the manufacturer and has met the testing requirements outlined in Appendix A of the VGP for biodegradation, toxicity and nonbioaccumulation.
 - b. It is OSPAR-approved. The OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic is the current legislative instrument regulating international cooperation on environmental protection in the North-East Atlantic.
 - c. It has been granted EAL certification by the European Ecolabel (EEL).
3. It is compatible with in-service oil as demonstrated by extensive Tier 2 testing per ASTM D 7155.
 - a. It is compatible with seals, paints, wetted surfaces, polymers, etc.
 4. It meets or exceeds performance criteria for turbine oils, with possible specific exemptions after thorough user-defined discussion, e.g., viscosity.
 5. It can be easily cleaned-up (absorbent pads, skimming) in the event of a spill.
 6. Filtration or processing can be easily conducted which does not degrade properties (ex. particle filtration or varnish removal). Existing oil-water separation techniques would continue in its efficacy.
 7. Preferably no design or system changes should be implemented. This includes existing monitors, sensors, drainage sump monitors, etc.
 8. Bearing temperatures do not increase.
 9. The fluid performs well through the Stribeck curve (from boundary lubrication through elastohydrodynamic to hydrodynamic)

2.8 Suggestions for oils

At the time of preparing this manuscript, some suggestions for EA acceptable fluids include:

- EcoSafe TF-25 (turbine fluid) by Dow Chemical Company
- Ecosafe EHC (hydraulic fluid by Dow Chemical Company
- Low Tox Turbine Oil (6412-6414) (turbine fluid) by Lubrication Engineers
- TURWADA SYNTH or TURWADA SYNTH E (turbine fluid) by Panolin Inc.

- ATLANTIS, HLP SYNTH, HLP SYNTH E, ORCON SYNTH E, POLAR SYNTHE, or SYNTHSAFE by Panolin Inc.
- Bio-SynXtra, Bio-Ultimax 1000, 1500, 2000, AW1000, Bio-fleet (ISO 22, 32, 46, 68), BioUltimax 1200LT, Bio-SynXtra Marine Hydraulic Fluid, Bio-SynXtra Powerlift Fluid, BioHVO, Bio-HVO2, Bio-MIL-PRF-32073, Bio-AW/AL, Bio-AW, Bio-Hydraulic Hoist Oil, Bio-Bottle Jack, Bio-SynXtra Stern Tube Lubes Hydraulic Fluids by Renewable Lubricants
- Bio-Drip or Bio-Gearhead Turbine Fluids by Renewable Lubricants
- Greenplus R&O Lube ES, Line Shaft Turbine Fluid ES (turbine oils) by Greenland Corporation
- Greenplus Hydraulic Fluid ES by Greenland Corporation
- ZF Series Hydraulic Fluids, Marine-Safe Hydraulic Oils, SYNXTREME AC Series, PGO Series, BIO-SYNXTREME HF Series, UTF-Bio-Based/Green, Biodegradable Penetrating Oil Multi-Purpose Lubricating Fluid by Dymar Chemicals Ltd.
- RSC Futerra HF Hydraulic Fluid series and RSC Envirologic HF Hydraulic Fluid Series by RSC Biosolutions
- Pro Eco HE 801 series – hydraulic fluids – BASF Corporation
- Novus hydraulic fluids – Cargill Corporation
- Lubriplate Biobased Green Hydraulic Fluid Series – Lubriplate Corporation
- Pure Lube AW hydraulic fluid series – GC Lubricants
- Ecoshield Biodegradable Hydraulic Fluid series – Schaeffer’s Specialized Lubricants
- Clarity Synthetic EA Hydraulic Oil – Chevron Lubricants

The list above is by no means comprehensive, as there are many more suppliers through the various worldwide markets. None of the fluids listed above have been assessed through EA testing. They are simply suggestions based on manufacturer’s input and website marketing material.

3.0 CONCLUSIONS AND RECOMMENDATIONS

One of the biggest challenges is the development of a universal biodegradable base stock that can be used to replace mineral oils in ubiquitous applications as the next generation of lubricants focused on the environment. The need for eco-friendly products is being discussed in various forums (CEATI, ASTM, IEEE, etc.), however the real motivation will occur when various governmental institutions initiate a mandate for change.

People responsible for decisions regarding their utility (purchasing, operations, maintenance, environmental and regulator reporting, etc.) can use the results obtained from this test plan, or EA status as a guideline for EA acceptability. The costs of EA fluids may be initially higher (purchase and compatibility) than conventional mineral oils, but the life cycle costs of EA fluids are likely less than conventional mineral oils (considering spill clean-up, reputation damage, etc.). Rapid biodegradability and favourable ecotoxicological characteristics must be obtained, in addition to the equipment the fluid is intended for, and at an acceptable price. Stakeholders would be encouraged to conduct bench-testing in an experimental setting to generate a ‘short list’ of EA candidates. Upon successful completion, the end-user(s) would be encouraged to test the ‘short list’ of EA candidates in a test rig before rolling the EA fluid out in field operations.

Future work should consider EA replacement of FRF fluids, particularly phosphate esters, hydraulic fluids and gear oils.

Lubricant users and suppliers are encouraged to form a partnership [13]. Ultimately, a successful green lubrication program is the responsibility of the end user. A world class lubricant reliability program improves equipment reliability and minimal downtime with the benefit of using an EA acceptable fluid. The foundation of a successful green lubrication program is the EA fluid itself. The program relies on trained employees, keeping the fluid clean (with various actions), with the objective of keeping equipment running longer, running more efficiently and using less energy.

Numerous studies show that when a successful lubrication reliability program is implemented, the end user can reduce costs and improve profitability, thus improving environmental, economic and social (personnel and customers) sustainability: the three pillars of sustainability.

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Appendix C
Hydro Maintenance Group Procedure for Lubrication, Lubricant Sampling, Sample Analysis and Reporting

**GRANT COUNTY PUD
HYDRO ENGINEERING DEPARTMENT**

HYDRO MAINTENANCE GROUP PROCEDURE

FOR

LUBRICATION, LUBRICANT SAMPLING, SAMPLE ANALYSIS AND REPORTING

Rev: 0

Approved _____

Effective Issue Date _____

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1. PURPOSE

This procedure establishes the Hydro lubrication and condition monitoring lubricant sampling, sample analysis, evaluation and process control using Dingo Software and CMMS Maximo.

2. SCOPE AND OVERVIEW

This procedure is the basis for any and all lubricant related job plans used in the Hydro preventive maintenance program. The job plans are constructed in the Maximo CMMS.

The requirements for this procedure apply to all Hydro Personnel who engage in lubricant sampling activities from originating a requirement to work to closing and archiving oil sample results including all intermediate activities. The above activities are required when job plans are used in the Maximo CMMS to generate work orders. In particular, the duties of the following organization positions with respect to lubricant sampling, analysis and reporting are to be controlled by the job plans built in accordance with this procedure and work orders built in accordance with the requirements of the Hydro work control procedure.

Planner
Scheduler
Mechanical Craftsmen
Electrical Craftsmen
Predictive Manager/Engineer
RCM Engineer

This procedure is based on a Best Practices model that is used by many organizations. The model is known to be effective and efficient. When implemented properly, this procedure:

Ensures that job plans will be applicable.
Ensures that lubrication will be optimum
Ensures that sampling methods will be suited to the sample and will be standardized
Ensures samples will be analyzed using appropriate methods
Ensures that analytical results will support the RCM predictive maintenance requirements
Ensures that analytical results will be evaluated to provide corrective action feedback

Tribology is a complex discipline. Hydro has designated an engineer as the tribology subject matter expert (SME). The SME is responsible for maintaining this procedure.

3. DEFINITIONS, ABBREVIATIONS, PREFIXES AND LETTER SYMBOLS

The definitions used in this program are contained in the glossary. The RCM analysis, preventive task development and predictive task development must use the definitions of words and terms as they are listed in the glossary. Abbreviations and symbols are also defined in the glossary.

4. GENERAL

4.1. CLEANLINESS

Dirty and/or contaminated lubricants are one of the primary causes of failure of lubricated components. It is extremely important that the cleanliness guidelines in this procedure be carefully adhered to. Cleanliness of lubricating fluids refers in general to any contamination including particulate and fluid matter.

Lubricant cleanliness requirements must be specified in job plans based on this procedure. Each instance of use of a lubricant will contain the minimum cleanliness requirements and will be based on the following information.

If only one change could be made to the lubrication program, improving cleanliness would provide the most return on investment.

Particles in Oil

The measure of particles in oil is defined by the ISO code. An example using an ISO code follows. Suppose the ISO code is -

16 / 15 / 12

The first number, "16", is the range code number that corresponds to a range of the number of particles/ml present in an oil with size greater than 4 microns (μm or micrometers). The second number, "15", is the range code number corresponding to the number of particles/ml with size greater than 6 microns and the third number corresponds to the number of particles/ml with size greater than 14 microns in size. It should be noted that the first range code includes the particles from both the second and third range codes. Likewise, the second range code includes the particles counted in the third range code. Note that the numbers are codes and they indicate a range of minimum and maximum number of particles/ml.

The actual numbers of particles counted per milliliter in each size category (4, 6, and 14 microns) are converted to the appropriate ISO Code via the chart in Table 2.

ISO/Range Code	Min particles /ml	Max particles /ml
1	0	0.02
2	0.02	0.04
3	0.04	0.08
4	0.08	0.15
5	0.15	0.3
6	0.3	0.6
7	0.6	1.3
8	1.3	2.5
9	2.5	5
10	5	10
11	10	20
12	20	40
13	40	80
14	80	160
15	160	320
16	320	640
17	640	1,300
18	1,300	2,500
19	2,500	5,000

20	5,000	10,000
21	10,000	20,000
22	20,000	40,000
23	40,000	80,000
24	80,000	160,000
25	160,000	320,000
26	320,000	640,000
27	640,000	1,300,000
28	1,300,000	2,500,000
29	2,500,000	5,000,000
30	5,000,000	10,000,000

Table 2 - ISO Cleanliness Codes

For example, if a particle counter determined that there were 501 particles/ml greater than 4 microns, the corresponding ISO code would be 16. If 199 particles/ml were greater than 6 microns, the corresponding ISO code would be 15. Finally, if the counter determined that 27 particles/ml were greater than 14 microns, then the corresponding ISO code would be 12. The overall cleanliness of the lubricant would be reported as 16/15/12. Most particle counters do this conversion automatically.

The following characteristics should be noted: The number of particles/ml will always correspond to the same ISO code independent of the particle size being measured.

- The overall ISO code structure - XX/YY/ZZ - will always correspond to the particle counts at the sizes:
- XX - greater than 4 microns
- YY - greater than 6 microns
- ZZ - greater than 14 microns
- Each ISO code increase represents roughly a doubling of the particle count

However, an increase of only 1 particle/ml at a particular size can also give the appearance by the ISO code that the oil is twice as dirty since one count over the breakpoint in the table causes the reported ISO number to jump to the next range. Cleanliness of lubricating fluids is specified as an ISO Cleanliness Code. The code specifies the amount and size of particles entrained in the lubricant. Cleanliness levels are specified as –

Clean	100 particles >10 micron in size per milliliter of oil
Super Clean	10 particles >10 micron in size per milliliter of oil
Ultra Clean	1 particle >10 micron in size per milliliter of oil

Oil, which has entrained particles in excess of the CLEAN level, is considered dirty oil.

While each application will be unique, some general guidelines for lubricant cleanliness have been established for different types of machines or machine components. Typical target ISO cleanliness codes for various machines and machine components are listed in Table 1. Keep in mind that these are typical targets. Factors that could lead to cleaner oil requirements include machine criticality, severe duty, expected service life of more than seven years, or if system failure

could cause safety or environmental issues. The more of these issues that apply, the cleaner the lubricant should be. Systems that have higher operating viscosities may need to operate at somewhat less stringent cleanliness targets due to the difficulty of filtering higher viscosity fluid. In the RCM process, the effects of a given level of cleanliness will be used as the guidelines for specifying the required cleanliness.

Machine/Component	Typical Target ISO Cleanliness Code (ISO 4406:1999)
Servo valve	13/12/10
Proportional valve	14/13/11
Ball bearing	14/13/11
Roller bearing	15/14/12
Variable volume pump	15/14/12
Fixed piston pump	16/15/12
Vane pump	16/15/12
Gear pump	16/15/12
Journal Bearing	16/15/12
Screw Pump	16/15/12
Turbine	17/15/12
Diesel Engine	17/16/14
Industrial Gearboxes	18/14/12

Table 1 - Machine/Component Target ISO Cleanliness Codes

Water (moisture) in Oil

Typical target water limits are not as well established, as are those for particulates. The interaction of water with lubricant film strength and chemical interactions with the lubricant additives and machine surfaces can be devastating. Water content in a lubricant can exist in three forms: free, emulsified, and dissolved. Free and emulsified water pose more of a problem than dissolved water, and maintaining content well below the saturation point of the lubricant will minimize its harmful effects.

Saturation point is dependent on the particular nature of the lubricant and the oil temperature. The higher the oil temperature, the more water it can hold in the relatively harmless dissolved state. However, caution must be noted in applications where operating or ambient temperatures can vary widely. The saturation point of the bulk oil in the reservoir may be significantly different than that at various points in the lubricating system and at different times of the day or year (due to temperature variation).

Experience indicates that many industrial machines utilizing rust and oxidation inhibited circulating oils, or gear oils can be expected to have water concentrations below 100 ppm. In a proactive maintenance program, typical water limits and appropriate responses can be summarized in Table 3.

Water Concentration, ppm	Status	Action
100 – 300	Alert	Check seals, breathers, coolers, etc., for ingress sources; watch trend

300 – 800	Danger	Aggressively investigate and correct source of ingress and implement effective water removal activities
800+	Extreme Danger	Immediate action is required to eliminate ingress and effect removal of water to minimize damage to machine and lubricant

Table 3 - General Water Concentration Limits

These limits are very general in nature. Systems that involve rolling element bearings, extremely low temperatures, certain synthetics, exposure to refrigerants, and transformer oils will typically require very low water content for maximum life. For those where the lubricant is exposed to combustion processes, a higher allowable water content is typical due to produced water. These lubricants are designed to emulsify the water until it can be driven off by the heat of combustion.

It should be noted that many tests for water cannot accurately detect content below 1000 ppm. The most effective way to accurately determine low water content is the Karl Fischer Co-Distillation method. This method distills the free, emulsified, and dissolved water from the lubricant, which is then titrated using the Karl Fischer reagents to determine the water content. In contrast, the Crackle Test and Fourier Transform Infrared Spectroscopy (FT-IR) methods can only detect free water accurately down to about 1000 ppm. The Crackle Test has the further limitation in that it is only a pass/fail test that cannot quantify the amount of water present.

Advantages of Clean and Dry Lubricants

Maintaining lubricants at minimal particle and water concentrations maximizes both machine and lubricant life. For example, a lubricant operating at a typical ISO Cleanliness Code of 21/18/15 could achieve a machine life improvement of 1.5 to 2 times if it were cleaned and maintained to a target ISO Cleanliness Code of 18/15/12. This obviously depends on the specifics of the application and the type of machine components involved, but serves to illustrate the point.

In some applications, maintaining water content in a lubricant at 1,000 ppm can result in a 75% reduction in component life versus operating at a water content of 100 ppm, if all other factors remain constant. Combining the effects of cleaner and drier lubricants provides a cumulative improvement in machine component life.

Cleanliness is not bought at any price. In the RCM process, the reliability of equipment and the cost of achieving the reliability are optimized. Too clean can be just as expensive as too dirty.

4.2. EQUIPMENT TO BE CONSIDERED IN A LUBRICATION PROGRAM

The RCM process ranks equipment in the Maximo database and determines if there is an applicable and effective preventive maintenance task. In the RCM process, each ranked equipment, is analyzed for functional failures, parts, modes and causes. If warranted, a PM task is developed. While the RCM process will determine the actual equipment to be placed in the lubrication program, the following lubricated equipment should be considered (note that this is not an all-inclusive list).

Cranes:

- Intake Gate Hoist (QC)
- Crane, Jib / Free Standing, 5 Ton (PEC) Project - Main Hoist Gear Reducer
- Crane, Hoist, Main, Electric Overhead (PEC) Power House Crane, 25 Ton,
- Bulkhead Gantry, Intake Deck (PR) 5-gear reducers
- Crane, 390 Ton, Emergency Gantry, Intake Deck (PR) 8-gear reducers
- Crane, 35 Ton, Bulkhead Gantry DT/XFMR Deck (PR) 5-gear reducers
- Crane 1, Bridge Generator Hall, (PR) 12-gear reducers
- Crane 2, Bridge Generator Hall, (PR) 12-gear reducers

Crane, 390 Ton, Emergency Gantry (Wan) 8 – gear reducers
Crane, 35 Ton, Draft Tube/TD Bulkhead Gantry (Wan) 5 - gear reducers
Crane, 35 Ton, 7- 1/2 Ton Wright Aux. Hoist (Wan) 5 – gear reducers
Crane, 25 Ton, Bulkhead Gantry, Aux. Hoist (Wan) 5 – gear reducers
Crane 1, Bridge Generator Hall (Wan) 12-gear reducers
Crane 2, Bridge Generator Hal (Wan) 12-gear reducers
Crane, Jib Slew, 25 TON Bulkhead Gantry, (WAN) Crane, Mobil,
American Carrier, (PR)
Crane, Mobil, American Carrier, (WAN)
Crane, Mobil, American 5530, (PR)
Crane, Mobil, American 5530, (WAN) Crane, Link-
Belt Mobile (MC)
Crane, Grove (Wan)
Spillway Chute, Gate Hoist (QC)
Draft Tube Bulkhead Gate & Hoist (QC)
Crane, Checo, 10 Ton, (WAN)
Crane, Bridge, Pump House, (WAN)

Engines:

LPG Engine Generator Set (PEC)
Emergency Generator Engine (PEC)
Spillway, Emergency Diesel Generator (Wan)
Spillway, Emergency Diesel Generator (PR)
Compressor, Emerg Diesel Gen., Wisconsin Engine (PR)
Emergency Diesel Generator/Engine, Station Svc. (Wan)
Emergency Diesel Generator/Engine, Station Svc. (PR)
Emergency Diesel Generator (SWYD)
Emergency Generator (QC)

Generator Bearings:

Generator Guide Bearing QC Switchgear Floor (QC)
Generator Thrust/Guide Bearing (QC)
Generator Thrust Bearings (Wan) & (PR) 1- 10
Generator Upper Guide Bearing (Wan) 1 – 10
Generator Lower Guide Bearing (Wan) & (PR) 1 – 10

Gearboxes:

Spillway Gate 1 - 22, Primary Gearboxes (PR)
Spillway Gate 1 – 12 Primary Hoist Gearboxes (Wan)
Gearbox, Pump, Main Fish 1, (PR) 1 - 5

Compressors:

Station Air Compressor 1 & 2 (PEC)
Station Air Compressor; St 29019-85w, 200 PSI (QC) Accumulator Air
Compressor for Lgrv/Lggv (Wan)
Governor Air Compressor 1 A (PR)
Governor Air Compressor 2 (PR)
Governor Air Compressor 3 (PR)
Governor Air Compressor 1 B (PR)
Governor Air Compressors 1 - 3 (Wan)
Station Air Compressors 1 & 2 (Wan)
Rt. Bank Air Compressor (Wan)
Depression Air Compressor 1 & 2 (Wan)

Compressor, Deluge Supervisory Air (PR)
Station Air Compressor 1 & 2 (PR)

Turbines:

Turbine Guide Bearing (Wan) & (PR) 1 – 10
Turbine Hub (Wan) & (PR) 1 – 10 Taken at Governor sump return Turbine W01 Wicket Gates 1-20 (Wan) & (PR) 1 – 10 Grease Samples

Hydraulic Systems:

Hydraulic Turbine at PEC (PEC)
Trashrack Rake / Hydraulically Powered (PEC)
Gravity Intake Gate (GIG) Hydraulic Cylinder (PR)
Hydraulic Lift, (MC)
Sluice Gate Hydraulic Operating Unit (Wan)
Right Bank Fish Ladder Rgrv/Rggv Hyd Sys (Rucker) (Wan)
Left Gravity Hydraulic System (Wan)
Hydraulic, unit for FAWP butterfly valves (PR)
High pressure Oil (HPU) System (QC)
Governor HPU at Pec (PEC)

Tanks:

Lube Oil Systems (QC)
Governor Sump Tank (Wan) & (PR) 1 – 10
T-3 & 4, Clean Turbine Oil Storage Tanks 1 & 2 (Wan) & (PR)
T-1 & 2, Dirty Turbine Oil Storage Tanks 1 & 2 (Wan) & (PR)
Lube Oil Systems (PEC)

Whenever new lubricated equipment is installed or lubricated equipment is modified, the RCM Engineer will ensure that the RCM process is applied to the installation or modification. In addition, the new equipment or modified equipment will be evaluated for sampling ports and breathers and these will be added as part of the installation or modification if required.

4.3. LUBRICATION PROGRAM CONTROLS

In order to enforce the general effectiveness of an RCM program, there is some necessary lubrication program controls. These controls are independent of any specific RCM analysis, but have been shown to be effective in a lubrication program in general. These controls include –

4.3.1. Lubricant Selection

Lubricants are selected for an application based on the manufacturer's recommendations or on the SME's analysis. Whenever possible, one brand of lubricant will be used. If the manufacturer recommends a lubricant that is not of the standard brand, a cross-referenced lubricant will be used whenever possible in order to minimize the number of different products used in the program. The cross-referenced lubricant must have the essential properties of the recommended lubricant. The SME will make this determination. It may not be possible to always cross-reference one brand of lubricant to another. Once a lubricant has been selected for an application, it will be listed in the specific job plan for the equipment and will be specified in the inventory tables in Maximo and connected to the affected equipment records using the "Where Used" screen.

4.3.2. Lubricant Procurement

Lubricants will be purchased as specified in the RCM program. Substitutes will not be made by the buyer without specific permission of the RCM Engineer who will discuss with the SME. Purchase receipts will be verified against the purchase order prior to acceptance. It is important to keep incorrect lubricants from being added to the storage system. Bulk lubricants will be sampled and analyzed before being released for use in the lubrication program. Normally, the supplier will be required to provide an as-shipped analysis. Historically, bulk lubricants can be very dirty and have excessive moisture content.

4.3.3. Lubricant Storage

Lubricants will be stored as required by state regulations. Lubricant storage will be specified in a storage instruction. In addition to any regulatory requirements, the instruction will address –

- ③ Storage and issue so that lubricants will be used in a FIFO order.
- ③ Storage that specifically identifies the lubricants to manufacturer types and grade. Lubricants must be identifiable to manufacturer, type and grade whether they are in the original containers or in a transfer container.
- ③ Storage that identifies shelf life if applicable.
- ③ Storage that identifies lubricant lots (if lotted).
- ③ Specific that will prevent contaminating lubricants.
- ③ Specific requirements to prevent lubricant contamination and oxidation. Open container storage is not allowed.
- ③ Lubricant issue methods to ensure portable containers will be controlled to prevent contamination.

4.3.4. Lubricant Application Control

Lubricants will be applied using controlled methods. The controls will be written in the job plans that specify changing or adding lubricants. The controls will ensure that the correct lubricant is applied, that the correct amount of lubricant is applied and that the application does not pose a hazard to the lubricated component.

The lubricant application for initial lubrication during installation, repair or replacement will be specified in the Maximo work plan. These instructions will comply with manufacturer's recommendations and best practices.

The application instructions will ensure that the lubricant to be applied is positively identified. It is not permissible to mix lubricants without specific agreement by the SME. The lubricant actually used will be recorded in Maximo ACTUALS.

Controlling the amount of lubricant applied will be addressed in the specific job plan for applying lubricant. The controls will prevent over lubricating or under lubricating.

Controlling lubricant cleanliness and contamination during application will be addressed in the specific job plan for applying lubricant.

Controlling used lubricant will be addressed in general Hydro procedures and implemented in specific job plans.

4.3.5. Lubricant Sampling

Any equipment to be sampled will be identified in the RCM program in Maximo and will have a sampling job plan applied via the Maximo PM program.

The sample point will be specified in the job plan and will be identified on the equipment. Identification on the equipment will be by permanent tagging or posting. Standard micarta labels and metal tags will be used as appropriate.

Sample points will be selected to minimize the possibility of contamination. Mid-level samples are desired. Special sampling ports will be provided when they are necessary to prevent sample contamination. Any special sampling port that is installed will be identified to a modification work order and the engineering drawings and parts lists will be

maintained in the engineering data system. Required spare parts will be entered into the Maximo inventory system. The SME will approve all lubricant sampling system modification packages.

Sampling instructions will be provided by the sampling job plan. As much as possible, standard sample connections and standard sampling methods will be used.

Sample sizes will be specified.

Sample containers and labeling will be specified and will be standardized.

The standard sample procedure identified in Section 5 will be used in job plans and modified to suit the particular sample.

4.3.6. Lubricant Analysis

Lubricant analysis is used to determine the quality of lubricants or to determine the wear condition of equipment or both. The analytical program control will meet the following requirements.

One source of analysis will be used. This will prevent data jumps due to procedure differences between labs. In keeping with one source of analysis, standard sampling, labeling and shipping will be used.

Each routine requirement for sampling will be specified in the Maximo PM program. The sampling will be periodic based on calendar or run time as determined by RCM. The sample may be to determine lubricant condition or equipment condition or both.

Some samples may be required only on lubricant change to determine equipment wear condition. These will be specified in the PM program.

Samples may be required as part of lubricant receipt. The requirement for these samples is external to the PM job plans.

The maintenance program may require grab samples as diagnostics. The requirement for these samples is external to the PM job plans.

All sample analysis results will be entered into the Dingo database. When the sample is not associated with a Maximo equipment, such as receipt sampling, the sample results will be entered against the lubricant type and location.

All analytical results, which exceed an established alert level, will be evaluated by the SME. Other possibly related information such as vibration analysis data will be included in the evaluation.

4.3.7. Oil Sump Breather Control

Breathers that contain particulate absolute filters and desiccant filters will protect oil sumps from water and particulate entry. They may contain other devices depending on the requirements to measure breather conditions for servicing. Each sump that is modified will be identified to a modification work order and the engineering drawings and parts lists will be maintained in the engineering data system. Required spare parts will be entered into the Maximo inventory system. The SME will approve all breather control modification packages.

Breather servicing will be included in the Maximo PM program.

4.3.8. Changing Lubricants

Any change in lubricants recommended by RCM for systems that have already been lubricated will require SME concurrence. The following will be considered –

If the old lubricant is no longer used, it will be removed from stores.

If oil is being changed, completely drain the system and flush the sump.

For grease changes, purge the system until the new grease can be seen at the relief or drain.

For grease changes, pull bearings, clean and repack with the new grease. Ensure that the cleaning does not cause the bearings to rotate dry.

If greasing is done with automatic greasers set the cycle time to half of what it was previously.

Start the lubricated machine and monitor bearing temperatures for several hours. If the machine is in the vibration-monitoring program, take a standard set of readings as a baseline. If greased bearing temperature increases beyond normal, re-grease the bearing and check vibration. If oil lubricated bearing temperature increases beyond normal, check that flow is proper and that the oil is not emulsified and check vibration. Note that it may be difficult to accurately determine bearing temperature if temperature detectors are not installed in the bearing.

It is not unusual to have bearing problems after changing lubricant and sometimes it may be necessary to change bearings along with the lubricant change.

Note that it is possible to mix greases inadvertently if the bearings are received pre-greased. Some manufacturers use polyurea grease, which may be incompatible with lithium-based grease.

After a week of normal operation, reset auto-greaser cycle time back to normal.

4.3.9. Flushing Lubricant Sumps

In each case where a sump is to be flushed, the work plan will detail how to flush the sump. The work plan will contain as a minimum.

- Completely drain the sump.
- Physically clean the sump as much as possible. Do not steam lance or use any cleaning solvents.
- Flush the sump using flushing oil. Do not use solvents, diesel fuel, gasoline, etc. Fill the sump to the point where the oil can be circulated. Circulate the oil for about 15 minutes (not through the equipment) and then drain. Save the flushing oil for reuse.
- Refill the sump and place system back on line. Monitor operation for several hours to ensure bearing temperatures are normal.
- Sample the oil for a baseline.

Note that it is easier to keep oil sumps clean than it is to clean them. For older sumps this may be impossible since it requires filtering and conditioning prior to oil return to the sump. Once the oil is in the sump, particulate will precipitate.

4.3.10. Lubed-for-life Components

In many cases, lubed for life bearings out perform other bearings in terms of overall cost. More and more rotating components are being sold with lubed-for-life bearings. It is possible to lube some gear cases only once in about 15 years using some modern gear oils.

When the total cost of lubricating a component is considered, it can be quite high, and if there are significant numbers of equipment to be lubricated the total cost can be very high. Extended intervals or lube-for-life may be capable of making important savings in the maintenance program.

Each time that the RCM program considers lubrication in its analysis, the analysis should include checking on the possibility of a change to lube-for-life. For short life replaced components, it is often quite possible to never have to lubricate during the component lifetime.

5. STANDARD OIL SAMPLING PLAN

It is important that lubricant samples be uncontaminated and properly identified. The following standard sampling plan contains the minimum sampling requirements. When used in a Maximo job plan, it may be modified to suit the actual sampling.

- a. Use the standard sampling kit. This kit contains –

16 oz sample purge bottle

Hand held vacuum pump with release valve and folding stand

Sample port adapter with 1/4" hose barb

1/4" O.D. plastic tubing from Oil Analysis Lab, Inc.

Sample bottle kit that contains

Addressed shipping box

8 oz glass sample bottle from Oil Analysis Lab, Inc. (currently contracted lab)

Identification sheet. Plastic sandwich bag

- b. Use the specified sampling point. Sampling points may be special sampling points installed specifically to support sampling or may be an existing opening that will be used for sampling.

Match the equipment route sample points from Maximo PM with the route setup in Dingo.

Pick up the required number of sample bottles (should be staged).

Pick up a few extra sample bottles and blank labels

Print the sample bottle labels for the route using the Dingo label printing. Attach labels and cover with clear tape.

- c. Ensure sample will not be contaminated.

③ Use lint free rags when rags are required

③ Clean all dirt and buildup from access plugs, inspection plates, etc., prior to removal for sampling

③ On special installed sample ports, clean the dust cover before removal and inspect the sample port for dirt prior to sampling.

③ Use new plastic sample tubing for each sample

③ Cut off any plastic tube that has been exposed to the oil bath or reservoir before pulling the tube out of the vacuum pump access.

③ For drain valve samples, flush the valve with oil prior to sampling. Drain valves should be capped or plugged to prevent contamination. Clean the valve and cap and or plug before removing for sampling.

- d. Sampling from installed sample point:

③ Verify sample point from Oil Route work order and verify sample bottle label on the sample bottle before taking oil sample.

- Verify that the oil system being sampled has been circulated or is circulating prior to taking the oil sample.
- ③ If equipment has not been running, turn equipment on to operate 10 minutes prior to taking sample.
 - ③ (DO NOT TAKE ANY OIL SAMPLE FROM A SYSTEM OR GEARBOX THAT HAS BEEN SITTING UNCIRCULATED FOR 30 MINUTES OR LONGER).
 - ③ If the equipment that is being sampled requires boarding or access will jeopardize the craftsman safety, install Clearance Tags.
 - ③ Wipe sample port cap or valve and the area around the sample port of all dirt with lint free rag.
 - ③ Install sample bottle onto the hand pump, keeping the bottle cap free from contamination, dust, and dirt.
 - ③ Attach a proper length of plastic tubing, which will allow ease of sampling, into the head of the hand pump, approx. ¾" or just past the threads of the hand pump and tighten the compression thumbscrew, enough to secure the tubing from slipping.
 - ③ Remove sample port cap and install sample port adapter until swivel is hand tight.
 - ③ Attach the plastic tubing on to the adapter barb.
 - ③ Pump the hand pump with three to four strokes until oil begins flowing through the plastic tubing and into the sample bottle allowing the bottle to fill ¾ full.
 - ③ **CAUTION:** When taking oil sample from high pressure line, just before the filter, extreme care must be taken as the bottle will fill quickly, engage adapter swivel just enough to start oil flow to fill bottle, and unscrewing swivel when oil level has been reached.
 - ③ **(Note: For small gearboxes only fill bottle ½ full, to minimize loss of oil or completely full if taken at an oil change).**
 - ③ When the bottle is ¾ full unscrew the bottle from the hand pump, ¾ of a turn to stop the flow of oil, and finish unscrewing the bottle from the hand pump and cap the sample bottle.
 - ③ Loosen the thumb screw on the top of the hand pump and push the plastic tubing through the hand pump head another inch or two and cut off 1 inch of tubing and pull the plastic tubing out of the hand pump very slowly and discard the tubing. **(Note: never use the tubing twice)**
 - ③ Remove the sample port adapter and replace the sample port dust cap.
 - ③ Top off any reservoir low on oil after sampling.
 - ③ Install new tubing and clean sample bottle and move to next sample location and repeat the sampling process.
 - ③ Match all samples taken with the route work order to insure all samples were taken.
 - ③ Note any samples that were not taken and reason for not taking sample, to correct or reschedule.
 - ③ If the oil sample is obviously unusual, take an extra sample for local inspection.
- e. Drop tube sampling:
- ③ Verify sample point from Oil Route work order and verify sample bottle label on the sample bottle before taking oil sample.
 - ③ Verify that the oil system being sampled has been circulated or is circulating prior to taking the oil sample.
 - ③ If equipment has not been running, operate equipment for 10 minutes prior to taking sample.
 - ③ (DO NOT TAKE ANY OIL SAMPLE FROM A SYSTEM OR GEARBOX THAT HAS BEEN SITTING UNCIRCULATED FOR 30 MINUTES OR LONGER).
 - ③ Lock out or install clearances on equipment that will be sampled.
Prior to removing the inspection cover, Desiccant Breather, or fill plug, which ever will allow access to gearbox or reservoir, clean the area on and around the access of all dirt so nothing will fall into the reservoir upon removal of access.
 - ③ Remove access that will allow oil sampling and set out of the way, keeping access free from contamination.
 - ③ If inspection cover is removed, a quick survey of components should taken for any damage.
 - ③ Install sample bottle onto the hand pump, keeping the bottle cap free from contamination, dust, and dirt.
 - ③ Cut plastic tubing to length that will allow ease of sampling and to facilitate tubing that will reach the centerline of the oil bath being sampled.

- ③ Push tubing into the head of the hand pump, approx. $\frac{3}{4}$ " or just past the threads of the hand pump and tighten the compression thumbscrew, enough to secure the tubing from slipping.
- ③ Secure tubing so the end of tubing will not become contaminated falling to the ground or on dirty equipment.
- ③ (DO NOT TAKE ANY OIL SAMPLE FROM A SYSTEM OR GEARBOX THAT HAS BEEN SITTING UNCIRCULATED FOR 30 MINUTES OR LONGER).
- ③ There are several options to facilitate getting the plastic tubing to the centerline of the oil bath. "Have a sample port adapter, and or Stainless Rod 3 feet long, and small plastic ties prior to taking an oil sample route."
 - 1. Take plastic tubing and begin reverse bending the tubing in two inch increment's to straighten tubing until a length is reached that will allow extending the tubing into the oil bath and extract the oil sample.
 - 2. Clean a Sample Port Adapter with solvent and dry with lint free rags. Attach the adapter to the end of the tubing and secure tubing on adapter with a plastic tie, to eliminate the adapter from falling off of the tubing. Extend the adapter into the centerline of the oil bath and holding the adapter at that level extract the oil sample.
 - 3. Secure an 1/8" stainless steel rod two to three feet long, and attach the tubing using plastic ties, 1 1/2" from one end of the stainless steel rod. Lower the rod until the rod rests on the bottom the reservoir or to the centerline of the oil bath and extract the oil sample.
- ③ Pump the hand pump with three to four strokes until oil begins flowing through the plastic tubing and into the sample bottle allowing the bottle to fill $\frac{3}{4}$ full.
- ③ When the bottle is $\frac{3}{4}$ full unscrew the bottle from the hand pump, $\frac{3}{4}$ of a turn to stop the flow of oil, and finish unscrewing the bottle from the hand pump and cap the sample bottle.
- ③ (Note: For small gearboxes only fill bottle $\frac{1}{2}$ full, to minimize loss of oil or completely full if taken at an oil change).
- ③ Loosen the thumb screw on the top of the hand pump and push the plastic tubing through the hand pump head another inch or two and cut off 1 inch of tubing and pull the plastic tubing out of the hand pump very slowly and discard the tubing. (Note: never use the tubing twice) ③ Top off any reservoir low on oil after sampling.
- ③ Reinstall inspection cover, desiccant Breather, or Fill Plug, taking care to replace any damaged gaskets or O-rings that were damaged during removal.
- ③ Remove Lock Out or Clearance Tags if this is the last sample taken on this equipment, or the equipment needs to be circulated or operated because the duration between samples was to long.
- ③ Install clean sample bottle and move to next sample location and repeat the sampling process.
- ③ Match all samples taken with the route work order to insure all samples were taken.
Note any samples that were not taken and reason for not taking sample, to correct or reschedule.
- ③ If the oil sample is obviously unusual, take an extra sample for local inspection.

f. Drain-port sampling:

Important: When taking an oil sample from a drain port a close nipple or a close nipple with a street L must be installed at the end of the drain valve prior to sampling, so that oil will not flow over pipe threads while taking an oil sample. Pipe threads will collect contamination and obscure the oil sample by as much as two ISO levels.

"This type of sampling is the least desired type of sampling if the reservoir dose not have a sample port installed." (Note: Use sample port method, if sample port has been installed.)

"Should only be used if this is the only way of acquiring a sample, and only if the oil reservoir has been drained, flushed, and new oil added prior to starting sampling routes for trending."

- ③ Verify sample point from Oil Route work order and verify sample bottle label on the sample bottle before taking oil sample.
- ③ Verify that the oil system being sampled has been circulated or is circulating prior to taking the oil sample.
- ③ If equipment has not been running, operate equipment for 10 minutes prior to taking sample.

- ③ (DO NOT TAKE ANY OIL SAMPLE FROM A SYSTEM OR GEARBOX THAT HAS BEEN SITTING UNCIRCULATED FOR 30 MINUTES OR LONGER).
- ③ If the equipment that is being sampled requires boarding, or access will jeopardize the craftsman safety while taking oil samples, install Clearance Tags.
- ③ Clean drain valve and area around the valve of all dirt using lint free rags prior to taking sample.
- ③ Remove pipe cap from close nipple installed at end of valve, keeping cap from any contamination.
- ③ Using a waste container that will allow access, drain off 10 to 12 ounces and discard prior to taking oil sample, to enable flushing of reservoir sump and valve assembly.
- ③ Take labeled sample bottle, remove cap keeping bottle cap from contamination, open drain valve and fill sample bottle $\frac{3}{4}$ full and install bottle cap.
- ③ **(Note: For small gearboxes only fill bottle $\frac{1}{2}$ full, to minimize loss of oil, or completely full if taken at an oil change).**
- ③ Top off any reservoir low on oil after sampling
- ③ Reinstall pipe cap on close nipple and remove any clearances that were applied.
- ③ Match all samples taken with the route work order to insure all samples were taken.
- ③ Note any samples that were not taken and reason for not taking sample, to correct or reschedule.
- ③ If the oil sample is obviously unusual, take an extra sample for local inspection.

6. OIL ANALYSIS

Oil samples are analyzed by a contracted lab. The following steps are required.

- ③ Associate each oil sample with an ID sheet. When the sample bottle labels were printed, Dingo printed a corresponding ID sheet.
- ③ Verify the sample bottle label information is the same as the ID sheet.
- ③ Check that the sample bottle is securely capped.
- ③ Place the sample bottle in the sandwich bag that is in the kit.
- ③ Place the ID sheet and sample bottle in the shipping box that is part of the kit.
- ③ Tape the shipping box lid to prevent opening during transit.
- ③ Samples may be shipped individually in the small shipping boxes or the small shipping boxes may be packed into a larger shipping box.
- ③ If a larger shipping box is used, ensure the shipping label is correct. ③ Address shipping boxes to the current contracted lab -

OIL ANALYSIS LAB, INC
(ATTN: RANDY)
1514 EAST SPRAGUE AVE.
SPOKANE, WA 99202

- ③ Ship via next day FEDEX by dropping off at the Warehouse.
- ③ Complete the Maximo work order. Include the sample date and the shipping date and note any problems. Change the work order status to COMP. Do not close until the lab results have been received.

When Oil Analysis Lab, Inc. has completed the analysis, the results will be e-mailed back to Hydro. Oil Analysis Lab, Inc will perform the following tests:

Basic Analysis of every sample
Spectral analysis for additives and wear metals
Viscosity
Water > 1%. If greater than 1-% water by Karl Fisher test will be done
FT-IR if required by Karl Fisher
Particle count on every sample
Total Acid Number (TAN) IAW ASTM D-664
Digital Color Photomicrograph (baseline samples and exceptions)

7. STANDARD GREASE APPLICATION PLAN

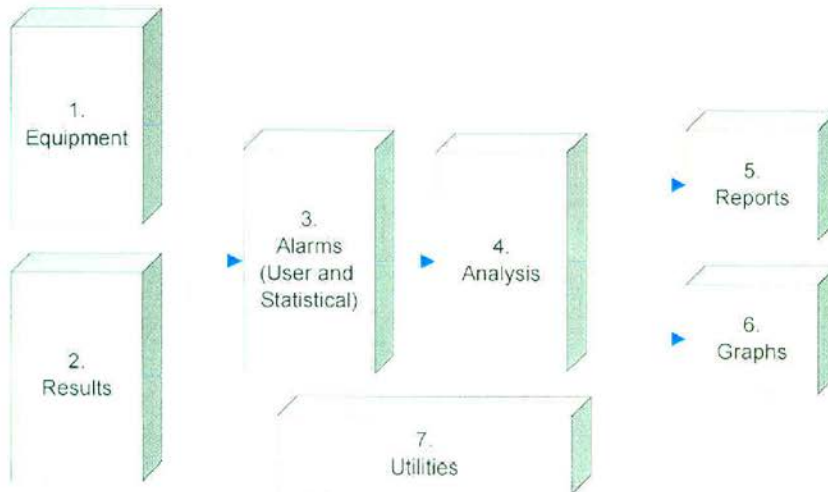
- ③ The storage of all lubricating greases are to be stored in a well ventilated area and arranged with salving to keep the grease containers from being stored on the floor or exposed to high temperature conditions.
- ③ The identification of the proper lubricant, the volume to be used, and all the locations on the equipment that require greasing, must be part of the route used to periodically add grease to the equipment.
- ③ With condition based greasing it is important to understand the proper way to grease a bearing and how to use a grease gun so as to not damage a bearing or its seals.
- ③ The grease gun types used at the different projects should be standardized, so that the number of pump strokes delivered are a known volume so the delivery amount is uniform.
- ③ The volume should be expressed grams or ounces per pump for the lever type hand pumps

- ③ Air powered grease delivery should only be use in high-volume applications and th e volume should be determined per second or other meeting device.
- ③ Grease guns are to be dedicated to particular grease applications and identified by tagging each grease gun for the type of grease that will be used in this gun for a given application.
- ③ To minimize contamination of grease with dirt and foreign material, Cartridges should always be used when ever possible.
- ③ Hydraulic Ball check grease fittings should always be used for all grease applications.
- ③ Lubrication Points are to be clearly labeled by tagging, type of lubrication used at each grease point and identification of the point name.
- ③ When time interval greasing is used in condition based lubrication, it is critical that the amount of grease necessary to properly lubricate a bearing is specified clearly in the Work Order or lubrication task.
- ③ The quantity must be translated into a value the craft can easily understand what is needed, i.e. two full strokes of a lever type grease gun.
- ③ Calibrate grease guns regularly to ensure the proper delivery and amount per stroke or half stroke.
- ③ Caution is always needed that over lubrication dose not occur. Destruction of rolling element bearings will occur due to over lubrication.
- ③ The proper method of lubricating a grease fitting has the following steps.
 1. Identify the grease type call out on the PM Work Order to the Grease Gun being used.
 2. Compare the grease points I.D. tags to the Work Order description to verify grease point application.
 3. Remove any drain plugs and any hardened grease.
 4. Before applying grease to the grease point, wipe the grease gun tip with a clean lint free rag, and wipe the grease point jerk with a lint free rag.
 5. Apply two full strokes of the lever type grease gun to the grease point.
 6. After two strokes have been applied to the grease point leave a small amount of grease on the jerk fitting to keep any dirt and chemical to end this fitting.
 7. When greasing motors is complete, keep the drain plugs out and run the motor for a few minutes to allow the grease to expand and relieve any over lubrication optional.
 8. Reinstall drain plug after relief cycle on motor bearings.
- ③ Install pressure relief fittings (15 to 20 psi) that will allow the cavity to be pressurized to 20 psi max. only, and will allow greasing a motor while running.

8. USING THE FLEETOIL SYSTEM

1.2 Organisation of Information

The following flow chart illustrates the general organization of the Fleetoil system. The numbers in the top left of each section corresponds to the numbered descriptions of the modules that follow the chart.



1. The **Equipment module** contains detailed information about all the equipment that you perform oil analysis on (serial number, make, model, etc). This information is used to identify equipment items as samples are taken and then when the results are returned, match them back to the equipment. You also setup relationships between items of equipment, which parts are components of others, and set meter readings.
2. The **Results module** is a combination of many programs that allow you to print sample labels, setup the lab details, automatically dial the lab to obtain the results, enter fuel and oil usage, record events and even import pictures.
3. Setting alarms in the **Alarms module** is the basis of the system. There are many different types of alarms including user alarms, statistical alarms and confidence alarms. To trigger alarms for certain events, expert alarms can be setup based on multiple criteria.
4. The **Analysis module** allows you to look at the details of the samples taken previously, and what alarms have been triggered. You can sort the details by either alarm severity or by equipment number. You can also breakdown equipment items to see what components have the alarms, and graph details as required.
5. The **Reports module** will allow you to print reports based on your current equipment, sample and alarm status. You can print them to the screen or to the printer.
6. The **Graphs module** allow you to view trends on items of equipment for certain predictors, and during certain events. You can add notes to a graph, change the scale, and include/exclude the predictors that you want to see. Alarm levels can also be plotted on the graphs.
7. The **Utilities module** has no direct bearing on the equipment, samples or alarms. However it provides the facility for corrupt file fixing, backup and restore options and many other programs. These are detailed during the administrator's course.

8.1. System Setup

- ③ All equipment that is setup in the FleetOil database will be setup to mirror the equipment numbers and descriptions setup in the Maximo database.
- ③ All lubrication that is referenced to in the equipment setup will be setup to mirror the inventory that is setup in the Maximo data base, description and stores numbers.
- ③ Following are the steps when entering equipment information into the FleetOil database that will reference the equipment setup in the Maximo database.
- ③ Equipment numbers and equipment descriptions are the only modes of searching and linking between FleetOil and Maximo CMMS system, therefore they must be identical in both data bases.
- ③ When entering equipment information on the equipment page of the equipment form, SEE Illustration 8.1.1.

The screenshot shows a software window titled "Form: Equipment". It contains several input fields and buttons. The "Equipment Information" section includes fields for "Eq #:" (1001), "Description:" (LETORNEAU L1000), "SerialNum:" (1LE1058), "In Service:" (checked), "In Service Note:", "Make:", "Model:", "Location:", "EqType:" (L1100), "User:", "Person Resp:", "Parent:", and "PrincipleEq:" (1001). The "FleetOil Information" section includes fields for "Default InfoSource:" (EATM), "Calculation Method:" (Meter), "Date:", "AlarmGroupID:", "EcGroupID:", and "Meter Location:" (1001). At the bottom, there are tabs for "Equipment", "Fluids", and "Parent/Child". On the right side, there are buttons for "OK", "Cancel", and "Help".

- ③ FleetOil requires that each piece of equipment be assigned a unique equipment number.
- ③ You must also specify Principle Equipment Number and an Alarm Group if you wish to generate alarms.
- ③ All other fields hold information for your use, you may leave fields that you do not need blank.
- ③ To get access to this program, from the main menu select the equipment button by clicking on it, and then select from the menu the equipment details.
- ③ A screen similar to the shot below should be displayed.

- ③ To add a new piece of equipment, click on the button, the screen will clear and you can start the entry.
- ③ To delete a piece of equipment, click on the button, and provided the equipment is not in use anywhere else in the system, it will then be removed.
- ③ To duplicate a piece of existing equipment, find the equipment item you want by either using the video buttons, or the search buttons.
- ③ Click on the button and a piece of equipment called New Equipment will be created.
- ③ Simply change the equipment number to be what you want and it is then created. Blue fields are defined as lookup fields, these have predefined entries that yours must match.
- ③ If you know what is needed in the fields then you can just type it in; otherwise double click on the field and a list of available entries will be displayed for your selection.
- ③ The Tab, Fluids is used to record the fluids details for the particular piece of equipment. SEE Illustration 8.1.2.

The screenshot shows a software window titled "Form: Equipment". It features a toolbar with navigation icons (back, forward, search, etc.). Below the toolbar, there are input fields for "EqNum" (containing "1001") and "Description" (containing "LETORNEAU L1000"). The "Fluids" section is highlighted, showing fields for "FluidID" (with a red background), "FluidType", "Capacity", "Viscosity", "Grade", "Description", "Manufacturer", "Make", "Sample Interval", and "Change Interval". On the right side of the "Fluids" section are "OK", "Cancel", and "Help" buttons. At the bottom of the window are three tabs: "Equipment", "Fluids" (which is selected), and "Parent/Child".

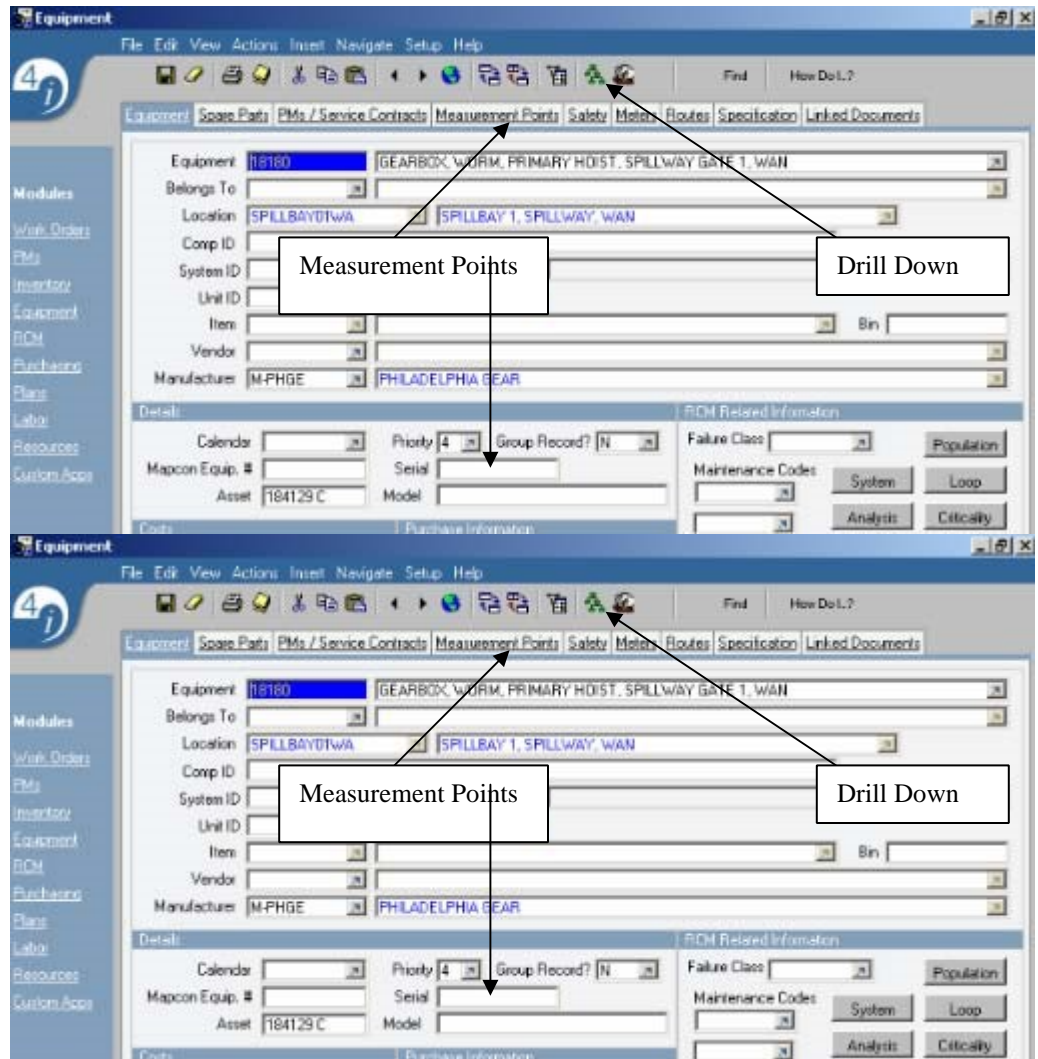
- ③ The Fluids Details page is used to record the fluid details for the particular piece of equipment.
 - ③ From the equipment main screen click on the details tab on the bottom of the window and a screen similar to the one above will be displayed.
 - ③ Fill in the required details as necessary.
- Fluid ID:** A code for the type of fluid that is used on the current item of equipment.
- Fluid Type:** User defined field for the type of fluid being entered, F and enter for fuel, or O and enter for oil.
- Capacity:** The amount of fluid that the Current equipment item can hold.
- Viscosity:** The viscosity of the fluid.
- Grade:** The grade of the fluid.
- Description:** The description of the fluid.
- Manufacturer:** The manufacturer of the fluid.
- Make:** The make of the fluid. Synthetic, Mineral

8.2. System Setup for Maximo

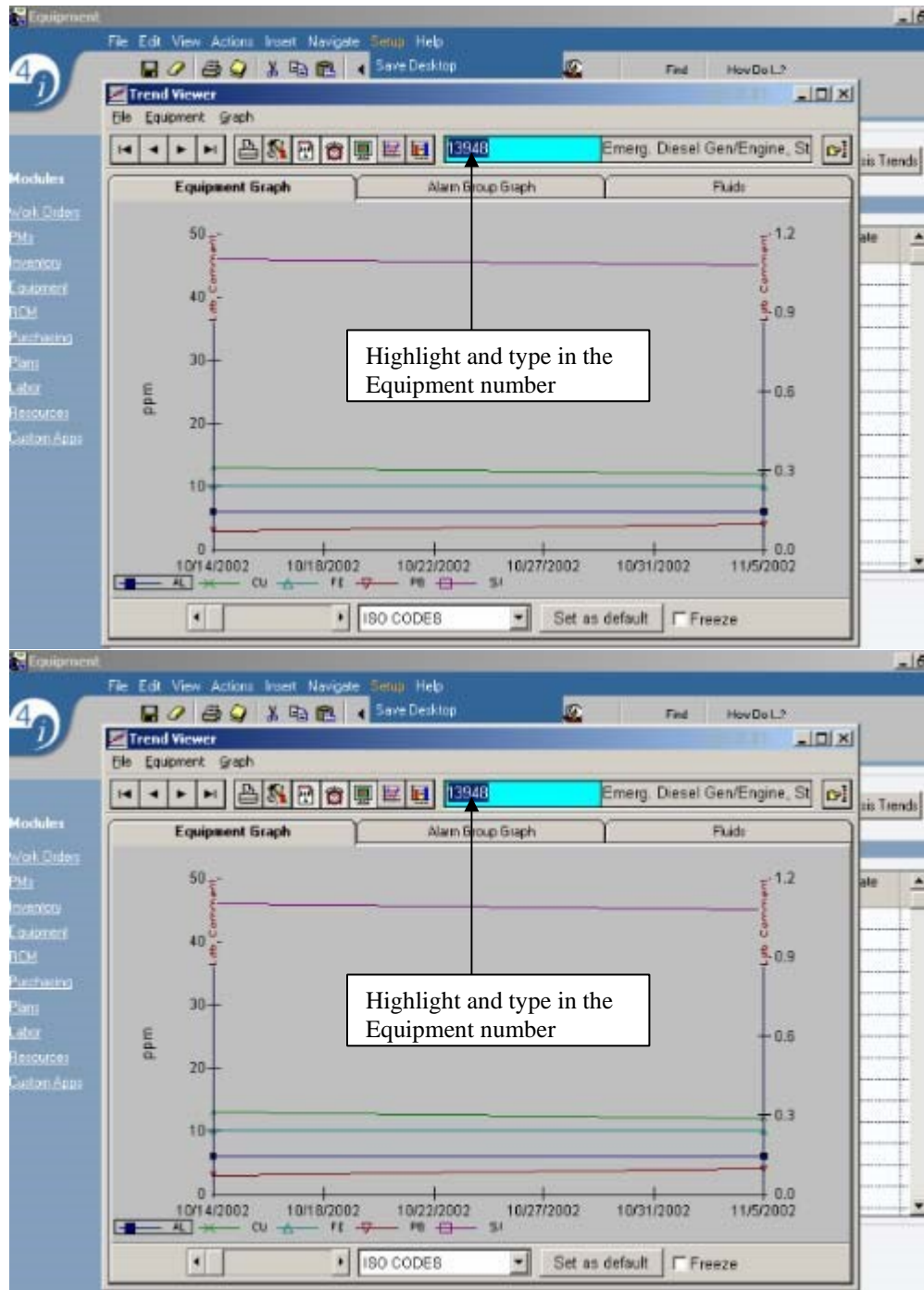
- ③ The Hierarchy within Maximo and FleetOil are the same Equipment numbers and equipment descriptions to reference Oil Analysis Trends of equipment.
- ③ Maximo and FleetOil databases are independent of one another, and do not store data information between databases.
- ③ When equipment has been identified within Maximo for Trend Graph viewing, the Exe. File is executed with a written macro, to access the Trend Viewer within FleetOil for viewing the equipment selected which is stored in the FleetOil database.
- ③ The procedure to access Trend Viewer within Maximo from the FleetOil database for viewing oil analysis results is as follows.
- ③ Sign-on to the Maximo data base to enable access to the Maximo information screen.
- ③ With in the Maximo information screen, select the Equipment Module as seen BELOW.



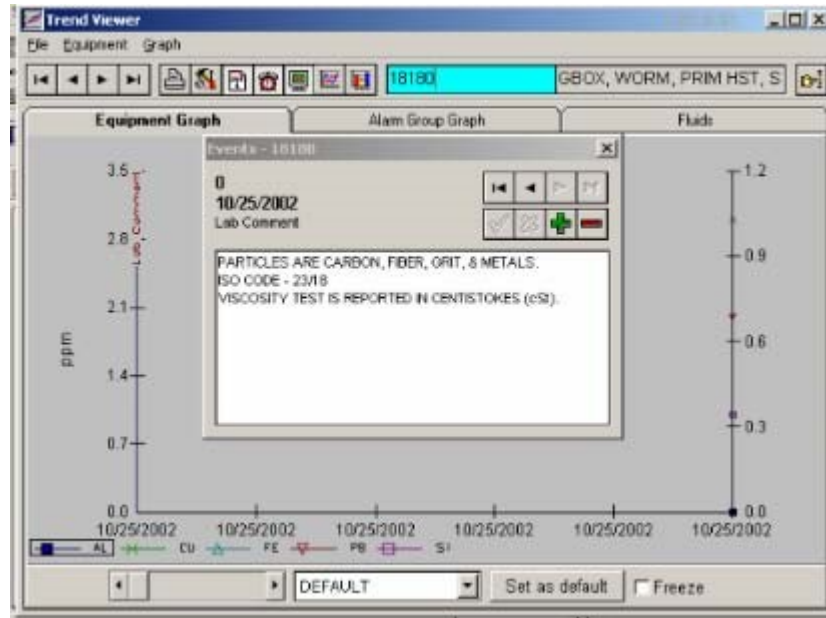
- ③ Within the Equipment screen there are two steps to execute.
1. Click on the drill down and go through the hierarchy and select the equipment number, or if number is known type in the equipment number in the equipment field.
 2. After the equipment has been selected, click on the Measurement Points Tab to bring up the next screen. As seen BELOW:



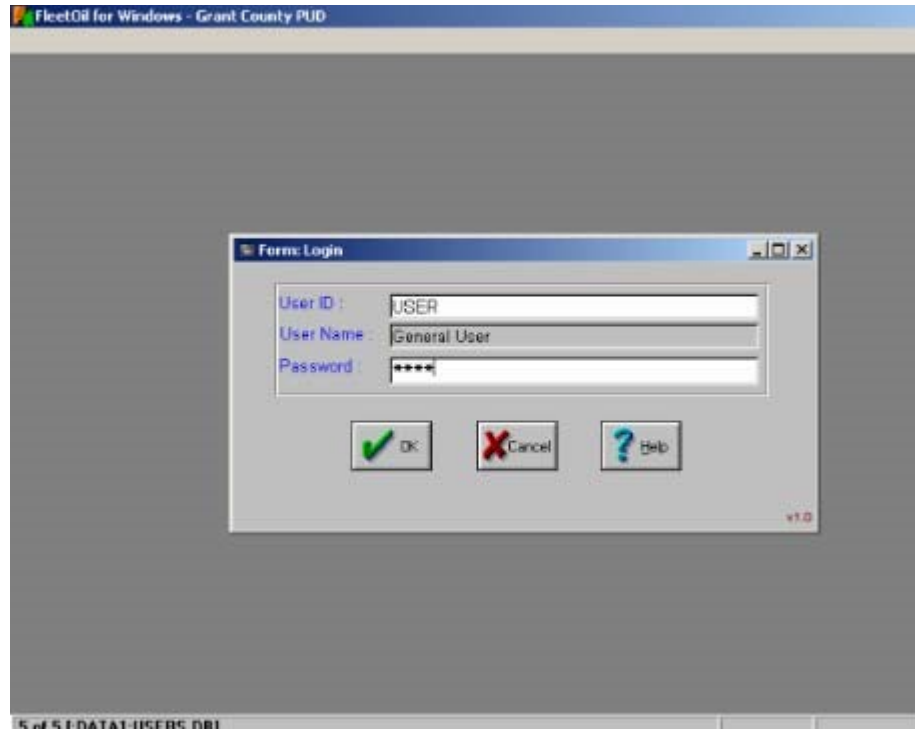
- ③ When the Measurement Points screen has been selected there will appear in the top right hand corner of the screen a button called Oil Analysis Trends, click on this button to execute the FleetOil Exe. File and Macro as seen BELOW.



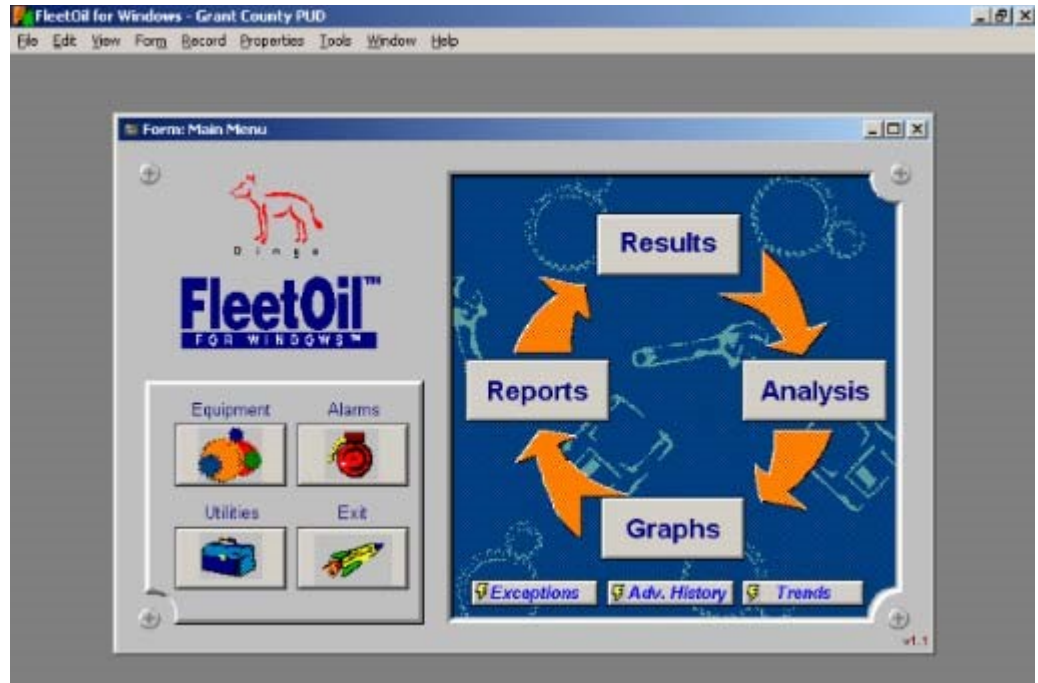
- ③ When the desired equipment has been entered the Trend Viewer will display the information for the equipment selected as see BELOW.



- ③ After the desired equipment has been selected there are options that can be selected to view the information from this screen.
 1. Click on Lab Comments on the left hand side of the screen for information from the Oil Analysis Lab concerning this equipment.
 2. There are three tabs in the top of the screen that will give information about this equipment oil condition.
 - i. Equipment Tab – Shows the wear metal particulate found in the oil sample and the amount found shown in ppm - parts per million.
 - ii. Alarm Group Graph – Shows if there are any wear metals, dirt, silicon that have passed by an alarm that has been set for the oil in this equipment.
 - iii. Fluids – Gives all the information as to type of oil used in this equipment, oil changes that have been made, any oil that has been added to top off the system.
 3. The default window arrow at the bottom of the graph – Give options to look at the 5 & 15 ISO levels over time.
 4. Trend the additives contained in this oil and there levels, weather they are being used up, looking at alarm levels of high or low levels needed within this oil.
- ③ If more detailed information is desired by looking at other graph options, access in the FleetOil database will be needed to obtain more detailed information.
- ③ To access the FleetOil database and Read Only version must be loaded on the PC being used.
- ③ After installing FleetOil User version, Sign-on using (USER) in both the User field and the Password field as seen BELOW.



- ③ Upon entry to the database select the following tabs options to view more detail of sampled oil as seen BELOW.



8.3. Uploading Lab Results:
Save the Lab File From Your Email:

- ③ When the lab sends you an email attachment file of your results, you need to save this file onto the network.
- ③ Save the attached file from the lab to the folder P:\Program\Fleetwin\infosrc\oald which is the input folder where FleetOil will look for the file when reading in results.

Read the File into FleetOil:

- ③ From the main menu of FleetOil, click Results | Results Input
- ③ On the Info source Tab, click the button Selected Info Source.
- ③ The Oil Analysis Lab Driver interface should start and count through the results as it reads in.

Check For Abnormal Sample Data:

- ③ Now Click onto the Results tab
- ③ Scroll down and check that all result records have equipment numbers.
- ③ Any results that don't have an equipment number shown in the EqNum column will also say "EqNum not found" in the Matching Comments field and will need to be matched to equipment or discarded.
- ③ If a result needs to be matched, work out what equipment number it should be assigned to and double-click in the EqNum field.
- ③ Scroll down and select the correct equipment number. If the equipment is not in the database it will need to be added in the Equipment area before you can match the equipment.

Process Results:

- ③ Once all the data is correct in the results input area, from the Results tab, click the button Process Results and click Yes when prompted. This will check all the samples against the filters setup in the Utilities section.
- ③ It will check for Zero meter readings, earlier sample dates, lower meter readings or duplicate results depending on whether these are set to True or False in Utilities.
- ③ Once the process is complete, scroll down and check the list of results for any comments other than “OK”. All results with a matching comment of “OK” will then be available in the database.
- ③ Click Cancel to exit the Results Input form.

Check Exceptions:

- ③ From the Main Menu, click Exceptions to check results that have been flagged by the lab or have set off exceptions based on your alarm settings for that equipment.
- ③ It is probably easier to go straight to the Exception Details tab and work from there. All compartments for a particular unit will be stored there if they generated an exception. Use the Equipment Number field down arrow and scroll bar to navigate to different units as you work through.
- ③ Click onto the Event Notes tab to check for any pointers from the lab.
- ③ It may help to use the Trend Viewer to check results as you work through the exceptions:
- ③ Click on FleetOil (on the task bar at the bottom of the screen) to bring it in front of the exceptions form Click on the Trends button to start the Trend Viewer.
- ③ Type the equipment number directly into the blue field at the top center and hit enter
- ③ Select different graph views using the down arrow button on the field at the bottom of the trend viewer window.
- ③ If you find no problems, check the entry off the exceptions list by clicking in the checkbox to the right of the equipment number on the left portion of the Exception Details tab.
- ③ A Red X mark indicates that you want the entry off the list and no maintenance action will be taken.
- ③ If there are problems indicated:
- ③ Add an interpretation comment: on the Event Notes tab, click the button Add/Edit an exception comment and type in your text.
- ③ Click OK when finished.
- ③ Check off the equipment entry: click twice in the checkbox to the right of the equipment number so a green check mark appears.
- ③ This indicates some maintenance action is required.
- ③ When finished, close down the exceptions and click Yes to post updates to the database.

8.4. Post Upload Analysis

- ③ The Oil Process Owner will view this section by selecting the Analysis button from the main menu of FleetOil then Exception Analysis or select the Exceptions quick start button from the bottom of the main menu.
- ③ **Exception Overview Section**
- ③ The first page of the exception analysis screen shows an overview of the equipment for which exceptions has been triggered. As seen Below

Form: Analyze 1.09.0.07

File View Options Launch Information

Print
Print plain graph
Print trend chart
Print setup...

Report creator...

Exit

Standard
Engine
Gearbox
Fuel Drive

Current view ordered by:
Sample Date, Alarm Priority, Equipment Number

	number	Sample date	Number	Description	Sample time
	604.315	21/02/96	5	EUCUD R50 TRANS-PS-FRONT	09:00:00 AM
	525.401	21/02/96	4	SOUTH DRIVE GEARBOX	09:00:00 AM
	1504.407	16/01/96	8	DEHAVILAND PRATT & WHITNEY 120A	09:00:00 AM
ACCELERATING	1504.422	16/01/96	6	DEHAVILAND HYDRAULIC SYSTEM 2 D	09:00:00 AM
INCREASING	1504.408	16/01/96	7	DEHAVILAND HYDRAULIC SYSTEM 1 D	09:00:00 AM
EXTREME	1504.327	16/01/96	4	DEHAVILAND APV TURBINE DASH 8	09:00:00 AM
SPIKE	604.327	13/12/95	2	EUCUD R50 R DIFFERENTIAL	09:00:00 AM
SPIKE	604.401	13/12/95	11	EUCUD R50 RT FINAL DRIVE	09:00:00 AM
SPIKE	604.402	13/12/95	3	EUCUD R50 LT FINAL DRIVE	09:00:00 AM
SPIKE	604.418	13/12/95	11	EUCUD R50 LEFT FRONT HUB	09:00:00 AM
SPIKE	604.505	13/12/95	5	EUCUD R50 HYDRAULIC SYSTEM	09:00:00 AM
EXTREME	604.430	13/12/95	3	EUCUD R50 STEERING SYSTEM	09:00:00 AM
MOD	904.327	28/11/95	1	CAT 988B R DIFFERENTIAL	09:00:00 AM
MOD	904.405	28/11/95	1	CAT 988B RT F FINAL DRIVE	09:00:00 AM
MOD	904.408	28/11/95	1	CAT 988B LT F FINAL DRIVE	09:00:00 AM
MOD	904.407	28/11/95	1	CAT 988B RT R FINAL DRIVE	09:00:00 AM
INCREASING	307.567	13/11/95	3	BE 295B1 L H CROWD	09:00:00 AM
EXTREME	307.344	13/11/95	2	BE 295B1 R H PROPEL G/CASE	09:00:00 AM
EXTREME	307.345	13/11/95	1	BE 295B1 L H PROPEL G/CASE	09:00:00 AM
EXTREME	307.568	13/11/95	1	BE 295B1 R H CROWD	09:00:00 AM
EXTREME	307.924	13/11/95	12	BE 295B1 NO2 SWING G/BOX	09:00:00 AM
EXTREME	307.925	13/11/95	12	BE 295B1 NO1 SWING G/BOX	09:00:00 AM
EXTREME	307.547	30/05/95	1	BE 295B1 L H SWING DRIVE	09:00:00 AM
EXTREME	307.402	05/02/95	1	BE 295B1 LT FINAL DRIVE	09:00:00 AM
EXTREME	525.420	24/09/93	12	NORTH DRIVE GEARBOX	09:00:00 AM

Exception Overview Exception Details

25 records. 6 items selected.

- ③ Review exception analysis screen, for the worst type of alarm triggered by both name and alarm symbol for the particular sample, the total number of alarms triggered, and the sample time.
 - ③ After all exceptions have been reviewed and selected, review the Lab data, Trend Charts, and Alarm graphs to determine the following symptoms found from the exception report.
 1. Water Content
 2. Type and Amount of Metal wear particles.
 3. Levels of Additive packages within the oil.
 4. Amount of dirt and silicon found in oil –ISO level example ISO 23/18
 5. How sever the alarm level is for this sample and its trend, and how many alarm levels triggered.
 - ③ Based on the determined symptoms, perform a detailed analysis and determine the following steps to be taken.
 - ③ For those alarm levels that are Moderate, clear the alarms within the exception module and take the next oil sample and observe the trend.
 - ③ For those alarms above Moderate levels, The Process Owner will review data with RCM Engineer for plan of action.
 - ③ Upon review, the Oil Process Owner will write Follow-up Work Orders in Maximo, describing the data found and recommended action to correct the alarm generated.
- Example-
1. Drain, flush, gearbox and add new oil to this system.
 2. Remove inspection cover and inspect this system of gear damage.
 3. Replace filter on this system and resample in 2 weeks.

4. Resample this gearbox to confirm oil sample alarm on this system.
 5. Sever levels of Wear Metals have been detected. Shut equipment down and determine Root Cause of Wear Metals.
 6. Install a Polish Cart on this system and polish for 7 days and resample after 7days of filtering. Oil has high levels of dirt and silicon.
 7. Replace system filter and resample in 7days.
- ③ After the Follow-up Work Orders are written the Work Order Number and a brief description will be recorded in Equipment History file of the equipment module of FleetOil and Maximo Long Description screen.
 - ③ When the corrective action has been completed the Work Order will be completed in Maximo by the shift supervisor and turned over to the RCM Engineer for RCM analysis review.
 - ③ Any completed Work orders reviewed by the RCM Engineer will be given to the Oil Process Owner for review also, to update FleetOil database of completed Work Orders and add any amounts of oil changed of add to the equipment because of the Work Oder.
 - ③ Add any information to the Equipment History in both FleetOil and Maximo Long Description screen.

8.5. Oil Change Tracking

- ③ All oil changes that are called out on a PM Work Order, or CM Work order, calling for a oil change due to oil sample results, will be recorded on the work order as completed.
- ③ The oil change information should include, amount of oil added, type of oil, and date the oil change was completed.
- ③ When working from PM Work Orders that require Inspections or Oil Samples, all oil that is added to a system to bring the gearbox or oil reservoir back to the full level will be recorded on the work order indicating the amount and type.
- ③ Work orders that have this information recorded, will be given to the Oil Program Owner and enter into the FleetOil database in the Following steps.
- ③ From the Main Menu select the Results Button.
- ③ From the display menu, select the Fuel & Oil Entry option by clicking on the box corresponding to the menu item
- ③ Once the selection has been made, the Fuel & Oil Form screen will display to allow the addition of information for a particular piece of equipment.
- ③ The lookup features of FleetOil can be used to locate the EqNum by high lighting the equipment field and pressing Ctrl-Enter.
- ③ Select the equipment item that is wanted by using the scroll bars, video buttons or search keys.
- ③ Once the item is found that is wanted, highlight the equipment selection and click on OK, or double click on the item that is wanted.
- ③ Enter usage details as required in the Amount column.
- ③ If this was an oil change, click the changed button as well to create an event history item.
- ③ To observe the trend or see a displayed graph click on the Added or Accumulative tab, which has the option to print the displayed chart or graph.
- ③ Best practice for oil top-off is the recording of volumes of oil added to each machine through the PM Work Order notations.

8.6. Reporting

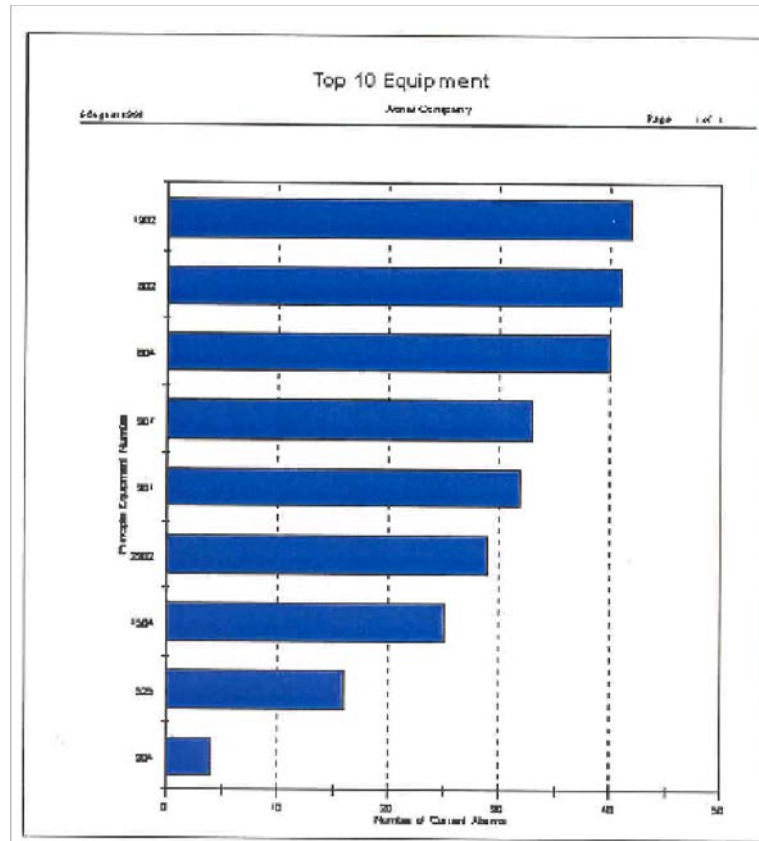
- ③ Oil Monitoring Reports will be posted once per month for the following information.
 1. Top Ten Equipment – Graph: This report will show the number of current alarms that exist or each piece of equipment. Ranking from the dirtiest to the cleanest system tested, during that one-month period.

2. Exception - Detailed Report – This report will show all equipment during the month that has triggered an alarm. It displays the equipment details, the predictor and the alarm that was triggered doing a comparison of last three samples taken
3. Equipment Report - For each piece of equipment that generated the writing of a Follow-up Work Order and Work Order Number. This report shows the Wear Metals, physical Properties, Contaminants found, Trend Graph of the elements that were found in the oil sample, their levels and the alarms that were triggered.
4. Sample Summery Report – This report is a summery of the oil samples collected for any given month. It will show the equipment sampled, the date sample taken, the properties found and the amounts reported in ppm, and the ISO Cleanliness level of this sample.
5. From the Simple Maximo Report Section of the Maintenance Management System Folder two reports are to be run and posted for review.
 1. PM Work Order Elapsed Days Report
 2. CAN vs. CLOSE PM Status
- ③ Oil Monitoring Reports will be sent to the following personal, Project Director, Hydro Supervisor, Shift Foreman at each dam, Planners & Schedulers, RCM Engineer, Director of Engineering at HED.
- ③ Oil Monitoring Reports will be posted on the RCM/Maximo file on the Hydro Intranet, (Our Source) Information Screen.
- ③ To access Condition Monitoring Reports in the Maintenance Management System File, Go to Internet Explorer Screen and click on the Hydro Tab.
- ③ After accessing the Hydro Division Screen, scroll to the Maintenance Management System section and click on the RCM/Maximo file and select Condition Monitoring Reports to view the posted condition monitoring reports.
- ③ Examples of these reports can be seen BELOW

9. REVIEWING REPORT INFORMATION FROM FLEETOIL

It is convenient to review information contained in Dingo while using Maximo.

- 9.1. FleetOil - Top Ten Equipment – Report: This report will show the number of current alarms that exist on each piece of equipment. Ranking from the dirtiest to the cleanest by alarms on equipment tested, during a one-month period.



- 9.2. Exception - Detailed Report – This report will show all equipment during the month that has triggered an alarm. It displays the equipment details, the predictor and the alarm that was triggered doing a comparison of last three samples taken.

Exception List - Detailed							
			Report date: 11/18/99		Page: 1		
Equipment Number	Alarm Level	Predictor	Current	Alarm	Previous 1	Previous 2	Previous 3
4/30/96							
634-PD	INCREASING	V40	330.00	0.00	281.00	265.00	162.00
	MOD	SN	0.01	0.01	0.00	0.00	0.00
640-DRRLH	INCREASING	V40	416.00	0.00	400.00	398.00	385.00
	MOD	V40	416.00	415.93	400.00	398.00	385.00
640-DRRRH	INCREASING	V40	415.00	0.00	411.00	410.00	391.00
	HIGH	SI	78.00	73.39	85.00	55.00	70.00
640-PD	MOD	CR	0.01	0.00	0.00	0.00	0.00
801-FRH	INCREASING	SI	125.00	0.00	95.00	38.00	9.00
	EXTREME	SI	125.00	114.53	95.00	38.00	9.00
4/15/96							
633-DRFLH	HIGH	SI	44.00	43.20	47.00	44.00	42.00
633-DRFRH	INCREASING	SI	39.00	0.00	37.00	36.00	35.00
633-DRRLH	MOD	SI	53.00	49.38	58.00	53.00	57.00
633-PD	MOD	SN	0.01	0.01	0.00	0.01	0.00
804-H	HIGH	SN	0.00	0.00	0.00	0.00	
4/11/96							
802-E	INCREASING	ST	0.27	0.00	0.22	0.20	0.17
802-FLH	SPIKE	SN	0.00	0.00	0.00	0.00	0.00
	HIGH	SN	0.00	0.00	0.00	0.00	
802-FRH	SPIKE	SN	0.00	0.00	0.00	0.00	0.00
	HIGH	SN	0.00	0.00	0.00	0.00	
	MOD	CR	0.00	0.00	0.00	0.00	0.00

- 9.3. Equipment Report - For each piece of equipment that generated the writing of a Follow-up Work Order and Work Order Number. This report shows the Wear Metals, physical Properties, Contaminants found, Trend Graph of the elements that were found in the oil sample, their levels and the alarms that were triggered.

446-E - Engine Report

Equipment : 446-E
 Description : DRESSER DRESR830 ENGINE
 Serial Number : GF31769 AFE-32X
 Make : DRESSER
 Model : DRESR830

Report Date : 08 Nov 1999
 Oil Type : FUEL
 Name : Fuel
 Typical Viscosity :
 Capacity : 0

All time meter reading	17284	17070	16737	16562	16336	16336
Current meter reading	17249	17036	16702	16527	16301	16336
Pressure	Units	Level	Method	Extreme	High	Moderate
				30APR96	20MAR96	08FEB96

Wear Metals

Aluminum	ppm	User	4	1	1	1	1	1	1
Chromium	ppm			2	2	2	2	2	2
Copper	ppm			6	8	11	11	24	24
Iron	ppm			20	22	15	17	25	23
Lead	ppm			4	1	4	2	3	3
Tin	ppm			5	4	5	6	5	5
Calcium	ppm			0	0	0	0	0	0

Physical Properties

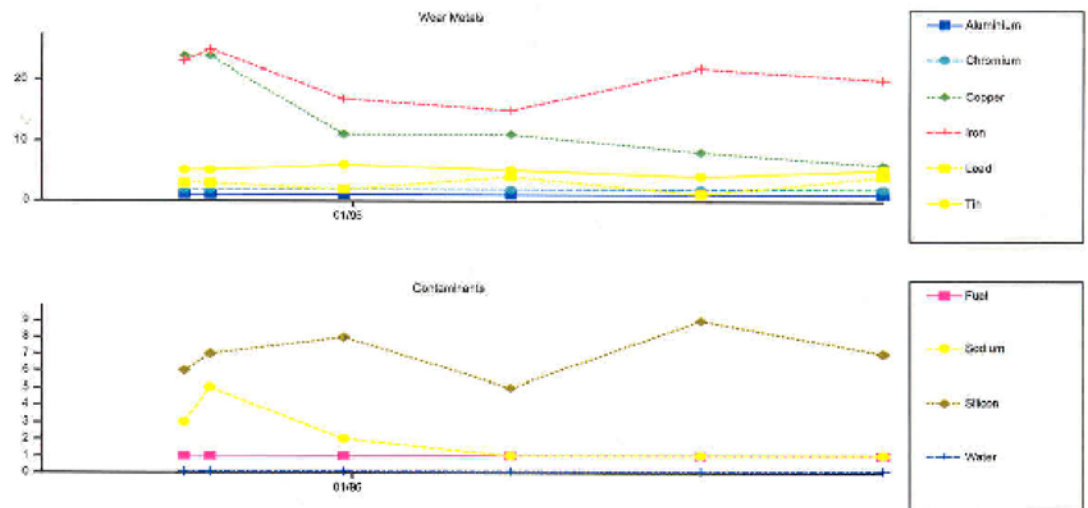
Oxidation	ppm			0	0	0	0	0	0
Viscosity @ 100°C	ppm			0	0	0	0	0	0
Nitration	ppm			0	0	0	0	0	0
Viscosity @ 40°C	ppm	High	StdDev	216.43	189.88	174.71	0	0	0
Molybdenum	ppm			0	0	0	0	0	0

Contaminants

Fuel	%			1	1	1	1	1	1
Sodium	ppm			1	1	1	2	5	3
Silicon	ppm	StdDev	31.42	26.83	24.49	7	9	5	8
Water	ppm			0.05	0.05	0.05	0.05	0.05	0.05
Titanium	ppm			0	0	0	0	0	0

LABCOMMENT (4/30/96)

ALL WEAR RATES NORMAL. ABRASIVE AND OTHER CONTAMINANT LEVELS SATISFACTORY. VISCOSITY NORMAL. CONDITION OF OIL SATISFACTORY FOR TIME IN SERVICE. AS OIL AND FILTER(S) ALREADY CHANGED; RESAMPLE NEXT RECOMMENDED SERVICE INTERVAL TO FURTHER MONITOR.



- 9.4. Sample Summery Report – This report is a summery of the oil samples collected for any given month. It will show the equipment sampled, the date sample taken, the properties found and the amounts reported in ppm. Oil added to system, and Oil Changes.

Sample Summary Report

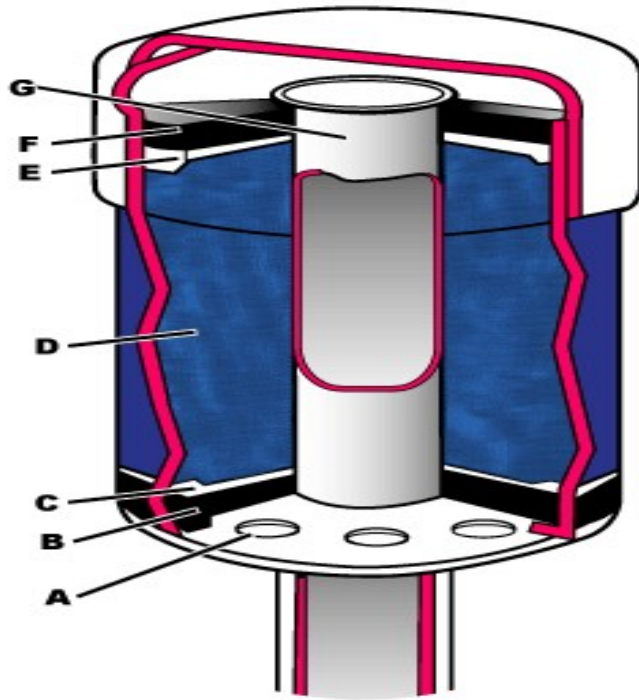
(by Sample date)

Printed 19 Nov 1999

Equipment Number	Description				Load date	Exceptions
13 May 1996						
801-T	CAT CATD11 TRANS-PS-PRIMARY				07 May 1996	No
	Aluminium	Chromium	Copper	Iron	Sodium	Lead
	2	1	34	23	1	6
801-H	CAT CATD11 HYDRAULIC				07 May 1996	No
	Aluminium	Chromium	Copper	Iron	Sodium	Lead
	2	1	5	5	1	3
801-FRH	CAT CATD11 RH FINAL DRIVE				10 May 1996	Yes
	Aluminium	Chromium	Copper	Iron	Sodium	Lead
	37	7	2	290	1	2
801-FLH	CAT CATD11 LT FINAL DRIVE				10 May 1996	No
	Aluminium	Chromium	Copper	Iron	Sodium	Lead
	13	3	6	145	1	2
640-PD	LeTOURNEAU MARL1400 PUMP DRIVE				07 May 1996	Yes
	Aluminium	Chromium	Copper	Dielectric Constant	Iron	Fuel
	1	1	4	16	8	0
	Sodium Added since last Oil Change Days since last Oil Change Units since last Oil Change				Lead	PQ Index
	1	0	0	197	1	-not tested-
640-H	LeTOURNEAU MARL1400 HYDRAULIC				07 May 1996	No
	Aluminium	Chromium	Copper	Dielectric Constant	Iron	Fuel
	1	1	5	10	5	0
	Sodium Added since last Oil Change Days since last Oil Change Units since last Oil Change				Lead	PQ Index
	1	0	0	13639	1	-not tested-
640-E	LeTOURNEAU MARL1400 ENGINE				10 May 1996	No
	Aluminium	Chromium	Copper	Dielectric Constant	Iron	Fuel
	1	1	3	17	9	1
	Sodium Added since last Oil Change Days since last Oil Change Units since last Oil Change				Lead	PQ Index
	1	0	0	197	8	-not tested-
640-DRRRH	LeTOURNEAU MARL1400 RHR DRIVER				10 May 1996	Yes
	Aluminium	Chromium	Copper	Dielectric Constant	Iron	Fuel
	8	2	10	16	200	0
	Sodium Added since last Oil Change Days since last Oil Change Units since last Oil Change				Lead	PQ Index
	18	0	0	8578	3	-not tested-
640-DRRLH	LeTOURNEAU MARL1400 LHR DRIVER				10 May 1996	Yes
	Aluminium	Chromium	Copper	Dielectric Constant	Iron	Fuel
	1	2	10	17	140	0
	Sodium Added since last Oil Change Days since last Oil Change Units since last Oil Change				Lead	PQ Index
	18	0	0	8578	4	-not tested-
640-DRFRH	LeTOURNEAU MARL1400 RHF DRIVER				10 May 1996	No
	Aluminium	Chromium	Copper	Dielectric Constant	Iron	Fuel
	1	2	10	16	85	0
	Sodium Added since last Oil Change Days since last Oil Change Units since last Oil Change				Lead	PQ Index
	16	0	0	1567	4	-not tested-
640-DRFLH	LeTOURNEAU MARL1400 LHF DRIVER				10 May 1996	Yes

10. ATTACHMENTS

10.1. Breather Illustration



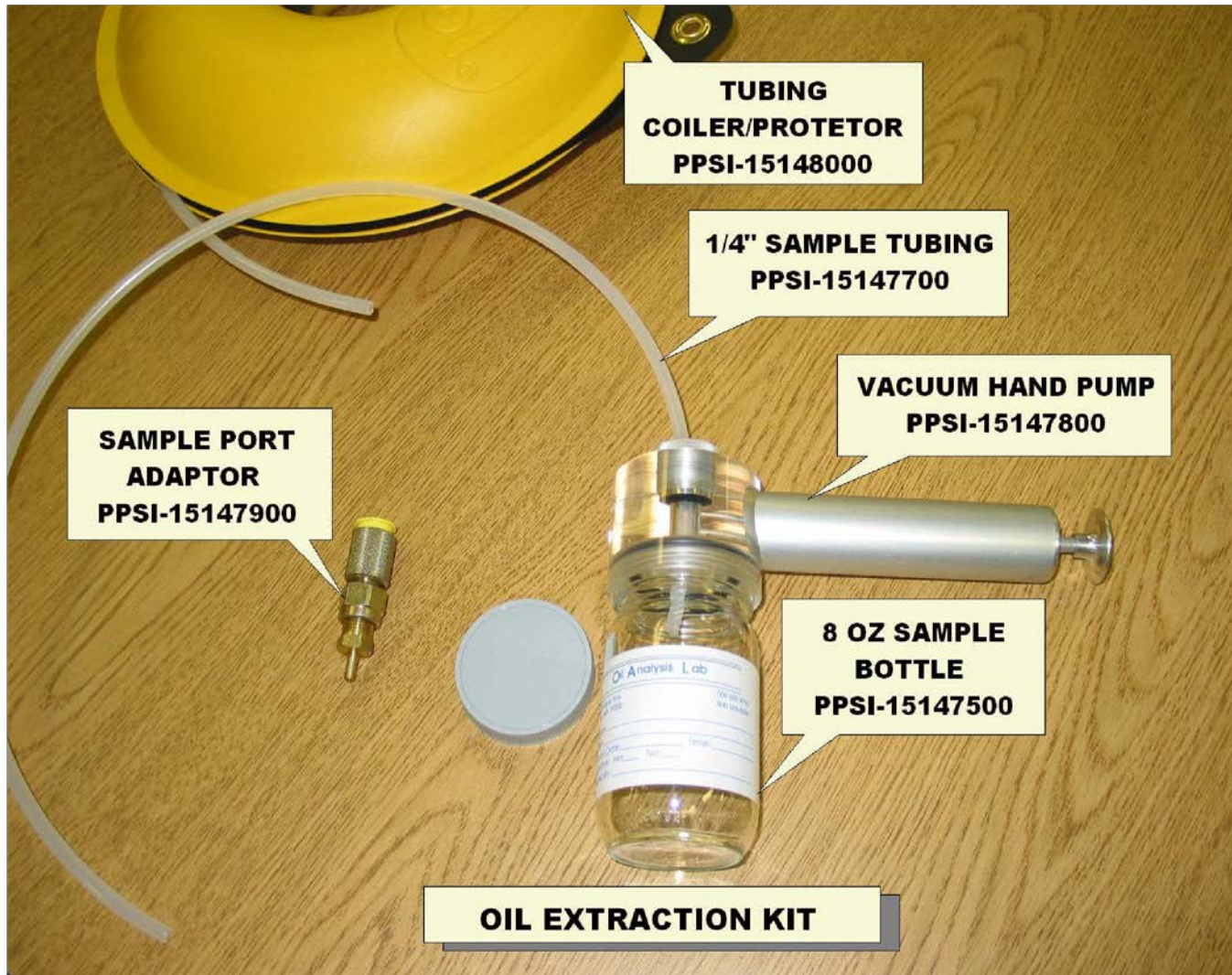
- | | | |
|---|----------------------|-------------------|
| A | Atmospheric openings | |
| B | Rough pre-filter | |
| C | 3 Micron pre-filter | |
| D | Desiccant | |
| E | Micron post-filter | Rough post-filter |
| F | | |
| G | Sump access tube | |

The breather may be integrated as part of a sample point and fill ports and may also have a vacuum indicator that can indicate when the micron filters are plugged. This integration is achieved by using a base unit with fill and sample connections and by using a breather model that has an installed vacuum gage.

10.2. Sample Point Illustration



10.3. Sampling Apparatus



- Vacuum Hand Pump : PPSI 1514 7800 Grant County Wanapum Dam Warehouse, Containing –
1- Tubing Thumb Screw
1-8oz sample bottle head with hand pump
- Sample Port Adapter : Adapter, Sample Port, oil, w/tubing barb for .250" O.D. plastic tubing.
Model tp-dga20-1 brass body with swivel connector and tubing barb.
- Plastic Tubing : Tubing, Plastic, oil sampling, .170" I.D. x .250" O.D. x .040" wall natural, Low Density tubing, 100 foot coils.
- Tubing Coiler Protector : Coiler, Tubing, Oil Sampling, Cord Pro for 100 feet plastic tubing.

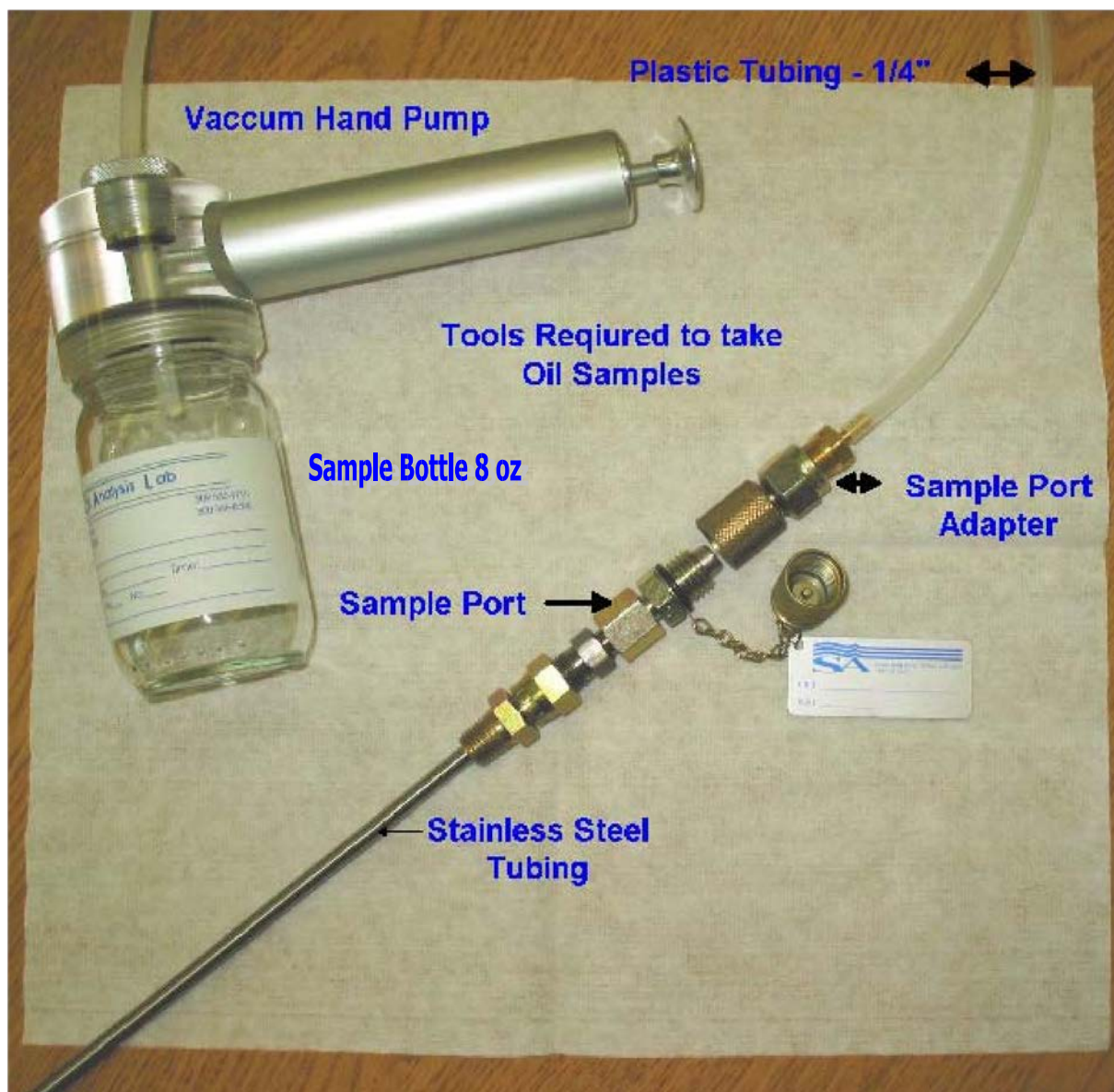
10.4. Sample Bottle Kit

- Sample Bottle Kit : PPSI 1514 7500 Grant County Wanapum Dam Warehouse, Containing –
1- 8oz sterilized Sample Bottle
1-Identification sheet with ID Sample Number and 1- Addressed shipping box for each sample taken.

- ### 10.5. Tools Required for Oil Sampling

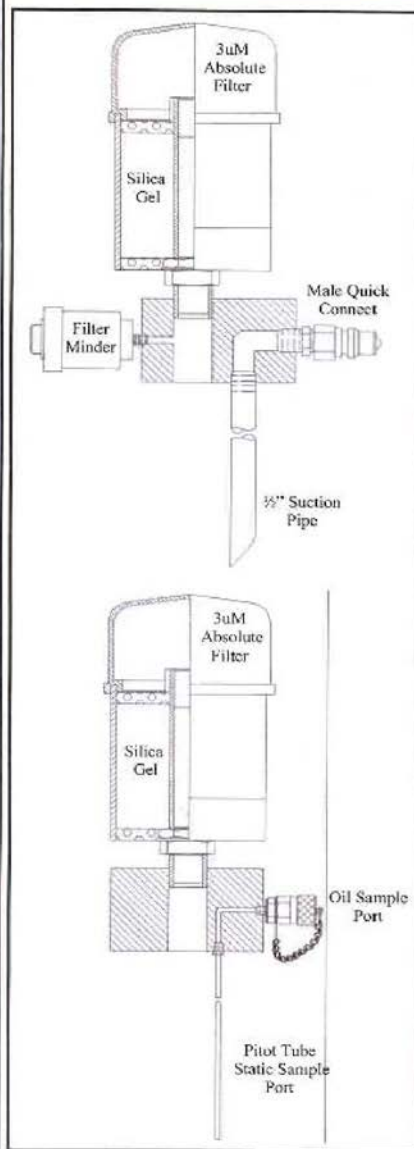






10.6. Reservoir Breather /Sample Point Illustration

Reservoir Management Kits and Adapters



The Schematic Approach Desiccant Breather Kit has been specifically designed to maintain a permanent closure on all your hydraulic reservoirs. The unique multi-port adapter lets you approach lubricant maintenance in a whole new way.

The Schematic Approach Desiccant Breather Kit comes complete with all the components needed for a successful approach to the proactive maintenance of your system. The two stage breather removes airborne particles 3microns and larger and the color coded desiccant will remove the moisture before it can reach your oil. The filter and the desiccant are completely independent of one another and are completely replaceable.

The vacuum gauge will let you know exactly when to change your filter and the color change of the desiccant tells you when you need to replace the water removal section. Now your replacements are based on condition. No more guess work.

The male quick connect is plumbed to a 1/2" NPT port, so fitting a down pipe is fast and simple. The down pipe will let you fill your reservoir with new oil through a filter cart without opening your system to the environment. The male quick connect also promotes pre-filtering of your oil before it goes into service. Quick connects are available in different sizes and colors so cross contamination from different oils in different filter carts is a thing of the past. Add another quick connect to the drain port on your reservoir and you have the perfect set-up for filtering the system with your filter cart while you maintain a closed system.

The Schematic Approach Desiccant Breather Kit also has the ideal solution to static sampling of your oil from the reservoir. The multi-port adapter has incorporated a no-mess sample port connected to a sample tube that extends right to the middle of your oil level. Now you can take an accurate, data rich sample from the same place every time.*

The bolt pattern on our adapter matches that of a standard filter/breather cap so that installation is fast and simple.

The Schematic Approach Desiccant Breather Kit with the unique multi-port adapter plate is the easiest way to manage your hydraulic systems and reservoirs.

*Please note that Sample Port Adapter (TP-DGA20-1/4-RRR) is not included to draw a sample from a lower Port Tube and Sample Ports.



Ordering Code Information

90 SERIES Desiccant Breather Kits With Sample Port

SERIES	BREATHER SIZE	ADAPTER	VACUUM GAUGE	QUICK CONNECT*	TUBE LENGTH**
BR					
CODE	SIZE	CODE	TYPE	CODE	LENGTH
DB93	72gram*	FM	FILTER MINDER	12	12 inches
DB96	144gram*	--	OMIT FOR NONE	18	18 inches
				24	24 inches
				--	OMIT FOR NONE
		CODE	TYPE		
		AP1	DUAL PORT ADAPTER	CODE	SIZE
		AP3	DUAL PORT ADAPTER W/ SAMPLE PORT	QDM	1/2" MALE
		DBA75	3/4" MALE NPT X 3/4" FEMALE BSP	QDF	1/2" FEMALE
		--	OMIT FOR NONE	--	OMIT FOR NONE

*Maximum Water Uptake

**Available with adapter AP3 only

*Not available with DBA75

10.7. Gearbox Desiccant Disposable Breathers



10.8. GLOSSARY (Courtesy of OilAnalysis.com) **A.G.M.A.**

Abbreviation for "American Gear Manufacturers Associations," an organization serving the gear industry.

A.S.T.M. = American Society for Testing Materials"

A society for developing standards for materials and test methods.

Abrasion

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A general wearing away of a surface by constant scratching, usually due to the presence of foreign matter such as dirt, grit, or metallic particles in the lubricant. It may also cause a break down of the material (such as the tooth surfaces of gears). Lack of proper lubrication may result in abrasion.

Abrasive wear

(Or cutting wear) comes about when hard surface asperities or hard particles that have embedded themselves into a soft surface and plough grooves into the opposing harder surface, e.g., a journal.

Absolute filtration rating

The diameter of the largest hard spherical particle that will pass through a filter under specified test conditions. This is an indication of the largest opening in the filter elements.

Absolute Pressure

The sum of atmospheric and gage pressure.

Absolute Viscosity

A term used interchangeably with viscosity to distinguish it from either kinematic viscosity or commercial viscosity. Absolute viscosity is the ratio of shear stress to shear rate. It is a fluid's internal resistance to flow. The common unit of absolute viscosity is the poise. Absolute viscosity divided by fluid density equals kinematic viscosity. It is occasionally referred to as dynamic viscosity. Absolute viscosity and kinematic viscosity are expressed in fundamental units. Commercial viscosity such as Saybolt viscosity is expressed in arbitrary units of time usually seconds.

Absorbent filter

A filter medium that holds contaminant by mechanical means.

Absorption

The assimilation of one material into another: in petroleum refining, the use of an absorptive liquid to selectively remove components from a process stream.

AC Fine Test Dust (ACFTD)

A test contaminant used to assess both filters and the contaminant sensitivity of all types of tribological mechanisms.

Accumulator

A container in which fluid is stored under pressure as a source of fluid power.

Acid

In a restricted sense, any substance containing hydrogen in combination with a nonmetal or nonmetallic radical and capable of producing hydrogen ions in solution.

Acid number

The quantity of base, expressed in milligrams of potassium hydroxide, that is required to neutralize the acidic constituents in 1 g of sample.

Acid sludge

The residue left after treating petroleum oil with sulfuric acid for the removal of impurities. It is a black, viscous substance containing the spent acid and impurities.

Acid treating

A refining process in which unfinished petroleum products, such as gasoline, kerosene, and lubricating oil stocks, are contacted with sulfuric acid to improve their color, odor, and other properties **Acidity**

In lubricants, acidity, denotes the presence of acid-type constituents whose concentration is usually defined in terms of total acid number. The constituents vary in nature and may or may not markedly influence the behavior of the lubricant.

Actuator

A device used to convert fluid energy into mechanical motion.

Additive

A chemical substance added to a petroleum product to impart or improve certain properties. Common petroleum product additives are: antifoam agent, anti-wear additive, corrosion inhibitor, demulsifier, detergent, Dispersent, emulsifier, EP additive, oiliness agent, oxidation inhibitor, pour point depressant, rust inhibitor, tackiness agent, viscosity index (VI.) improvers.

Additive level

The total percentage of all additives in an oil - (Expressed in % of mass (weight) or % of volume) **Additive stability**

The ability of additives in the fluid to resist changes in their performance during storage or use.

Adhesion

The property of a lubricant that causes it to cling or adhere to a solid surface.

Adhesive wear

Is often referred to as galling, scuffing, scoring, or seizing. It happens when sliding surfaces contact one another, causing fragments to be pulled from one surface and to adhere to the other.

Adsorbent filter

A filter medium primarily intended to hold soluble and insoluble contaminants on its surface by molecular adhesion.

Adsorption

Adhesion of the molecules of gases, liquids, or dissolved substances to a solid surface, resulting in relatively high concentration of the molecules at the place of contact; e.g. the plating out of an anti-wear additive on metal surfaces.

Adsorptive filtration

The attraction to, and retention of particles in, a filter medium by electrostatic forces, or by molecular attraction between the particles and the medium. **Aeration**

The state of air being suspended in a liquid such as a lubricant or hydraulic fluid. **Agglomeration**

The potential of the system for particle attraction and adhesion.

AGMA lubricant numbers

AGMA specification covering gear lubricants. The viscosity ranges of the AGMA numbers (or grades) conform to the International Standards Organization (ISO) viscosity classification system (see ISO viscosity classification system).

Air Bleeder

A device for removal of air from a hydraulic fluid line.

Air Breather

A device permitting air movement between atmosphere and the component in/on which it is installed.

Air entrainment

The incorporation of air in the form of bubbles as a dispersed phase in the bulk liquid. Air may be entrained in a liquid through mechanical means and/or by release of dissolved air due to a sudden change in environment. The presence of entrained air is usually readily apparent from the appearance of the liquid (i.e., bubbly, opaque, etc.) while analysts can only determine dissolved air.

Air motor

A device that converts compressed gas into mechanical force and motion. It usually provides rotary mechanical motion.

Air, Compressed

Air at any pressure greater than atmospheric pressure.

Air, free

Air at ambient temperature, pressure, relative humidity, and density.

Air/Oil Systems

A lubrication system in which small measured quantities of oil are introduced into an air/oil mixing device which is connected to a lube line that terminates at a bearing, or other lubrication point. The air velocity transports the oil along the interior walls of the lube line to the point of application. These systems provide positive air pressure within the bearing housing to prevent the ingress of contaminants, provide cooling air flow to the bearing, and perform the lubrication function with a continuous flow of minute amounts of oil.

Air-Gap solenoid

A solenoid that is sealed to prevent leakage of the liquid into the plunger cavity **Alkali**

Any substance having basic (as opposed to acidic) properties. In a restricted sense it is applied to the hydroxides of ammonium, lithium, potassium and sodium. Alkaline materials in lubricating oils neutralize acids to prevent acidic and corrosive wear in internal combustion engines.

Almen EP lubricant tester

A journal-bearing machine used for determining the load-carrying capacity or Extreme Pressure properties (EP) of gear lubricants.

Aluminum alloy

White particles that indicate wear of aluminum component such as a casing wall. **Ambient**

temperature

Temperature of the area or atmosphere around a process, (not the operating temperature of the process itself).

Amp

Ampere

Analytical Ferrography

The magnetic precipitation and subsequent analysis of wear debris from a fluid sample as this approach involves passing a volume of fluid over a chemically treated microscope slide, which is supported over a magnetic field. Permanent magnets are arranged in such a way as to create varying field strength over the length of the substrate. This varying strength causes wear debris to precipitate in a distribution with respect to size and mass over the Ferrogram. Once rinsed and fixed to the substrate, this debris deposit serves as an excellent media for optical analysis of the composite wear particulates.

Anhydrous

Devoid of water.

Aniline point

The minimum temperature for complete miscibility of equal volumes of aniline and the sample under test ASTM Method D611. A product of high aniline point will be low in aromatics and naphthenes and, therefore, high in paraffin's. Aniline point is often specified for spray oils, cleaning solvents, and thinners, where effectiveness depends upon aromatic content. In conjunction with API gravity, the aniline point may be used to calculate the net heat of combustion for aviation fuels.

ANSI

American National Standards Institute

Anti-foam agent

One of two types of additives used to reduce foaming in petroleum products: silicone oil to break up large surface bubbles and various kinds of polymers that decrease the amount of small bubbles entrained in the oils.

Anti-friction bearing

A rolling contact type bearing in which the rotating or moving member is supported or guided by means of ball or roller elements. Does not mean without friction.

Anti-oxidants

Prolong the induction period of base oil in the presence of oxidizing conditions and catalyst metals at elevated temperatures. The additive is consumed and degradation products increase not only with increasing and sustained temperature, but also with increases in mechanical agitation or turbulence and contamination **Antistatic additive**
An additive that increases the conductivity of a hydrocarbon fuel to hasten the dissipation of electrostatic charges during high-speed dispensing, thereby reducing the fire/explosion hazard.

Anti-wear additives

Improve the service life of tribological elements operating in the boundary lubrication regime. Anti-wear compounds (for example, ZDDP and TCP) start decomposing at 90 degrees to 100 degrees C and even at a lower temperature if water (25 to 50 ppms) is present.

API (American Petroleum Institute)

A trade association of petroleum producers, refiners, marketers, and transporters, organized for the advancement of the petroleum industry by conducting research, gathering and disseminating information, and maintaining cooperation between government and the industry on all matters of mutual interest.

API engine service categories

Gasoline and diesel engine oil quality levels established jointly by API, SAE, and ASTM, and sometimes called SAE or API/SAE categories; formerly called API Engine Service Classifications.

API gravity

A gravity scale established by the American Petroleum Institute and in general use in the petroleum industry, the unit being called "the A.P.I. degree." This unit is defined in terms of specific gravity as follows:

Apparent viscosity

The ratio of shear stress to rate of shear of a non-Newtonian fluid such as lubricating grease, or a multi-grade oil, calculated from Poiseuille's equation and measured in poises. The apparent viscosity changes with changing rates of shear and temperature and must, therefore, be reported as the value at a given shear rate and temperature (ASTM Method D 1092).

Aqueous decontamination

Removal of a chemical or biological hazard with a water-base solution

Aromatic

Derived From, or characterized by, the presence's of the benzene ring.

ARP

Aeronautical Recommended Practice

Ash

A measure of the amount of inorganic material in lubricating oil. Determined by burning the oil and weighing the residue. Results expressed as percent by weight.

ASLE

American Society of Lubrication Engineers: Changed now to Society of Tribologist and Lubrication Engineers (STLE).

ASME

Asperities

Microscopic projections on metal surfaces resulting from normal surface-finishing processes. Interference between opposing asperities in sliding or rolling applications is a source of friction, and can lead to metal welding and scoring. Ideally, the lubricating film between two moving surfaces should be thicker than the combined height of the opposing asperities.

ASTM

American Society for Testing Materials

ASTM D2670 Pin and V-Block Test

ASTM Test Method D2670 is for measuring the anti-wear properties of liquid lubricants. The load is applied to the jaws and maintained by a toothed wheel. The wear is a function of the number of the tooth, which needs to be engaged to keep the load constant for a fixed time.

ASTM D5302 Sequence VE

ASTM Test Method D 5302, the Sequence VE gasoline engine test, has been correlated with vehicles used in

ASTM D5533 Sequence IIIF

ASTM Test Method D 5533, the Sequence IIIE gasoline engine test, has been correlated with vehicles used in high-temperature service prior to 1988, particularly with regard to oil thickening and valve train wear.

ATM

Atmosphere

Atomic absorption spectroscopy

Measures the radiation absorbed by chemically unbound atoms by analyzing the transmitted energy relative to the incident energy at each frequency. The procedure consists of diluting the fluid sample with methyl isobutyl ketone (MIBK) and directly aspirating the solution. The actual process of atomization involves reducing the solution to a fine spray, dissolving it, and finally vaporizing it with a flame. The vaporization of the metal particles depends upon their time in the flame, the flame temperature, and the composition of the flame gas. The spectrum occurs because atoms in the Vapor State can absorb radiation at certain well-defined characteristic wavelengths. The wavelength bands absorbed are very narrow and differ for each element. In addition, the absorption of radiant energy by electronic transitions from ground to excited state is essentially and absolute measures of the number of atoms in the flame and is, therefore, the concentration of the element in a sample.

Atomization

The conversion of a liquid into a spray of very fine droplets.

Automatic Transmission Fluid (ATF)

Fluid for automatic hydraulic transmissions, in motor vehicles.

Axial-load bearing

A bearing in which the load acts in the direction of the axis of rotation.

Babbitt

A soft, white, non-ferrous alloy bearing material composed principally of copper, antimony, tin and lead.

Background contamination

The total of the extraneous particles, which are introduced in the process of obtaining, storing, moving, transferring and analyzing a fluid sample.

Bacteria

Microorganisms often composed of a single cell.

Bactericide

Additive included in the formulations of water-mixed cutting fluids to inhibit the growth of bacteria promoted by the presence of water, thus preventing odors that can result from bacterial action.

Baffle

Devices to prevent direct fluid flow or impingement on a surface.

Ball bearing

An anti-friction rolling type bearing containing rolling elements in the form of balls.

Barrel

A unit of liquid volume of petroleum oils equal to 42 U.S. gallons or approximately 35 Imperial gallons.

Base

A material, which neutralizes acids. An oil additive containing colloiddally dispersed metal carbonate, used to reduce corrosive wear.

Base number

The amount of acid, expressed in terms of the equivalent number of milligrams of potassium hydroxide, required in neutralize all basic constituents present in 1 g of sample

Base Oil

Base oil is a base stock or blend of base stocks used in API-licensed engine oil.

Base stock

The base fluid, usually a refined petroleum fraction or a selected synthetic material, into which additives are blended to produce, finished lubricants.

Batch

Any quantity of material handled or considered as a “unit” in processing. I.e., any sample taken from the same ‘batch’ will have the same properties and/or qualities.

Bearing

A support or guide by means of which a moving part such as a shaft or axle is positioned with respect to the other parts of a mechanism. **Bellows seal**

A type of mechanical seal which utilizes bellows, for providing secondary sealing and spring-type loading.

Bernoulli’s theory

If no work is done on or by a flowing, frictionless liquid, its energy, due to pressure and velocity, remains constant at all points along the streamline.

Beta Rating

The method of comparing a filter performance based on efficiency. This is done using the Multi-Pass Test, which counts the number of particles of a given size before and after fluid passes through a filter.

Beta-Ratio

The ratio of the number of particles greater than a given size in the influent fluid to the number of particles greater than the same size in the effluent fluid, under specified test conditions (see "Multi-Pass Test").

Bevel Gear

A straight-toothed gear with the teeth cut on sloping faces and the gear shafts at an angle (normally a right angle)

Biocides

Additive designed to inhibit the growth of microorganisms in liquids

Biodegradation

The chemical breakdown of materials by living organisms in the environment. The process depends on certain microorganisms, such as bacteria, yeast, and fungi, which break down molecules for sustenance. Certain chemical structures are more susceptible to microbial breakdown than others; vegetable oils, for example, will biodegrade more rapidly than petroleum oils. Most petroleum products typically will completely biodegrade in the environment within two months to two years.

Bitumen

Also called asphalt or tar, bitumen is the brown or black viscous residue from the vacuum distillation of crude petroleum. It also occurs in nature as asphalt "lakes" and "tar sands." It consists of high molecular weight hydrocarbons and minor amounts of sulfur and nitrogen compounds.

Black oils

Lubricants containing asphalt type materials, which impart extra adhesiveness, that are used for open gears and steel cables.

Bleeding

The separation of some of the liquid phase from a grease

Blending

The process of mixing lubricants or components for the purpose of obtaining the desired physical and/or chemical properties (see compounding)

Blow-by

Passage of unburned fuel and combustion gases past the piston rings of internal combustion engines, resulting in fuel dilution and contamination of the crankcase oil.

Boiling point

The temperature at which a substance boils, or is converted into vapor by bubbles forming within the liquid; it varies with pressure

Boiling range

For a mixture of substances, such as a petroleum fraction, the temperature interval between the initial and final boiling points.

Bomb Oxidation

A test for the oxidation stability of a product obtained by sealing it in a closed container with oxygen under pressure. The drop in pressure of the oxygen is a measure of the amount of oxidation that has occurred.

Boundary lubrication

Form of lubrication between two rubbing surfaces without development of a full-fluid lubricating film. Boundary lubrication can be made more effective by including additives in the lubricating oil that provide a stronger oil film, thus preventing excessive friction and possible scoring. There are varying degrees of boundary lubrication, depending on the severity of service. For mild conditions, oiliness agents may be used; by plating out on metal surfaces in a thin but durable film, oiliness agents prevent scoring under some conditions that are too severe for a straight mineral oil. Compounded oils, which are formulated with polar fatty oils, are sometimes used for this purpose. Anti-wear additives are commonly used in more severe boundary lubrication applications. The more severe cases of boundary lubrication are defined as extreme pressure conditions; they are met with lubricants containing EP additives that prevent sliding surfaces from fusing together at high local temperatures and pressures.

Boyle's law

The absolute pressure of a fixed mass of gas varies inversely as the volume, provided the temperature remains constant.

Breakdown maintenance

Maintenance performed after a machine has failed to return it to an operating state.

Bridging

A condition of filter element loading in which contaminant spans the space between adjacent sections of a filter element, thus blocking a portion of the useful filtration. **Bright stock**

A heavy residual lubricant stock with low pour point, used in finished blends to provide good bearing film strength, prevent scuffing, and reduce oil consumption. Usually identified by its viscosity, SUS at 210°F or cSt at 100°C.

Brinelling

Permanent deformation of the bearing surfaces where the rollers (or balls) contact the races. Brinelling results from excessive load or impact on stationary bearings. It is a form of mechanical damage in which metal is displaced or upset without attrition.

Brookfield viscosity

Apparent viscosity in cP determined by Brookfield viscometer, which measures the torque, required in rotating a spindle at a constant speed in oil, at a given temperature. Basis for ASTM Method D 2983; used for measuring low temperature viscosity of lubricants.

BTU

British thermal Unit: The amount of heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit.

Bubble point

The differential gas pressure at which the first steady stream of gas bubbles is emitted from a wetted filter element under specified test conditions. **Built-in-dirt**

Material passed into the effluent stream composed of foreign materials incorporated into the filter medium.

Bulk modulus (of elasticity)

A ratio of normal stress to a change in volume: A term used in determining the compressibility of a fluid. Data for petroleum products can be found in the International Critical Tables.

Burst pressure rating

The maximum specified inside-out differential pressure that can be applied to a filter element without outward structural or filter-medium failure.

Bushing

A short, externally threaded connector with a smaller size internal thread.

Bypass Filtration

A system of filtration in which only a portion of the total flow of a circulating fluid system passes through a filter at any instant or in which a filter having its own circulating pump operates in parallel to the main flow.

Bypass valve (Relief valve)

A valve mechanism that assures system fluid flow when a preselected differential pressure across the filter element is exceeded; the valve allows all or part of the flow to bypass the filter element. **C or cent**

Centigrade

CAFE

Corporate Average Fuel Economy

Cams

Eccentric shafts used in most internal combustion engines to open and close valves.

Capacity

The amount of contaminants a filter will hold before an excessive pressure drop is caused. Most filters have bypass valves, which open, when a filter reaches its rated capacity. **Capillarity**

A property of a solid-liquid system manifested by the tendency of the liquid in contact with the solid to rise above or fall below the level of the surrounding liquid; this phenomenon is seen in a small-bore (capillary) tube.

Capillary Viscometer

A viscometer, in which the oil flows through a capillary tube.

Carbon

A non-metallic element - No. 6 in the periodic table: Diamonds and graphite are pure forms of carbon. Carbon is a constituent of all organic compounds. It also occurs in combined form in many inorganic substances; i.e., carbon dioxide, limestone, etc.

Carbon (deposit)

Solid black residue in piston grooves which can interfere with piston ring movement leading to wear and/or loss of power.

Carbon residue

Cooked material remaining after oil has been exposed to high temperatures under controlled conditions.

Carbon Type

The distinction between paraffinic, naphthenic, and aromatic molecules: In relation to lubricant base stocks, the predominant type present.

Carbonyl iron powder

A contaminant, which consists of up to 99.5% pure iron, spheres.

Carcinogen

A cancer-causing substance: Certain petroleum products are classified as potential carcinogens OSHA criteria. Suppliers are required to identify such products as potential carcinogens on package labels and Material Safety Data Sheets.

Cartridge seal

A completely self-contained assembly including seal, gland, sleeve, mating ring, etc., usually needing no installation measurement.

Case drain filter

A filter located in a line conducting fluid from a pump or motor housing to reservoir.

Case drain line

A line conducting fluid from a component housing to the reservoir.

Catalyst

A substance that initiates or increases the rate of a chemical reaction, without itself, being used up in the process.

Catalytic converter

An integral part of vehicle emission control systems since 1975. Oxidizing converters remove hydrocarbons and carbon monoxide (CO) from exhaust gases, while reducing converters control nitrogen oxide (NOx) emissions. Both use noble metal (platinum, palladium or rhodium) catalysts that can be "poisoned" by lead compounds in the fuel or lubricant.

Catastrophic failure

Sudden, unexpected failure of a machine resulting in considerable cost and downtime.

Caustic

A highly alkaline substance, such as sodium hydroxide.

Cavitation

Formation of an air or vapor pocket (or bubble), due to lowering of pressure in a liquid. Often as a result of a solid body, such as a propeller or piston, moving through the liquid; also, the pitting or wearing away of a solid surface as a result of the collapse of a vapor bubble. Cavitation can occur in a hydraulic system as a result of low fluid levels that draw air into the system, producing tiny bubbles that expand explosively at the pump outlet, causing metal erosion and eventual pump destruction.

Cavitation erosion

A material-damaging process, which occurs as a result of vaporous Cavitation: "Cavitation" refers to the occurrence or formation of gas- or vapor- filled pockets in flowing liquids due to the hydrodynamic generation of low pressure (below atmospheric pressure). This damage results from the hammering action when Cavitation bubbles implode in the flow stream. Ultra-high pressures caused by the collapse of the vapor bubbles produce deformation, material failure and, finally, erosion of the surfaces.

cc

Cubic

centimeter

Cellulose

Media

A filter material made from plant fibers. Because cellulose is a natural material, its fibers are rough in texture and vary in size and shape. Compared to synthetic media, these characteristics create a higher restriction to the flow of fluids.

Centi

Hundredth

Centipoise (cP)

A unit of absolute viscosity: 1 Centipoise = 0.01 poise.

Centipoises

Centistoke (cst): A unit of kinematic viscosity. 1 Centistoke = 0.01 stoke **Centralized**

lubrication

A system of lubrication: In which a metered amount of lubricant or lubricants for the bearing surfaces of a machine or group of machines are supplied from a central location.

Centrifugal separator

A separator that removes immiscible fluid and solid contaminants that have a different specific gravity than the fluid being purified by accelerating the fluid mechanically in a circular path and using the radial acceleration component to isolate these contaminants.

cfm

Cubic feet per minute

Channeling

The phenomenon observed among gear lubricants and greases when they thicken due to cold weather or other causes, to such an extent that a groove is formed through which the part to be lubricated moves without actually coming in full contact with the lubricant. A term used in percolation filtration; may be defined as, a preponderance of flow through certain portions of the clay bed.

Chemical stability

The tendency of a substance or mixture to resist chemical change.

Chip control (grit control, last-chance) filter

A filter intended to prevent only large particles from entering a component immediately downstream.

Chlorinated wax

Certain solid hydrocarbons treated with chlorine gas to form straight-chain hydrocarbons with a relatively high chlorine component. Chlorinated waxes are used primarily as polyvinyl chloride plasticizers, extreme pressure additives for lubricants, and formulation components for many cutting fluids

Chromatography

An analytical technique whereby a complex substance is adsorbed on a solid or liquid substrate and progressively eluted by a flow of a substance (the eluant) in which the components of the substance under investigation are differentially soluble. The eluant can be a liquid or a gas. When the substrate is filter paper and the eluant a liquid, a chromatogram of colored bands can be developed by use of indicators. For gas chromatography, electronic detectors are normally used to indicate passage of the various components from the system.

Circulating Header System

A lubrication system having isolated lube zones wherein the lube pump runs continuously and circulates oil through the header, a return filter and back to tank during the idle period. When lubrication is required, a normal open solenoid valve in the return loop is actuated, allowing pump pressure to build. The zone valves are then sequentially opened to provide lubricant to the individual zones. Oil dispensed to the friction points is not reused; therefore, the system is a terminating type.

Circulating lubrication

A system of lubrication: In which the lubricant, after having passed through a bearing or group of bearings, is recirculated by means of a pump.

Circulating oil

A lubrication system wherein the oil pump runs continuously and circulates oil to the friction points on a continuous basis. The oil is drained back to tank, filtered, cooled as required and reused.

Circulating System

A lubricating system: In which oil is recirculated from a central sump to the parts requiring lubrication, and then returned to the sump.

Clay filtration

A refining process using fuller's earth (activated clay), bauxite or other mineral to absorb minute solids from lubricating oil, as well as remove traces of water, acids, and polar compounds.

Clean

100 particles >10 micron per milliliter

Clean room

A facility or enclosure in which air content and other conditions (such as temperature, humidity, and pressure) are controlled and maintained at a specific level by special facilities and operating processes and by trained personnel.

Cleanable

A filter element which, when loaded, can be restored by a suitable process, to an acceptable percentage of its original dirt capacity.

Cleanliness level (CL)

A measure of relative freedom from contaminants.

Clearance bearing

A journal bearing, in which the radius of the bearing surface is greater than the radius of the journal surface.

Cleveland Open Cup (COC)

A flash point test in which the surface of the sample is completely open to the atmosphere, and which is therefore relatively insensitive to small traces of volatile contaminants.

Cloud point

The temperature at which, waxy crystals in an oil or fuel form a cloudy appearance. **cm**

Centimeter

Coalescor

A separator that divides a mixture or emulsion of two immiscible liquids, using the interfacial tension between the two liquids, and the difference in wetting of the two liquids on a particular porous medium.

Coefficient of friction

The number obtained by dividing the friction force resisting motion between two bodies by the normal force pressing the bodies together.

Cohesion

That property of a substance, that causes it to resist being pulled apart by mechanical means.

Coking

The undesirable accumulation of carbon (coke) deposits in the internal combustion engine or in a refinery plant. The process of distilling a petroleum product to dryness

Cold cranking simulator (CCS)

An intermediate shear rate viscometer that predicts the ability of oil to permit satisfactory cranking speed to be developed in a cold engine.

Collapse

Inward structural failures of a filter element, which can occur due to abnormally high pressure, drop (differential pressure) or resistance to flow. **Collapse pressure**

The minimum differential pressures that an element is designed to withstand without permanent deformation.

Complex grease

Lubricating grease thickened by a complex soap consisting of a normal soap and a complexing agent.

Compound

(1) Chemically speaking, a distinct substance formed by the combination of two or more elements in definite proportions by weight and possessing physical and chemical properties different from those of the combining elements. (2) In petroleum processing, generally connotes fatty oils and similar materials foreign to petroleum added to lubricants to impart special properties.

Compounded oil

A petroleum oil to which has been added other chemical substances.

Compounding

The addition of fatty oils and similar materials to lubricants to impart special properties: Lubricating oils to which such materials have been added are known as compounded oils.

Compressibility

A compound that enhances some property, or imparts some new property to, the base fluid: In some hydraulic fluid formulations, the additive volume may constitute as much as 20 percent of the final composition. The more important types of additives include anti-oxidants, anti-wear additives, corrosion inhibitors, viscosity index improvers, and foam suppressants.

Compression ratio

In an internal combustion engine, the ratio of the volume of combustion space at bottom dead center to that at top dead center.

Compressor

A device which converts mechanical forces and motion into pneumatic fluid power.

Consistency

The degree to which a semisolid material such as grease resists deformation: (See ASTM designation D 217.) Sometimes used qualitatively to denote viscosity of liquids.

Contaminant

Any foreign or unwanted substance, that can have a negative effect on system operation, life or reliability.

Contaminant (Dirt, ACFTD) capacity

The weight of a specified artificial contaminant that must be added to the influent to produce a given differential pressure across a filter at specified conditions. Used as an indication of relative service life.

Contaminant Failure

Any loss of performance due to the presence of contamination: Two basic types of contamination failure are: Perceptible

Contaminant lock

A particle or fiber-induced jam caused by solid contaminants.

Contamination control

A broad subject which applies to all types of material systems, (including both biological and engineering). It is concerned with planning, organizing, managing, and implementing all activities required to determine, achieve and maintain a specified contamination level.

Coolant

A fluid used to remove heat. See Cutting fluid.

Copper strip corrosion

The gradual eating away of copper surfaces as the result of oxidation or other chemical action. Acids or other corrosive agents cause it.

Core

The internal duct and filter media support.

Corrosion

The decay and loss of a metal, due to a chemical reaction between the metal and its environment: It is a transformation process in which the metal passes from its elemental form to a combined (or compound) form.

Corrosion inhibitor

Additive for protecting lubricated metal surfaces against chemical attack by water or other contaminants. There are several types of corrosion inhibitors. Polar compounds wet the metal surface preferentially, protecting it with a film of oil. Other compounds may absorb water by incorporating it in a water-in-oil emulsion so that only the oil touches the metal surface. Another type of corrosion inhibitor combines chemically with the metal to present a non-reactive surface. **Coupling**

A straight connector for fluid lines.

Coupling, quick disconnect

A coupling, which can quickly join or separate lines.

Cracking

The processes whereby large molecules are broken down by the application of heat and pressure to form smaller molecules.

Crankcase oil

Lubricant used in the crankcase of the internal combustion engine.

Crown

The top of the piston in an internal combustion engine above the fire ring, exposed to direct flame impingement. **Cryogenics**

The branch of physics relating to the production and effects of very low temperatures.

Cutting fluid

Any fluid applied to a cutting tool to assist in the cutting operation by cooling, lubricating or other means.

Cutting Oil

A lubricant used in machining operations for lubricating the tool in contact with the work piece, and to remove heat. The fluid can be petroleum based, water based, or an emulsion of the two. The term “emulsifiable cutting oil” normally indicates a petroleum-based concentrate to which water is added to form an emulsion, which is the actual cutting fluid.

Cycle

A single complete operation consisting of progressive phases starting and ending at the neutral position.

Cylinder

A device, which converts fluid power into linear mechanical force and motion: It usually consists of a moveable element such as a piston and piston rod, plunger rod, plunger or ram, operating within a cylindrical bore.

Cylinder oil

A lubricant for independently lubricated cylinders, such as those of steam engines and air compressors; also for lubrication of valves and other elements in the cylinder area. Steam cylinder oils are available in a range of grades with high viscosities to compensate for the thinning effect of high temperatures; of these, the heavier grades are formulated for super-heated and high-pressure steam, and the less heavy grades for wet, saturated, or low-pressure steam. Some grades are compounded for service in excessive moisture; see compounded oil. Cylinder oils lubricate on a once-through basis.

Deaerator

A separator, that removes air from the system fluid through the application of bubble dynamics.

Degas

Removing air from a liquid, usually by ultrasonic and/or vacuum methods. **Degradation**

The progressive failure, of a machine or lubricant.

Dehydrator

A separator that removes water from the system fluid.

Delamination wear

A complex wear process where a machine surface is peeled away or otherwise removed by forces of another surface acting on it in a sliding motion.

Demulsibility

The ability of a fluid that is insoluble in water, to separate from water, with which it may be mixed in the form of an emulsion.

Demulsifier

An additive that promotes oil-water separation in lubricants that are exposed to water or steam **Density**

The mass of volume of a substance: Its numerical value varies with the units used.

Deplete

The depletion of additives expressed as an approximate percentage.

Deposits

Oil-insoluble materials that result from oxidation and decomposition of lube oil and contamination from external sources and engine blow-by. These can settle out on machine or engine parts. Examples are sludge, varnish, lacquer and carbon.

Depth filter

A filter medium, that retains contaminants primarily within tortuous passages.

Dermatitis

Inflammation of the skin: Repeated contact with petroleum products can be a cause.

Desorption

Opposite of absorption or adsorption: In filtration, it relates to the downstream release of particles previously retained by the filter.

Detergent

In lubrication, either an additive or a compounded lubricant having the property of keeping insoluble matter in suspension thus preventing its deposition where it would be harmful. A detergent may also redisperse deposits already formed.

Detergent oil

Lubricating oil, possessing special sludge-dispersing properties usually conferred on the oil by the incorporation of special additives. Detergent oils hold formed sludge particles in suspension and thus promote cleanliness especially in internal-combustion engines. However detergent oils do not contain “detergents” such as those used for cleaning of laundry or dishes. Also detergent oils do not clean already “dirty” engines, but rather keep in suspension the sludge that petroleum oil forms so that the engine remains cleaner for longer period. The formed sludge particles are either filtered out by Oil Filters or drained out when oil is changed.

Dewaxing

Removal of wax from a base oil in order to reduce the pour point.

Dielectric Strength

A measure of the ability of an insulating material, to withstand electric stress (voltage) without failure. Fluids with high dielectric strength (usually expressed in volts or kilovolts) are good electrical insulators. (ASTM Designation D 877.)

Differential pressure indicator

An indicator, which signals the difference in pressure, between any two points of a system or a component.

Dirt capacity (dust capacity) (contaminant capacity)

The weight of a specified artificial contaminant that must be added to the influent to produce a given differential pressure across a filter at specified conditions. Used as an indication of relative service life.

Dispersant

In lubrication, a term usually used interchangeably with detergent. An additive, usually nonmetallic (“ashless”), which keeps fine particles of insoluble materials in a homogeneous solution. Hence, particles are not permitted to settle out and accumulate.

Disposable

A filter element intended to be discarded and replaced after one service cycle.

Dissolved air

Air, which is dispersed in a fluid to form a mixture.

Dissolved gases

Those gases that enter into solution with a fluid and are neither free nor entrained gases.

Dissolved water

Water, which is dispersed in the fluid to form a mixture.

Distillation method (ASTM D-95)

A method involving distilling the fluid sample in the presence of a solvent that is miscible in the sample but immiscible in water. The water distilled from the fluid is condensed and segregated in a specially designed receiving tube or trays graduated too directly indicate the volume of water distilled.

Double seal

Two mechanical seals designed to permit a liquid or gas barrier fluid between the seals mounted back-to-back or face-to-face.

Drag

The resistance to movement caused by oil viscosity.

Dropping point

In general, the dropping point is the temperature at which the grease passes from a semisolid to a liquid state. This change in state is typical of greases containing conventional soap thickeners. Greases containing thickeners other than conventional soaps may, without change in state, separate oil.

Drum

A container with a capacity of, 55 U.S. gallons.

Dry lubrication

A situation when moving surfaces has no liquid lubricant between them.

Dry sump

An engine design in which oil is not retained in a pan beneath the crankshaft thus permitting splash lubrication. There may be a remote sump from which oil is recirculated, or there may be a total loss system.

Dual-Line system

A positive displacement terminating (oil, or grease) lubrication system that employs two main lines supplied from a pump connected to a 4-way (reversing) valve. Pressure in one main line (while the other is open to tank) causes the measuring piston(s) in the dual-line valve(s) to stroke in one direction dispensing lubricant to one group of lube points. Switching the 4-way (reversing) valve directs pump flow to the second main line and opens the first main line to tank. This allows pressure to build in the second main line causing the dual-line valve(s) measuring piston(s) to stroke back to their original position dispensing lubricant to a second group of lube points. The system is a parallel type and each dual-line valves operates independently of any other in the system.

Duplex filter

An assembly of two filters: With valving for the selection of either or both filters. **Dynamic**

seal

A seal, that moves due to axial or radial movement of the unit.

Effluent

The fluid leaving a component.

Elastohydrodynamic lubrication

In rolling element bearings, the elastic deformation of the bearing (flattening) as it rolls, under load, in the bearing race. This momentary flattening improves the hydrodynamic lubrication properties by converting point or line contact to surface-to-surface contact.

Elastomer

Material, both natural and synthetic, used in making a wide variety of products, such as seals and hoses. In oil seals, an elastomer's chemical composition is a factor in determining its compatibility with a lubricant.

Electrical insulating oil

High-quality oxidation-resistant oil refined to give long service as a dielectric and coolant for electrical equipment, most commonly transformers. Insulating oil must resist the effects of elevated temperatures, electrical stress, and contact with air, which can lead to sludge formation and loss of insulation properties. It must be kept dry, as water is detrimental to dielectric strength – the minimum voltage required to produce an electric arc through an oil sample, as measured by test method ASTM D 877.

Electrostatic separator

A separator that removes contaminant from dielectric fluids by applying an electrical charge to the contaminant that is then attracted to a collection device of different electrical charge.

Element (Cartridge)

The porous device, that performs the actual process of filtration.

Emission spectrometer

Works on the basis that atoms of metallic and other particular elements emit light at characteristic wavelengths when they are excited in a flame, arc, or spark. Excited light is directed through an entrance slit in the spectrometer. This light penetrates the slit, falls on a grate, and is dispersed and reflected. The spectrometer is calibrated by a series of standard samples containing known amounts of the elements of interest. By exciting these standard samples, an analytical curve can be established which gives the relationship between the light intensity and its concentration in the fluid.

Emulsibility

The ability of a non-water-soluble fluid to form an emulsion with water.

Emulsifier

Additive that promotes the formation of a stable mixture, or emulsion, of oil and water. Common emulsifiers are metallic soaps, certain animal and vegetable oils, and various polar compounds.

Emulsion

Intimate mixture of oil and water, generally of a milky or cloudy appearance. Emulsions may be of two types: oil-in-water (where water is the continuous phase) and water-in-oil (where water is the discontinuous phase).

End cap

A ported, or closed cover for the end of a filter element.

Engine deposits

Hard or persistent accumulation of sludge, varnish and carbonaceous residues due to blow-by of unburned and partially burned fuel, or the partial breakdown of the crankcase lubricant. Water, from the condensation of combustion products, carbon residues, from fuel or lubricating oil additives, dust and metal particles also contributes.

Entrained air

A mechanical mixture of air bubbles having a tendency to separate from the liquid phase.

Environmental contaminant

All material and energy present in and around an operating system, such as dust, air moisture, chemicals, and thermal energy.

EP (Extreme Pressure) lubricants

Lubricants that impart to rubbing surfaces the ability to carry appreciably greater loads than would be possible with ordinary lubricants without excessive wear or damage.

EP oil

Lubricating oil formulated to withstand extreme pressure (EP) operating conditions.

Erosion

The progressive removal of a machine surface, by Cavitation, or by particle impingement at high velocities.

Externally pressurized seal

A seal that has pressure acting on the seal parts from an external independent source of supply.

Extreme pressure (EP) additive

Lubricant additive, that prevents sliding metal surfaces from seizing under conditions of extreme pressure. At the high local temperatures associated with metal-to-metal contact, an EP additive combines chemically with the metal to form a surface film that prevents the welding of opposing asperities, and the consequent scoring that is destructive to sliding surfaces under high loads. Reactive compounds of sulfur, chlorine, or phosphorus are used to form these inorganic films.

Fabrication integrity point

The differential gas pressure at which the first stream of gas bubbles is emitted from a wetted filter element under standard test conditions.

Face seal

A device that prevents leakage of fluids along rotating shafts. Sealing is accomplished by a stationary primary seal ring bearing against the face of a mating ring mounted on a shaft. Axial pressure maintains the contact between the seal ring and the mating ring.

False Brinelling

On needle roller bearings, is actually a fretting corrosion of the surface, since the rollers are the I.D. of the bearing. Although its appearance is similar to that of Brinelling, false Brinelling is characterized by attrition of the steel, and the load on the bearing is less than that required producing the resulting impression. It is the result of a combination of mechanical and chemical action that is not completely understood, and occurs when a small relative motion or vibration is accompanied by some loading, in the presence of oxygen. **Fat**

An animal or vegetable oil which will combine with an alkali to saponify and form a soap.

Fatigue chunks

Thick three-dimensional particles exceeding 50 microns indicating severe wear of gear teeth.

Fatigue life

The theoretical number of revolutions (or hours of operation) a bearing will last under a given constant load and speed before the first evidence of fatigue develops on one or more of the components.

Fatigue platelets

Normal particles between 20 and 40 microns found in gear box and rolling element bearing oil samples observed by analytical Ferrography. A sudden increase in the size and quantity of these particles indicates excessive wear. **Fatigued**

A structural failure of the filter medium due to flexing caused by cyclic differential pressure.

Ferrography

An analytical method of assessing machine health by quantifying and examining ferrous wear particles suspended in the lubricant or hydraulic fluid.

Fiber Grease

A grease, with a distinctly fibrous structure, which is noticeable when portions of the grease are pulled apart.

Film strength

Property of a lubricant, that acts to prevent scuffing or scoring of metal parts.

Filter

Any device or porous substance used as a strainer for cleaning fluids by removing suspended matter.

Filter Efficiency

Method of expressing a filter's ability to trap and retain contaminants of a given size.

Filter element

The porous device, which performs the actual process of filtration.

Filter head

An end closure for the filter cases, or bowl that contains one or more ports.

Filter housing

A ported enclosure, that directs the flow of fluid through the filter element.

Filter life test a type of filter capacity test in which a clogging contaminant is added to the influent of a filter, under specified test conditions, to produce a given rise in pressure drop across the filter or until a specified reduction of flow is reached. Filter life may be expressed, as test time required reaching terminal conditions at a specified contaminant addition rate.

Filter media, depth

Porous materials, which primarily retain contaminants, within a tortuous path were performing the actual process of filtration.

Filter media, surface

Porous materials, which primarily retain contaminants, on the influent, face performing the actual process of filtration.

Filtration

The physical or mechanical process of separating insoluble particulate matter from a fluid, such as air or liquid, by passing the fluid through a filter medium that will not allow the particulates to pass through it.

Filtration (Beta) ratio

The ratio, of the number of particles greater than a given size in the influent fluid, to the number of particles greater than the same size in the effluent fluid.

Fire point (Cleveland Open Cup)

The temperature to which a combustible liquid must be heated so that the released vapor will burn continuously when ignited under specified conditions.

Fire-resistant fluid

Lubricant used especially in high-temperature or hazardous hydraulic applications. Three common types of fire-resistant fluids are: (1) water-petroleum oil emulsions, in which the water prevents burning of the petroleum constituent; (2) water-glycol fluids; and (3) non-aqueous fluids of low volatility, such as phosphate esters, silicones, and halogenated hydrocarbon-type fluids.

Flash point (Cleveland Open Cup)

The temperature to which a combustible liquid must be heated to give off sufficient vapor to form momentarily a flammable mixture with air when a small flame is applied under specified conditions. (ASTM Designation D 92.)

Floc Point

The temperature at which wax or solids separate in oil

Flow fatigue rating

The ability of a filter element to resist a structural failure of the filter medium due to flexing caused by cyclic differential pressure.

Flow rate

The volumes, mass, or weight, of a fluid passing through any conductor per unit of time.

Flow, laminar

A flow situation, in which fluid moves in parallel lamina or layers.

Flow, turbulent

A flow situation, in which the fluid particles move in a random manner.

Flowmeter

A device which indicates either flow rate, total flow, or a combination of both.

Fluid

A general classification including liquids and gases.

Fluid compatibility

The suitability of filtration medium and seal materials for service with the fluid involved.

Fluid friction

Friction, due to the viscosity of fluids.

Fluid opacity

Related to the ability of a fluid to pass light.

Fluid power

Energy transmitted and controlled through use of a pressurized fluid.

Fluid, fire resistant

A fluid difficult to ignite which shows little tendency to propagate flame.

Flushing

A fluid circulation process designed to remove contamination from the wetted surfaces of a fluid system.

Foam

An agglomeration of gas bubbles separated from each other by a thin liquid film, which is observed as a persistent phenomenon on the surface of a liquid.

Foam inhibitor

A substance introduced in a very small proportion to a lubricant or a coolant to prevent the formation of foam due to aeration of the liquid, and to accelerate the dissipation of any foam that may form

Foaming

A frothy mixture of air and a petroleum product (e.g., lubricant, fuel oil) that can reduce the effectiveness of the product, and cause sluggish hydraulic operation, air binding of oil pumps, and overflow of tanks or sumps. Foaming can result from excessive agitation, improper fluid levels, air leaks, Cavitation, or contamination with water or other foreign materials. Foaming can be inhibited with an antifoam agent. The foaming characteristics of a lubricating oil can be determined by blowing air through a sample at a specified temperature and measuring the volume of foam, as described in test method ASTM D 892.

Force-feed lubrication

A system of lubrication: In which the lubricant is supplied to the bearing surface under pressure.

Four Ball Tester

This name is frequently used to describe either of two similar laboratory machines, the Four-Ball Wear Tester and the Four-Ball EP Tester. These machines are used to evaluate a lubricant's anti-wear qualities, frictional characteristics or load carrying capabilities. It derives its name from the four 1/2 inch steel balls used as test specimens. Three of the balls are held together in a cup filled with lubricant while the fourth ball is rotated against them.

Free Water

Water droplets or globules in the system fluid that tend to accumulate at the bottom or top of the system fluid depending on the fluid's specific gravity. **Fretting**

Wear phenomena taking place between two surfaces having oscillatory relative motion of small amplitude.

Fretting corrosion

Can take place when two metals are held in contact and subjected to repeated small sliding, relative motions. Other names for this type of corrosion includes wear oxidation, friction oxidation, chafing, and Brinelling.

Friction

The resisting force encountered at the common boundary between two bodies when, under the action of an external force, one body, moves or tends to move relative to the surface of the other.

FTIR = Fourier Transform Infrared Spectroscopy

A test where infrared light absorption is used for assessing levels of soot, sulfates, oxidation, nitro-oxidation, glycol, fuel, and water contaminants.

Full-flow filter

A filter that, under specified conditions, filters all influent flow.

Full-flow filtration

A system of filtration: In which the total flow of a circulating fluid system passes through a filter.

Full-fluid-film lubrication

Presence of a continuous lubricating film sufficient to completely separate two surfaces, as distinct from boundary lubrication. Full-fluid-film lubrication is normally hydrodynamic lubrication, whereby the oil adheres to the moving part and is drawn into the area between the sliding surfaces, where it forms a pressure

FZG test

A German gear test for evaluating EP properties.

Gage

An instrument or device for measuring, indicating or comparing a physical characteristic.

Galling

A form of wear in which seizing or tearing of the gear or bearing surface occurs. **Gasohol**

A blend of 10% anhydrous ethanol, (ethyl alcohol) and 90% gasoline by volume. Used as a motor fuel.

Gear

A machine part, which transmits motion and force by means of successively engaging projections, called teeth. The smaller gear of a pair is called the pinion, the larger, the gear. When the pinion is on the driving shaft, the gear set acts as a speed reducer; when the gear drives, the set acts as a speed multiplier. The basic gear type is the spur gear, or straight-tooth gear, with teeth cut parallel to the gear axis. Spur gears transmit power in applications utilizing parallel shafts. In this type of gear, the teeth mesh along their full length, creating a sudden shift in load from one tooth to the next, with consequent noise and vibration. This problem is overcome by the helical gear, which has teeth cut at an angle to the center of rotation, so that the load is transferred progressively along the length of the tooth from one edge of the gear to the other. When the shafts are not parallel, the most common gear type used is the bevel gear, with teeth cut on a sloping gear face, rather than parallel to the shaft. The spiral bevel gear has teeth cut at an angle to the plane of rotation, which, like the helical gear, reduces vibration and noise. A

hypoid gear resembles a spiral bevel gear, except that the pinion is offset so that its axis does not intersect the gear axis; it is widely used in automobiles between the engine driveshaft and the rear axle. Offset of the axes of hypoid gears introduces additional sliding between the teeth, which, when combined with high loads, requires a high-quality EP oil. A worm gear consists of a spirally grooved screw moving against a tooth wheel; in this type of gear, where the load is transmitted across sliding, rather than rolling surfaces, compounded oils or EP oils are usually necessary to maintain effective lubrication.

Gear oil

A high-quality oil with good oxidation stability, load-carrying capacity, rust protection, and resistance to foaming, for service in gear housings and enclosed chain drives. Specially formulated industrial EP gear oils are used where highly loaded gear sets or excessive sliding action (as in worm gears) is encountered.

Gearbox (gear housing)

A casing for gear sets that transmit power from one rotating shaft to another. A gearbox has a number of functions: it is precisely bored to control gear and shaft alignment, it contains the gear oil, and it protects the gears and lubricant from water, dust, and other environmental contaminants. Gearboxes are used in a wide range of industrial, automotive, and home machinery. Not all gears are enclosed in gearboxes; some are open to the environment and are commonly lubricated by highly adhesive greases.

Generated contaminant

Caused by a deterioration of critical wetted surfaces and materials or by a breakdown of the fluid itself.

GPM

Gallons per minute

Graphite

A crystalline form of carbon having a laminar structure, which is used as a lubricant. It may be of natural or synthetic origin.

Gravimetric analysis

A method of analysis whereby the dry weight of contaminant per unit volume of fluid can be measured showing the degree of contamination in terms of milligrams of contaminant per liter of fluid.

Gravity

See Specific Gravity: API Gravity.

Grease

A lubricant composed of oil or oils thickened with soap, or soaps or other thickener to a semisolid or solid consistency.

Hardness

The resistance of a substance to surface abrasion.

Head

An end closure for the filter case or bowl which contains one or more ports.

Heat exchanger

A device which transfers heat, through a conducting wall from one fluid to another.

Heavy Ends

The portion of a petroleum distillate fraction, which is highest boiling, and therefore distills over last if the temperature, is raised progressively.

Housing

A ported enclosure, which directs the flow of fluid through the filter element.

hp or HP

Horsepower

HVI

High Viscosity Index, typically from 80 to 110 VI units.

Hydraulic Fluid

Fluid serving as the power transmission medium in a hydraulic system. The most commonly used fluids are petroleum oils, synthetic lubricants, oil-water emulsions, and water-glycol mixtures. The principal requirements of a premium hydraulic fluid are proper viscosity, high viscosity index, anti-wear protection (if needed), good oxidation stability, adequate pour point, good Demulsibility, rust inhibition, resistance to foaming, and compatibility with seal materials. Anti-wear oils are frequently used in compact, high-pressure, and capacity pumps that require extra lubrication protection.

Hydraulic motor

A device, which converts hydraulic fluid power, into a mechanical force and motion, by transfer of flow under pressure. It usually provided rotary mechanical motion.

Hydraulic Oil

Oil specially suited for use as either the specific gravity or the API gravity of a liquid.

Hydraulic pump

A device, which converts mechanical, forces and motion into hydraulic fluid power by means of producing flow.

Hydraulic system

A system designed to transmit power through a liquid medium, permitting multiplication of force in accordance with Pascal's law, which stated that "a pressure exerted on a confined liquid is transmitted undiminished in all directions and acts with equal force on all equal areas." Hydraulic systems have six basic components: (1) a reservoir to hold the fluid supply; (2) a fluid to transmit the power; (3) a pump to move the fluid; (4) a valve to regulate pressure; (5) a directional valve to control the flow, and (6) a working component. Such as a cylinder and piston or a shaft rotated by pressurized fluid – to turn hydraulic power into mechanical motion. Hydraulic systems offer several advantages over mechanical systems. They eliminate complicated mechanisms such as cams, gears, and levers. Which are less subject to wear; are usually more easily adjusted for control of speed and force; are easily adaptable to both rotary and liner transmission of power; and can transmit power over long distances and in any direction with small losses.

Hydraulics

Engineering science pertaining to liquid pressure and flow.

Hydrocarbons

Compounds containing only carbon and hydrogen. Petroleum consists chiefly of hydrocarbons.

Hydrodynamic lubrication

A system of lubrication in which the shape and relative motion of the sliding surfaces causes the formation of a fluid film having sufficient pressure to separate the surfaces.

Hydro-Finishing

A process for treating raw extracted base stocks with hydrogen to saturate them for improved stability.

Hydrogenation

In refining, the chemical addition of hydrogen to a hydrocarbon in the presence of a catalyst; a severe form of hydrogen treating. Hydrogenation may be either destructive or non-destructive. In the former case, hydrocarbon chains are ruptured (cracked) and hydrogen is added where the breaks have occurred. In the latter, hydrogen is added to a molecule that is unsaturated with respect to hydrogen. In either case, the resulting products are highly stable. Temperatures and pressures in the hydrogenation process are usually greater than in hydro fining.

Hydrolysis

Breakdown process that occurs in anhydrous hydraulic fluids as a result of heat, water, and metal catalysts (iron, steel, copper, etc.)

Hydrolytic stability

Ability of additives and certain synthetic lubricants to resist chemical decomposition (hydrolysis) in the presence of water.

Hydrometer

An instrument for determining either the specific gravity of a liquid or the API gravity.

Hydrophilic

Compounds with an affinity for water.

Hydrophobic

Compounds, that repel water.

Hydrostatic lubrication

A system of lubrication in which the lubricant is supplied under sufficient external pressure to separate the opposing surfaces by a fluid film.

Hypoid gear lubricant

A gear lubricant having extreme pressure characteristics for use with a hypoid type of gear as in the differential of an automobile.

Hypoid Gears

Gears in which the pinion axis intersects the plane of the ring gear at a point below the ring-gear axle and above the outer edge of the ring gear, or above the ring-gear axle and below the outer edge of the ring gear. **Hz**

Hertz (cycles per second)

ILMA

The Independent Lubricant Manufacturers Association (ILMA) is a trade association of businesses engaged in compounding, blending, formulating, packaging, marketing, and distributing lubricants.

ILSAC

The International Lubricant Standardization and Approval Committee (ILSAC) is a joint committee of AAMA and JAMA members that assists in the development of new minimum oil performance standards.

Image analyzer

A sophisticated microscopic system involving a microscope, a television camera, a dedicated computer, and a viewing monitor similar to a television screen.

Immiscible

Incapable of being mixed without separation of phases. Water and petroleum oil is immiscible under most conditions, although they can be made miscible with the addition of an emulsifier.

Incompatible fluids

Fluids which when mixed in a system, will have a deleterious effect on that system, its components or its operation.

Indicator

A device, which provides external evidence of, sensed phenomena.

Indicator, differential pressure

An indicator, which signals the difference in pressure between two, points, typically between the upstream and downstream sides of a filter element.

Indicator, pressure

An indicator that signals pressure conditions.

Industrial Lubricant

Any petroleum or synthetic-base fluid or grease commonly used in lubricating industrial equipment, such as gears, turbines, and compressors.

Influent

The fluid entering a component.

Infrared (IR) analysis

A form of absorption spectroscopy that identifies organic functional groups present in a used oil sample by measuring their light absorption at specific infrared wavelengths; absorbance is proportional to concentration. The test can indicate additive depletion, the presence of water, hydrocarbon contamination of a synthetic lubricant, oxidation, nitration, and glycol contamination from coolant. Fourier Transform Infrared (FTIR) permits the generation of complex curves from digitally represented data.

Infrared spectra

A graph of infrared energy absorbed at various frequencies in the additive region of the infrared spectrum. The current sample, the reference oil and the previous samples are usually compared.

Infrared spectroscopy

An analytical method using infrared absorption for assessing the properties of used oil and certain contaminants suspended therein. See FTIR.

Ingested contaminants

Environmental contaminant that increases's due to the action of the system or machine.

Ingression level

Particles added per unit of circulating fluid volume.

Inhibitor

Any substance, that slows or prevents such chemical reactions as corrosion or oxidation.

In-line filter

A filter assembly in which the inlet, outlet and filter element axes is in a straight line.

Inside-mounted seal

A mechanical seal located inside the seal chamber with the pumped product's pressure at its O.D.

Insolubles

Particles of carbon or agglomerates of carbon and other material: Indicates deposition or dispersant dropout in an engine. Not serious in a compressor or gearbox unless there has been rapid increase in these particles.

Intensifier

A device, which converts low-pressure fluid power, into higher-pressure fluid power.

Intercooler

A device, which cools a gas, between the compressive steps of a multiple stage compressor.

Interfacial tension (IFT)

The energy per unit area present at the boundary of two immiscible liquids. It is usually expressed in dynes/cm (ASTM Designation D 971.) **ISO**

International Standards Organization, sets viscosity reference scales.
ISO Solid Contaminant Code (ISO 4406)

A code assigned on the basis of the number of particles per unit volume greater than 5 and 15 micrometers in size. Range numbers identify each increment in the particle population throughout the spectrum of levels.
ISO Standard 4021

The accepted procedure for extracting samples from dynamic fluid lines.
ISO viscosity grade

Viscosity of an industrial fluid lubricant at 40 degrees C (104 degrees F) as defined by ASTM Standard Viscosity System for Industrial Fluid Lubricants D 2422. Essentially identical to ISO Standard 3448.
JIC

Joint Industry Conference
Joule

A unit of work: energy, or heat. 1J (joule)=1 Nm (Newton meter).
Journal

That part of a shaft or axle that rotates or angularly oscillates in or against a bearing or about which a bearing rotates or angularly oscillates.
Journal bearing

A sliding type of bearing, having either rotating or oscillatory motion and in conjunction with which a journal operates. In a full or sleeve type journal bearing, the bearing surface is 360° in extent. In a partial bearing, the bearing surface is less than 360° in extent, i.e., 150°, 120°, etc.

Karl Fischer Reagent Method (ASTM D-1744-64)

The standard laboratory test to measure the water content of mineral base fluids. In this method, water reacts quantitatively with the Karl Fischer reagent. This reagent is a mixture of iodine, sulfur dioxide, pyridine, and methanol. When excess iodine exists, electric current can pass between two platinum electrodes or plates. The water in the sample reacts with the iodine. When the water is no longer free to react with iodine, an excess of iodine depolarizes the electrodes, signaling the end of the test.

kg

Kilograms

kHz

Thousand Hertz (cycles per second) **kilo**

Thousand

Kinematic viscosity

The time required for a fixed amount of oil to flow through a capillary tube under the force of gravity. The unit of kinematic viscosity, is the stoke or Centistoke - (1/100 of a stoke.). Kinematic viscosity may be defined as the quotient of the absolute viscosity in Centipoises divided by the specific gravity of a fluid, both at the same temperature.

km

Kilometer

Lacquer

A deposit resulting from the oxidation and polymerization of fuels and lubricants when exposed to high temperatures. Similar to, but harder, than varnish.

Laminar particles

Particles generated in rolling element bearings, which have been flattened out by a rolling contact.

Lead Naphthenate

A lead soap of naphthenic acids: the latter occurring naturally in petroleum.

Light Ends

Low-boiling volatile materials in a petroleum fraction: They are often unwanted and undesirable, but in gasoline the proportion of light ends deliberately included are used to assist low-temperature starting. **Light obscuration**

The degree of light blockage as reflected in the transmitted light impinging on the photodiode.

Lip seal

An elastomeric or metallic seal that prevents leakage in dynamic and static applications, by a scraping or wiping action at a controlled interference between itself and the mating surface.

Liquid

Any substance that flows readily or changes in response to the smallest influence: More generally, any substance in which the force required to produce a deformation depends on the rate of deformation rather than on the magnitude of the deformation.

Lithium Grease

The most common type of grease today, based on lithium soaps.

Load-carrying capacity

Property of a lubricant to form a film on the lubricated surface, which resists rupture under given load conditions. Expressed as maximum load the lubricated system can support without failure or excessive wear.

Load-wear index (LWI)

Measure of the relative ability of a lubricant to prevent wear under applied loads; it is calculated from data obtained from the Four Ball EP Method. Formerly called mean Hertz load.

log

Logarithm (common)

Lubricant

Any substance interposed between two surfaces in relative motion for the purpose of reducing the friction and/or the wear between them.

Lubrication

The control of friction and wear: By introduction of a friction-reducing film, between moving surfaces in contact. The lubricant used can be a fluid, solid, or plastic substance.

Lubricator

A device, which adds, controlled or metered amounts of lubricant into a pneumatic system.

Lubricity

Ability of an oil or grease to lubricate; also called film strength.

LVI

Low Viscosity Index, typically below 40 VI units.

M

Meter

Magnetic

A separator that uses a magnetic field to attract and hold ferromagnetic particles.

Magnetic filter

A filter element that, in addition to its filter medium, has a magnet or magnets incorporated into its structure to attract and hold ferromagnetic particles.

Magnetic plug

Strategically located in the flow stream to collect a representative sample of wear debris circulating in the system: for example, engine swarf, bearing flakes, and fatigue chunks. The rate of buildup of wear debris reflects degradation of critical surfaces.

Magnetic seal

A seal that uses magnetic material (instead of springs or a bellows) to provide the closing force that keeps the seal faces together.

Manifold

A filter assembly containing multiple ports and integral relating components, which services more than one fluid circuit.

Manifold filter

A filter in which the inlet and outlet port axes are at right angles, and the filter element axis is parallel to either port axis.

Material Safety Data Sheet (MSDS)

A publication containing health and safety information on a hazardous product (including petroleum). The OSHA Hazard Communication Standard requires that an MSDS be provided by manufacturers to distributors or purchasers prior to or at the time of product shipment. An MSDS must include the chemical and common names of all ingredients that have been determined to be health hazards if they constitute 1% or greater of the product's composition (0.1% for carcinogens). An MSDS also included precautionary guidelines and emergency procedures.

Media migration

Material passed into the effluent stream composed of the materials making up the filter medium.

Medium

The porous material that performs the actual process of filtration: The plural of this word is "media".

Mega

Million

Metal oxides

Oxidized ferrous particles, which are very old or have been recently produced by conditions of inadequate lubrication. Trend is important.

Metalworking lubricant

Any lubricant, usually petroleum-based, that facilitates the cutting or shaping of metal. Basic types of metalworking lubricants are, cutting, tapping fluids, and drawing compounds, etc.

Micro

Millionth

h

Microm

eter (μm)

See

Micron.

Micron

A unit of length: One Micron = 39 millionths of an inch (.000039"). Contaminant size is usually described in microns. Relatively speaking, a grain of salt is about 60 microns and the eye can see particles to about 40 microns. Many hydraulic filters are required to be efficient in capturing a substantial percentage of contaminant particles as small as 5 microns. A micron is also known as a micrometer, and exhibited as μm **Microscope method**
A method of particle counting which measures or sizes particles using an optical microscope.

MIL

Military **mill**

Thousandth of an inch.

Mineral oil

Oil derived from a mineral source, such as petroleum, as opposed to oils derived from plants and animals.

Mineral seal oil

A distillation fraction between kerosene and gas oil, widely used as a solvent oil in gas adsorption processes, as a lubricant for the rolling of metal foil, and as a base oil in many specialty formulations. Mineral seal oil takes its name – not from any sealing function – but from the fact that it originally replaced oil derived from seal blubber for use as an illuminant for signal lamps and lighthouses.

Miscible

Capable of being mixed in any concentration without separation of phases; e.g., water and ethyl alcohol are miscible.

Mold (release) lubricant

A compound, often of petroleum origin, for coating the interiors of molds for glass and ceramic products. The mold lubricant facilitates removal of the molded object from the mold, protects the surface of the mold, and reduces or eliminates the need for cleaning it.

Moly

Molybdenum disulfide, a solid lubricant and friction reducer, colloiddally dispersed in some oils and greases.

Molybdenum disulfide

A black, lustrous powder (MoS₂) that serves as a dry-film lubricant in certain high-temperature and highvacuum applications. It is also used in the form of pastes to prevent scoring when assembling press-fit parts, and as an additive to impart residual lubrication properties to oils and greases. Molybdenum disulfide is often called Moly or Moly sulfide.

Motor

A device, which converts fluid power into mechanical force and motion: It usually provides rotary mechanical motion.

MTBF

An abbreviation for Mean Time Between Failures.

Multi-grade oil

An oil meeting the requirements of more than one SAE viscosity grade classification, and may therefore be suitable for use over a wider temperature range than a single-grade oil.

Multi-pass or recirculation test

Filter performance tests in which the contaminated fluid is allowed to recirculate through the filter for the duration of the test. Contaminant is usually added to the test fluid during the test. The test is used to determine the Beta-Ratio (q.v.) of an element.

Naphthenic

A type of petroleum fluid derived from naphthenic crude oil, containing a high proportion of closed-ring methylene groups.

NAS

National Aerospace Standard

NASA

National Aeronautics and Space Administration

NEC

National Electrical

Code Needle bearing

Rolling type of bearings containing rolling elements that are relatively long compared to their diameter.

NEMA

National Electrical Manufacturers Association

Neutralization number

A measure of the total acidity or basicity of an oil; this includes organic or inorganic acids or bases or a combination thereof (ASTM Designation D974-58T)

Newtonian fluid

A fluid, with a constant viscosity at a given temperature regardless of the rate of shear: Single-grade oils are Newtonian fluids. Multi-grade oils are NON-Newtonian fluids because viscosity varies with shear rate.

NFPA

National Fluid Power Association

Nitration

Nitration products are formed during the fuel combustion process in internal combustion engines. Most nitration products are formed when an excess of oxygen is present. These products are highly acidic, form deposits in combustion areas and rapidly accelerate oxidation.

NLGI (National Lubricating Grease Institute)

Trade association whose main interest is greases and grease technology. NLGI is best known for its system of rating greases by penetration.

NLGI Automotive Grease Classifications

Automotive lubricating grease quality levels established jointly by SAE, ASTM and NLGI. There are several categories in two classifications: Chassis Lubricants and Wheel bearing Lubricants. Quality or performance levels within each category are defined by ASTM tests.

NLGI consistency grades

Simplified system established by the National Lubricating Grease Institute (NLGI) for rating the consistency of grease.

Nominal filtration rating

An arbitrary micrometer value indicated by a filter manufacturer. Due to lack of reproducibility this rating is deprecated.

Non-Newtonian fluid

Fluid, such as grease or a polymer-containing oil (e.g., multi-grade oil), in which shear stress is not proportional to shear rate.

Nonwoven medium

A filter medium composed of a mat of fibers.

Normal paraffin

A hydrocarbon consisting of molecules in which any carbon atom is attached to no more than two other carbon atoms; also called straight chain paraffin and linear paraffin.

Obliteration

A synergistic phenomenon, of both particle, silting, and polar adhesion: When water and silt particles coexist in a fluid containing long-chain molecules, the tendency for valves to undergo obliteration increases.

Oil

A greasy unctuous liquid of vegetable, animal, mineral, or synthetic origin.

Oil Consumption Ratio

Annual oil purchases divided by machine charge volume. For example, if you purchased 10,000 gallons of oil in one year and the total amount of oil that all of your machine holds is 4,200 gallons, your consumption ratio is 2.4.

Oil ring

A loose ring, the inner surface of which rides a shaft or journal and dips into a reservoir of lubricant from which it carries the lubricant to the top of a bearing by its rotation with the shaft. **Oilier**

A device for once-through lubrication: Three common types of oilers are drop-feed, wick-feed, and bottlefeed; all depend on gravity to induce a metered flow of oil to the bearing. The drop-feed oilier delivers oil from the bottom of a reservoir to a bearing one-drop at a time; flow rate is controlled by a needle valve at the top of the reservoir. In a wick-feed oilier, the oil flows through a wick and drops from the end of the wick into the bearing; feed is regulated by chaining the number of strands, by raising or lowering the oil level, or by applying pressure to the wick. In a bottle-feed oilier, a vacuum at the top of the jar keeps the fluid from running out; as tiny bubbles of air enter, the vacuum is reduced and a small amount of oil enters the bearing or is added to a reservoir from which the bearing is lubricated.

Oiliness

That property of a lubricant that produces low friction under conditions of boundary lubrication: The lower the friction, the greater the oiliness.

Oiliness Agent

An additive, usually polar in nature, used to improve the lubricity of a mineral oil. Now usually called a boundary lubrication additive.

Open bubble point (boil point)

The differential gas pressure at which gas bubbles are profusely emitted from the entire surface of a wetted filter element under specified test conditions.

Open gear

A gear that is exposed to the environment, rather than being housed in a protective gearbox: Open gears are generally large, heavily loaded, and slow moving. They are found in such applications as mining and construction machinery, punch presses, plastic and rubber mills, tube mills, and rotary kilns. Open gears require viscous, adhesive lubricants that bond to the metal surfaces and resist run-off. Such lubricants are often called gear shields. Top-quality lubricants for such applications are specially formulated to protect the gears against the effects of water and other contaminants.

OSHA

Occupational Safety and Health Administration

Outside-mounted seal

A mechanical seal with its seal head mounted outside the seal chamber that holds the fluid to be sealed. Outside seals have the pumped fluid's pressure at their I.D.

Oxidation

Occurs when oxygen attacks petroleum fluids. The process is accelerated by heat, light, metal catalysts and the presence of water, acids, or solid contaminants. It leads to increased viscosity and deposit formation.

Oxidation inhibitor

Substance added in small quantities to a petroleum product to increase its oxidation resistance, thereby lengthening its service or storage life; also called anti-oxidant. An oxidation inhibitor may work in one of these ways: (1) by combining with and modifying peroxides (initial oxidation products) to render them harmless, (2) by decomposing the peroxides, or (3) by rendering an oxidation catalyst inert.

Oxidation stability

Ability of a lubricant to resist natural degradation upon contact with oxygen.

P

Pressure – psi

Paper chromatography

A method, which involves placing a drop of fluid on a permeable piece of paper, and noting the development and nature of the halos, or rings, surrounding the drop through time. The roots of this test can be traced to the 1940s, when railroads used the "blotter spot" tests.

Paraffin

Any hydrocarbon identified by saturated straight (normal) or branched (Iso) carbon chains: Also called an alkane. The formula C_nH_{2n+2} can symbolize the generalized paraffinic molecule. Paraffin's are relatively non-reactive and have excellent oxidation stability. In contrast to naphthenic oils, paraffinic lubricating oils have relatively high wax content and pour point, and generally have a high viscosity index (VI.). Paraffinic solvents are generally lower in solvency than naphthenic or aromatic solvents.

Paraffinic

A type of petroleum fluid derived from paraffinic crude oil and containing a high proportion of straight chain saturated hydrocarbons. Often susceptible to cold flow problems.

Parallel Systems

Lubrication systems, where the dispensing devices are connected to the main line in parallel: Each dispensing device operates independent of any other in the system.

Particle counts

The number of particles present greater than a particular micron size per unit volume of fluid often stated as particles > 10 microns per milliliter.

Particle density

An important parameter in establishing an entrained particle's potential to impinge on control surfaces and cause erosion.

Particle erosion

Occurs when fluid-entrained particles moving at high velocity pass through orifices or impinge on metering surfaces or sharp angle turns.

Particle impingement erosion

A particulate wear process where high velocity, fluid-entrained particles are directed at target surfaces.

Particulates

Particles made up of a wide range of natural materials (e.g., pollen, dust, resins), combined with man-made pollutant (e.g., smoke particles, metallic ash); in sufficient concentrations, particulates can be a respiratory irritant.

Pascal

Unit of pressure, in the metric (SI) system.

Pascal's Law

A pressure applied to a confined fluid at rest is transmitted with equal intensity throughout the liquid and that pressure is considered to act at right angles to each surface contacted by the fluid. **Patch test**

A method by which a specified volume of fluid is filtered through a membrane filter of known pore structure: All particulate matter in excess of an "average size," determined by the membrane characteristics, is retained on its surface. Thus, the membrane is discolored by an amount proportional to the particulate level of the fluid sample. Visually comparing the test filter with standard patches of known contamination levels determines acceptability for a given fluid.

PCB

Polychlorinated biphenyl, a class of synthetic chemicals consisting of a homologous series of compounds beginning with monochlorobiphenyl and ending with decachlorobiphenyl. PCBs do not occur naturally in petroleum, but have been found as contaminants in used oil. PCBs have been legally designated as a health hazard, and any oil so contaminated must be handled in strict accordance with state and federal regulations.

Permeability

The relationship of flow, per unit area, to differential pressure across a filter medium.

Petrochemical

Any chemical substance derived from crude oil or its products, or from natural gas. Some petrochemical products may be identical to others produced from other raw materials such as coal and producer gas. **pH**

Measure of alkalinity or acidity in water and water-containing fluids. pH can be used to determine the corrosion-inhibiting characteristic in water-based fluids. Typically, pH > 8.0 is required to inhibit corrosion of iron and ferrous alloys in water-based fluids. **Phenol**

A white, crystalline compound (C₆H₅OH) derived from benzene, used in the manufacture of phenolic resins, weed killers, plastics, disinfectants; also used in solvent extraction, a petroleum refining process. Phenol is a toxic material; skin contact must be avoided.

Phosphate ester

Any groups of synthetic lubricants having superior fire resistance. A phosphate ester generally has poor hydrolytic stability, poor compatibility with mineral oil, and a relatively low viscosity index (VI). It is used as a fire-resistant hydraulic fluid in high-temperature applications.

Pinion

The smaller of two mating or meshing gears; can be either the driving or the driven gear.

Pitting

A form of extremely localized attack characterized by holes in the metal. Pitting is one of the most destructive and insidious forms of corrosion. Depending on the environment and the material, a pit may take months, or even years, to become visible.

Pleated filter

Filter elements whose medium consist of a series of uniform folds and have the geometric form of a cylinder, cone, disc, plate, etc. Synonymous with "convoluted" and "corrugated".

PNA (polynuclear aromatic)

Any of numerous complex hydrocarbon compounds consisting of three or more benzene rings in a compact molecular arrangement. Some types of PNA's are formed in fossil fuel combustion and other heat processes, such as catalytic cracking.

Pneumatics

Engineering science pertaining to gaseous pressure and flow.

Poise (absolute viscosity)

A measure of viscosity numerically equal to the force required moving a plane surface of one square centimeter per second when the surfaces are separated by a layer of fluid one-centimeter in thickness. It is the ratio of the shearing stress to the shear rate of a fluid and is expressed in dyne seconds per square centimeter (DYNE SEC/CM²); 1 Centipoise equals .01 poise.

Polar compound

Chemical compound, whose molecules exhibit electrically positive characteristics at one extremity and negative characteristic at the other: Polar compounds are used as additives in many petroleum products. Polarity gives certain molecules a strong affinity for solid surfaces, as lubricant additives (oiliness agents), such molecules plate out to form a tenacious, friction-reducing film. Some polar molecules are oil-soluble at one end and water-soluble at the other end; in lubricants, they act as emulsifiers, helping to form stable oilwater emulsions. Such lubricants are said to have good metal-wetting properties. Polar compounds with a strong attraction for solid contaminants act as detergents in engine oils by keeping contaminants finely dispersed.

Polishing (bore)

Excessive smoothing of the surface finish of the cylinder bore or cylinder liner in an engine to a mirror-like appearance, resulting in depreciation of ring sealing and oil consumption performance.

Polyglycols

Polymers of ethylene or propylene oxides used as a synthetic lubricant base. Properties include very good hydrolytic stability, high viscosity index (VI), and low volatility. Used particularly in water emulsion fluids.

Polymer

A substance formed by the linkage (polymerization) of two or more simple, molecules, called monomers, to form a single larger molecule having the same elements in the same proportions as the original monomers; i.e. each monomer retains its structural identity. A polymer may be liquid or solid; solid polymers may consist of millions of repeated linked units. A polymer made from two or more similar monomers is called a copolymer; a copolymer composed of three different types of monomers is a terpolymer. Natural rubber and synthetic rubbers are examples of polymers. Polymers are commonly used as viscosity index improvers in multi-grade oils and tackifiers in lubricating greases.

Polymerization

The chemical combination of similar-type molecules, to form larger molecules.

Polyol ester

A synthetic lubricant base, formed by reacting fatty acids with a polyol (such as a glycol) derived from petroleum. Properties include good oxidation stability at high temperatures and low volatility. Used in formulating lubricants for turbines, compressors, jet engines, and automotive engines.

Polyol Esters

Synthetic lubricants made by reacting fatty acids with polyhydric alcohol's.

Polyolefin

A polymer derived by polymerization of relatively simple olefins. Polyethylene and polyisoprene are important polyolefins.

Pore

A small channel or opening in a filter medium which allows passage of fluid.

Pore size distribution

The ratio number of effective holes of a given size, to the total number of effective holes per unit area expressed as a percent and as a function of whole size.

Porosity

The ratio of pore volume to total volume of a filter medium expressed as a percent.

Positive crankcase ventilation (PCV)

System for removing blow-by gases from the crankcase and returning them through the carburetor intake manifold to the combustion chamber where the recirculated hydrocarbons are burned. A PC valve controls the flow of gases from the crankcase to reduce hydrocarbon emissions.

Pour point

Lowest temperature at which an oil or distillate fuel is observed to flow, when cooled under conditions prescribed by test method ASTM D 97. The pour point is 3°C (5°F) above the temperature at which the oil in a test vessel shows no movement when the container is held horizontally for five seconds.

Pour point depressant

An additive, which retards the adverse effects of wax crystallization, and lowers the pour point.

Pour stability

The ability of a pour depressed oil to maintain its original ASTM pour point when subjected to long-term storage at low temperature approximating winter conditions.

Power unit

A combination of pump, driver, reservoir, controls and conditioning components, which may be required for its application.

PPM

Parts per million (1/ppm = 0.000001). Generally by weight: 100 ppm = 0.01%; 10,000 ppm = 1% **Predictive**

maintenance

A type of condition-based maintenance, emphasizing early prediction of failure, using non-destructive techniques such as vibration analysis, thermography, and wear debris analysis.

Pressure

Force per unit area, usually expressed in pounds per square inch.

Pressure Drop

Resistance to flow created by the element (media) in a filter. Defined as the difference in pressure upstream (inlet side of the filter) and downstream (outlet side of the filter).

Pressure gage

Pressure differential above or below atmospheric pressure.

Pressure line filter

A filter located in a line conducting working fluid to a working device or devices.

Pressure Absolute

The sum of, the atmospheric and gage pressures.

Pressure Atmospheric

Pressure exerted by the atmosphere at any specific location. (Sea level pressure is approximately 14.7 pounds per square inch absolute.)

Pressure Back

The pressure encountered on the return side of a system.

Pressure Cracking

The pressure at which a pressure operated valve begins to pass fluid.

Pressure Rated

The qualified operating pressure, which is recommended for a component or a system by the manufacturer.

Pressure System

The pressure which overcomes the total resistances in a system. It includes all losses as well as useful work.

Preventive Maintenance

Maintenance performed according to a fixed schedule involving the routine repair and replacement of machine parts and components.

Proactive Maintenance

A type of condition-based maintenance emphasizing the routine detection and correction of root cause conditions that would otherwise lead to failure. Such root causes as high lubricant contaminant, alignment and balances are among the most critical.

Process Oil

Oil, that serves as a temporary, or permanent component of a manufactured products. Aromatic process oils have good solvency characteristics; their applications include proprietary chemical formulations, ink oils, and extenders in synthetic rubbers. Low pour points and good solvency properties characterize naphthenic process oils. Paraffinic process oils are characterized by low aromatic content and light color.

psi

Pounds per

square inch **psia**

Pounds per square inch absolute

PSIA

Pounds per square inch absolute. (PSIG + 14.696)

PSID

Pounds per square inch differential.

PSIG

Pounds per square inch gauge (PSIA - 14.696)

Pump

A device which converts mechanical forces and motion into hydraulic fluid power.

Pump, fixed displacement

A pump, in which the displacement per cycle, cannot be varied.

Pump, variable displacement

A pump, in which the displacement per cycle can be varied.

Pumpability

The low temperature, low shear stress-shear rate viscosity characteristics of an oil that permit satisfactory flow to and from the engine oil pump and subsequent lubrication of moving components.

Pusher seal

A mechanical seal in which the secondary seal is pushed along the shaft or sleeve to compensate for misalignment and face wear.

Q

Flow rate - GPM

Quenching oil

(Also called heat treating oil) a high-quality, oxidation-resistant petroleum oil used to cool metal parts during their manufacture, and is often preferred to water because the oil's slower heat transfer lessens the possibility of cracking or warping of the metal. Quenching oil must have excellent oxidation and thermal stability, and should yield clean parts, essentially free of residue. In refining terms, quenching oil is oil introduced into high temperature vapors of cracked (see cracking) petroleum fractions to cool them. **Quick Disconnect**

A coupling, which can quickly join or separate a fluid line, without the use of tools or special devices.

R & O - Rust-and-oxidation inhibited

A term applied to highly refined industrial lubricating oils formulated for long service in circulating lubrication systems, compressors, hydraulic systems, bearing housing, gear boxes, etc. The finest R&O oils are often referred to as turbine oils.

Rate of shear

The difference between the velocities along the parallel faces of a fluid element divided by the distance between the faces. **Rated Flow**

The maximum flows that the power supply system is capable of maintaining at a specific operating pressure.

Reducer

A connector having a smaller line size at one end than the other.

Refining

A series of processes for converting crude oil and its fractions to finished petroleum products. Following distillation, a petroleum fraction may undergo one or more additional steps to purify or modify it. These refining steps include; thermal cracking, catalytic cracking, polymerization, alkylation, reforming, hydrocracking, hydro-forming, hydrogenation, hydrogen treating, hydro-finishing, solvent extraction, dewaxing, deoiling, acid treating, clay filtration, and deasphalting. Refined lubricating oils may be blended with other lube stocks, and additives may be incorporated, to impart special properties.

Refraction

The change of direction or speed of light as it passes from one medium to another. **Refrigerator**

oil

The lubricant added to the working fluid in an expansion-type-cooling unit, which serves to lubricate the pump mechanism.

Rerefining

A process of reclaiming used lubricant oils and restoring them to a condition similar to that of virgin stocks by filtration, clay adsorption or more elaborate methods.

Reservoir

A container, for storage of liquid in a fluid power system.

Reservoir (sump) Filter

A filter installed in a reservoir in series with a suction or return line.

Residual dirt Capacity

The dirt capacity remaining in a service loaded filter element after use, but before cleaning, measured under the same conditions as the dirt capacity of a new filter element.

Return line

The line conducting fluid from working device to reservoir.

Return Line Filtration

Filters located upstream of the reservoir but after fluid has passed through the system's output components (cylinders, motors, etc.).

Reynolds's number

A numerical ratio of the dynamic forces of mass flow to the shear stress due to viscosity. Flow usually changes from laminar to turbulent between Reynolds's Number 2,000 and 4,000.

Rheology

The study of the deformation and flow of matter, in terms of stress, strain, temperature, and time. Penetration and apparent viscosity commonly measure the rheological properties of grease. **Ring Lubrication**

System of lubrication, in which the lubricant, is supplied to the bearing by an oil ring.

Ring Sticking

Freezing of a piston ring in its groove in a piston engine or reciprocating compressor due to heavy deposits in the piston ring zone.

Rings

Circular metallic elements, that rides in the grooves of a piston, and provides compression sealing during combustion. Also used to spread oil for lubrication.

Roller Bearing

An antifriction bearing comprising rolling elements in the form of rollers.

Rolling Oil

An oil used in hot- or cold-rolling of ferrous and non-ferrous metals to Facilitate feed of the metal between the work rolls, improve the plastic deformation of the metal, conduct heat from the metal, and extend the life of the work rolls. Because of the pressures involved, a rolling oil may be compounded or contain EP additives. In hot rolling, the oil may also be emulsifiable.

Roll-off Cleanliness

The fluid system contamination's level at the time of release from an assembly or overhaul line. Fluid system life can be shortened significantly by full-load operation under a high fluid contamination condition for just a few hours. Contaminant implanted and generated during the break-in period can devastate critical components unless removed under controlled operating and high performance filtering conditions.

Rotary seal

A mechanical seal, which rotates with a shaft, and is used with a stationary-mating ring.

rpm

Revolutions per minute

Rust inhibitor

A type of corrosion inhibitor used in lubricants to protect surfaces against rusting.

Rust prevention test (turbine oils)

A test for determining the ability of an oil to aid in preventing the rusting of ferrous parts in the presence of water.
SAE

Society of Automotive Engineers: An organization serving the automotive industry.

SAE port

A straight thread port used to attach tube and hose fittings. It employs an “O” ring compressed in a wedged-shaped cavity. A standard of the Society of Automotive Engineers J514 and ANSI/B116.1 **SAE**

viscosity

The viscosity classification of motor oil, according to the system developed by the Society of Automotive Engineers, and now in general use. “Winter” grades are defined by viscosity measurements at low temperatures and have “W” as a suffix, while “Summer” grades are defined by viscosity at 100° C and have no suffix. Multi-grade oils meet both a winter and a summer definition and have designations such as SAE 10W-30, etc.

Sample preparation

Fluid factors that can enhance the accuracy of the particulate analysis. Such factors include particle dispersion, particle settling, and sample dilution.

Saponification number

The number of milligrams of potassium hydroxide (KOH) that combine with one gram of oil under conditions specified by test method ASTM D 94. Saponification number is an indication of the amount of fatty saponifiable material in compounded oil. Caution must be used in interpreting test results if certain substances - such as sulfur compounds or halogens - are present in the oil, since these also react with KOH, thereby increasing the apparent Saponification number.

Saturation level

The amount of water, that can dissolve in a fluid.

Saybolt Universal Viscosity (SUV) or Saybolt Universal Seconds, (SUS)

The time in seconds required for 60 cubic centimeters of a fluid to flow through the orifice of the Standard Saybolt Universal Viscometer at a given temperature under specified conditions. (ASTM Designation D 88.)

Scoring

Distress marks on sliding metallic surfaces in the form of long, distinct scratches in the direction of motion. Scoring is an advanced stage of scuffing.

Scuffing

Abnormal engine wear due to localized welding and fractures. It can be prevented through the use of antiwear, extreme-pressure and friction modifier additives.

Scuffing particles

Large twisted and discolored metallic particles resulting from adhesive wear due to complete lubricant film breakdown.

Seal

A device designed to prevent the movement of fluid from one area to another, or to exclude contaminants.

Seal assembly

A group of parts, or a unitized assembly, that includes sealing surfaces, provisions for initial loading, and a secondary sealing mechanism that accommodates the radial and axial movement necessary for installation and operation. **Seal chamber**

The area between the seal chamber bore and a shaft in which a mechanical seal is installed.

Seal face

It is either of the two lapped surfaces in a mechanical seal assembly forming the primary seal. **Seal**

face width

The radial distance from the inside edge to the outside edge of the sealing face.

Seal Swell (rubber swell)

The swelling of rubber (or other elastomer's) gaskets, or seals when exposed to petroleum, synthetic lubricants, or hydraulic fluids. Seal materials vary widely in their resistance to the effect of such fluids. Some seals are designed so that a moderate amount of swelling improves sealing action.

Semisolid

Any substance, having the attributes of both solid and a liquid: Similar to semi-liquid but being more closely related to a solid than a liquid. More generally, any substance in which the force required to produce a deformation depends both on the magnitude and on the rate of the deformation.

Servo Valve

A valve, which modulates output as a function, of an input command.

Severe sliding

Large ferrous particles, which are produced by sliding contacts: Trend is important to determine whether abnormal wear is taking place.

Shear rate

Rate at which adjacent layers of fluid move with respect to each other, usually expressed as reciprocal seconds.

Shear stress

Frictional force overcome in sliding one "layer" of fluid along another, as in any fluid flow. The shear stress of petroleum oil or other Newtonian fluid at a given temperature varies directly with shear rate (velocity). The ratio between shear stress and shear rate is constant; this ratio is termed viscosity of a Newtonian fluid, the greater the shear stress as a function of rate of shear. In a non-Newtonian fluid **Silt**

Contaminant particles, 5 μm and less.

Silting

A failure generally associated with a valve which movements are restricted due to small particles that have wedged in between critical clearances (e.g., the spool and bore.)

Single-pass test

Filter performance tests, in which contaminant, which passes through a test, filter is not allowed to recirculate back to the test filter.

Sintered medium

A metallic or nonmetallic filter medium processed to cause diffusion bonds at all contacting points.

Sleeve bearing

A journal bearing, usually a full journal bearing.

Sloughing off

The release of contaminant, from the upstream side of a filter element, to the upstream side of the filter enclosure.

Sludge

Insoluble material formed as a result either of deterioration reactions in oil or of contamination of oil, or both.

Solid

Any substance having a definite shape which it does not readily relinquish. More generally, any substance in which the force required to produce a deformation depends upon the magnitude of the deformation rather than upon the rate of deformation.

Solvency

Ability of a fluid to dissolve inorganic materials and polymers, which is a function of aromaticity.

Solvent

A material with a strong capability to dissolve a given substance: The most common petroleum solvents are mineral spirits, xylene, toluene, hexane, heptane, and naphthas. Aromatic-type solvents, have the highest solvency for organic chemical materials, followed by naphthenes and paraffin's. In most applications, the solvent disappears, usually by evaporation, after it has served its purpose. The evaporation rate of a solvent is very important in manufacture.

Solvent Extraction

A refining process used to separate components (unsaturated hydrocarbons) from lube distillates in order to improve the oil's oxidation stability, viscosity index, and response to additives. The oil and the solvent extraction media are mixed in an extraction tower, resulting in the formation of two phases: a heavy phase consisting of the undesirable unsaturates dissolved in the solvent. And a lighter phase consisting of high quality oil with some solvent dissolved in it. The phases are separated and the solvent recovered from each by distillation.

Specific gravity

The ratio, of the weight of a given volume of material to the weight of an equal volume of water.

Specific gravity (liquid)

The ratio of the weight of a given volume of liquid, to the weight of an equal volume of water.

Spectrographic analysis

Determines the concentration of elements represented in the entrained fluid contaminant.

Spectrographic Oil Analysis Program (SOAP)

Procedures for extracting fluid samples from operating systems and analyzing them spectrographically for the presence of key elements. **Spindle oil**

Light-bodied oil used principally for lubricating textile spindles and for light, high-speed machinery.

Spin-on filter

A throwaway type bowl and element assembly that mates with a permanently installed head.

Splash lubrication

A system of lubrication, in which parts of a mechanism, dip into and splash the lubricant onto themselves and/or other parts of the mechanism.

SSU

Saybolt Universal Seconds (or SUS), a unit of measure used to indicate viscosity, e.g., SSU @ 100 deg F **Static**

friction

The force, just sufficient to initiate relative motion, between two bodies under load. The value of the static friction at the instant relative motion begins is termed breakaway friction.

Static seal

A seal between two surfaces which have no relative motion.

Stationary seal

A mechanical seal, in which the flexible members do not rotate with the shaft. **Statistical**

process control (SPC)

The use of control charts to track and eliminate variables in repetitive manufacturing processes, in order to ensure that the product is of consistent and predictable quality. If a chart reveals only chance variations that are inherent in the system, the process is said to be in a state of “statistical control”. If the chart reveals variations traceable to changes in equipment, procedures or workers, the process is said to be “out of control”. Statistical process control differs from statistical quality control in that the former monitors manufacturing process parameters and the latter monitors product quality parameters.

Stick-slip motion

Erratic, noisy motion characteristic of some machine ways, due to the starting friction encountered by a machine part at each end of its back-and-forth (reciprocating) movement. This undesirable effect can be overcome with a way lubricant, which reduces starting friction.

STLE

Society of Tribologists and Lubrication Engineers: Formerly ASLE: American Society of Lubrication Engineers.

Stoke (St)

Kinematic measurement of a fluid's resistance to flow defined by the ratio of the fluid's dynamic viscosity to its density.

Straight mineral oil

Petroleum oil, containing no additives. Straight mineral oils include such diverse products as low-cost onecrutch lubricants and thoroughly refined white oils. Most high-quality lubricants, however, contain additives.

Straight oil

A mineral oil, containing no additives.

Strainer

A coarse filter element (pore size over approximately 40 μ m)

Suction filter

A pump intake-line filter, in which the fluid is below atmospheric pressure.

Sulfated ash

The ash content of fresh, compounded lubricating oil as determined by ASTM Method D 874. Indicates level of metallic additives in the oil.

Sulfonate

A hydrocarbon in which a hydrogen atom has been replaced with the highly polar (SO₂OX) group, where X is a metallic ion or alkyl radical. Petroleum sulfonates are refinery by-products of the sulfuric acid treatment of white oils. Sulfonates have important applications as emulsifiers and chemical intermediates in petrochemical manufacture, and substituted sulfonates are widely used as corrosion inhibitors. Synthetic sulfonates can be manufactured from special feedstock's rather than from white oil base stocks.

Sulfur

A common natural constituent of petroleum products: While certain sulfur compounds are commonly used to improve the EP, or load carrying, properties of oil, high sulfur content in a petroleum product may be undesirable as it can be corrosive and create an environmental hazard when burned. For these reasons, sulfur limitations are specified in the quality control of fuels, solvents, etc.

Sulfurized Oil

Oil, to which sulfur or sulfur compounds have been added.

Super Clean

10 particles >10 micron per milliliter

Surface Fatigue Wear

The formation of surface or subsurface cracks and fatigue crack propagation. It results from cyclic loading of a surface.

Surface filtration

Filtration, which primarily retains contaminant on the influent surface.

Surface tension

The contractile surface force of a liquid, by which it tends to assume a spherical form and to present the least possible surface. It is expressed in dynes/cm or ergs/cm².

Surfactant

Surface-active agent, that reduces interfacial tension of a liquid. A surfactant used in petroleum oil may increase the oil's affinity for metals and other materials.

Surge

A momentary rise of pressure in a circuit.

SUS (SSU)

Saybolt Universal Seconds. A measure of lubricating oil viscosity in the oil industry. The measuring apparatus is filled with specific quantity of oil or other Fluid and its flow time through a standardized orifice is measured in Seconds. Fast flowing fluids (low viscosity) will have low value; slow flowing fluids (high viscosity) will have high value.

Swarf

The cuttings and grinding fines that result from metal working operations.

Switch, pressure

An electric switch operated by fluid pressure.

Synthetic hydrocarbon

Oil molecule with superior oxidation quality tailored primarily out of paraffinic materials.

Synthetic lubricant

A lubricant produced by chemical synthesis rather than by extraction or refinement of petroleum to produce a compound with planned and predictable properties.

Synthetic oils

Oils produced by synthesis (chemical reaction) rather than by extraction or refinement. Many (but not all) synthetic oils offer immense advantages in terms of high temperature stability and low temperature fluidity, but are more costly than mineral oils. Major advantage of all synthetic oils is their chemical uniformity. t

Time in seconds

T

Temperature change, Fahrenheit

Tacky

A descriptive term applied to lubricating oils and greases, which appear particularly sticky or adhesive.

TAN

(Total) acid number

TBN

(Total) base number

Thermal conductivity

Measure of the ability of a solid or liquid to transfer heat.

Thermal stability

Ability of a fuel or lubricant to resist oxidation under high temperature operating conditions.

Thermography

The use of infrared thermography can measure temperatures of a wide variety of targets, remotely and without contact. This is accomplished by measuring the infrared energy radiating from the surface of the target and converting this measurement to an equivalent surface temperature. **Thin film lubrication**

A condition of lubrication in which the film thickness of the lubricant is such that the friction between the surfaces is determined by the properties of the surfaces as well as by the viscosity of the lubricant.

Thixotropy

That property of a lubricating greases which is manifested by a softening in consistency as a result of shearing followed by a hardening in consistency starting immediately after the shearing is stopped.

Three-body abrasion

Particulates wear process by which particles are pressed between two sliding surfaces.

Thrust Bearing

An axial-load bearing.

Timken EP Test

Measure of the extreme-pressure properties of lubricating oil. The test utilizes a Timken machine, which consists of a stationary block pushed upward, by means of a lever arm system, against the rotating outer race of a roller bearing, which is lubricated by the product under test. The test continues under increasing load (pressure) until a measurable wear scar is formed on the block.

Timken OK Load

The heaviest load that a test lubricant will sustain without scoring the test block in the Timken Test procedures, ASTM Methods D 2509 (greases) and D 2782 (oils).

Total Acid Number (TAN)

The quantity of base, expressed in milligrams of potassium hydroxide, that is required to neutralize all acidic constituents present in 1 gram of sample. (ASTM Designation D 974.)

Total Base Number (TBN)

The quantity of acid, expressed in terms of the equivalent number of milligrams of potassium hydroxide that is required to neutralize all basic constituents present in 1 gram of sample. (ASTM Designation D 974.) **Tribology**

The science and technology of interacting surfaces in relative motion, including the study of lubrication, friction and wear. Tribological wear is wear that occurs as a result of relative motion at the surface.

Turbidity

The degree of opacity of a fluid.

Turbine oil

Top-quality rust- and oxidation-inhibited (R&O) oil that meets the rigid requirements traditionally imposed on steam-turbine lubrication. Good Demulsibility, a requisite of effective oil-water separation, also distinguishes quality turbine oils. Turbine oils are widely used in other exacting applications for which long service life and dependable lubrication are mandatory. Such compressors, hydraulic systems, gear drives, and other equipment. Turbine oils can also be used as heat transfer fluids in open systems, where oxidation stability is of primary importance.

Turbulent flow sampler

A sampler, that contains a flow path in which turbulence is induced in the main stream by abruptly changing the direction of the fluid.

Ultra Clean

1 particle >10 micron per milliliter

Unbalanced seal

A mechanical seal arrangement wherein the full hydraulic pressure of the seal chamber acts to close the seal faces.

Unloading

The release of contaminant, that was initially captured by the filter medium.

V

Total volume (gals)

Vacuum separator

A separator that utilizes subatmospheric pressures to remove certain gases and liquids from another liquid because of their difference in vapor pressure.

Valve

A device, which controls fluid flow direction, pressures, or flow rate.

Valve lifter

Sometimes called a "cam follower," a component in engine designs that use a linkage system between a cam and the valve it operates. The lifter typically translates the rotational motion of the cam to a reciprocating linear motion in the linkage system.

Valve, by-pass

A valve whose primary function is to provide an alternate flow path.

Valve, directional control

A valve whose primary function is to direct or prevent flow through selected passages.

Valve, directional control, servo

A directional control valve that modulates flows, or pressure, as a function of its input signal.

Valve, flow control

A valve whose primary function is to control flow rate.

Valve; pressure control, or relief

A pressure control valve whose primary function is to limit system pressure.

Valve, relief, differential pressure

A valve whose primary function is to limit differential pressure.

Vapor pressure

Pressure of a confined vapor in equilibrium with its liquid at specified temperature thus, a measure of a liquid's volatility.

Vapor Pressure-Reid (RVP)

Measure of the pressure of vapor accumulated above a sample of gasoline or other volatile fuel in a standard bomb at 100°F (37.8°C). Used to predict the vapor locking tendencies of the fuel in a vehicle's fuel system. Controlled by law in some areas to limit air pollution from hydrocarbon evaporation while dispensing.

Varnish

When applied to lubrication, a thin, insoluble, non-wipeable film deposit occurring on interior parts, resulting from the oxidation and polymerization of fuels and lubricants. Can cause sticking and malfunction of close-clearance moving parts. Similar to, but softer, than lacquer.

Viscometer or Viscosimeter

An apparatus for determining the viscosity of a fluid.

Viscosity

Measurement of a fluid's resistance to flow: The common metric unit of absolute viscosity, is the poise, which is defined as the force in dynes required moving a surface one square centimeter in area, past a parallel surface. At a speed of one centimeter per second, with the surfaces separated by a fluid film one centimeter thick. In addition to kinematic viscosity, there are other methods for determining viscosity, including Saybolt Universal Viscosity (SUV), Saybolt Furol viscosity, Engier viscosity, and Redwood viscosity. Since viscosity varies inversely with temperature, its value is meaningless until the temperature at which it is determined is reported.

Viscosity grade

Any of a number of systems, which characterize lubricants according to viscosity for particular applications, such as industrial oils, gear oils, automotive engine oils, automotive gear oils, and aircraft piston, engine oils.

Viscosity index (VI)

A commonly used measure, of a fluid's change of viscosity with temperature: The higher the viscosity index the smaller the relative changes in viscosity with temperature.

Viscosity index improvers

Additives that increase the viscosity of the fluid throughout its useful temperature range. Such additives are polymers that possess thickening power as a result of their high molecular weight and are necessary for formulation of multi-grade engine oils.

Viscosity modifier

Lubricant additive: usually a high molecular weight polymer, which reduces the tendency of oil's viscosity to change with temperature. **Viscosity, absolute**

The ratio of the shearing stress to the shear rate of a fluid. It is usually expressed in Centipoise.

Viscosity, kinematic

The absolute viscosity divided by the density of the fluid. It is usually expressed in Centistoke.

Viscosity, SUS

Saybolt Universal Seconds (SUS): Is the time in seconds for 60 milliliters of oil to flow through a standard orifice at a given temperature. (ASTM Designation D88-56.)

Viscosity-temperature relationship the manner in which the viscosity of a given fluid varies inversely with temperature. Because of the mathematical relationship that exists between these two variables, it is possible to predict graphically the viscosity of a petroleum fluid at any temperature within a limited range if the viscosities at two other temperatures are known. The charts used for this purpose are the ASTM Standard Viscosity-Temperature Charts for liquid Petroleum Products, available in 6 ranges. If two known viscosity-temperature points of a fluid are located on the chart and a straight line drawn through them, other viscosity-temperature values of the

fluid will fall on this line; however, values near or below the cloud point of the oil may deviate from the straight-line relationship.

Viscous

Possessing viscosity. Frequently used to imply high viscosity.

Volatility

This property describes the degree and rate at which a liquid will vaporize under given conditions of temperature and pressure. When liquid stability changes, this property is often reduced in value.

Water-Glycol fluid

A fluid, whose major constituents are water and one or more glycol's or Polyglycols.

Way

Longitudinal surfaces those guides the reciprocal movement of a machine part.

Way lubricant

Lubricant for the sliding ways of machine tools such as planers, grinders, horizontal boring machines, shapers, jig borers, and milling machines. A good way lubricant is formulated with special frictional characteristics designed to overcome the stick-slip motion associated with slow-moving machine parts.

Wear

The attrition or rubbing away, of the surface of a material as a result of mechanical action.

Wear debris

Particles that are detached from machine surfaces as a result of wear and corrosion. Also known as wear particles.

Wear inhibitor

An additive, which protects the rubbing, surfaces against wear, particularly from scuffing, if the hydrodynamic film is ruptured.

Weld point

The lowest applied load in kilograms at which the rotating ball in the Four Ball EP test either seizes and welds to the three stationary balls, or at which extreme scoring of the three balls results **Wicking**

The vertical absorption, of a liquid into a porous material, by capillary forces.

Work penetration

The penetration of a sample of lubricating grease immediately after it has been brought to 77F and then subjected to 60 stokes in a standard grease worker. This procedure and the standard grease worker are described in ASTM Method D 217.

ZDDP

An anti-wear additive found in many types of hydraulic and lubricating fluids. Zinc dialkyldithiophosphate.