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GE Power & Water

Lubricating Oil Recommendations for Gas Turbines With Bearing Ambients above 500°F (260°C)

The following notices will be found throughout this publication. It is important that the significance of each is thoroughly understood by those using this document. The definitions are as follows:

NOTE

Highlights an essential element of a procedure to assure correctness.

CAUTION

Indicates a potentially hazardous situation, which, if not avoided, could result in minor or moderate injury or equipment damage.

WARNING

INDICATES A POTENTIALLY HAZARDOUS SITUATION, WHICH, IF NOT AVOIDED, COULD RESULT IN DEATH OR SERIOUS INJURY

*****DANGER*****

INDICATES AN IMMINENTLY HAZARDOUS SITUATION, WHICH, IF NOT AVOIDED WILL RESULT IN DEATH OR SERIOUS INJURY.

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I. GENERAL

These instructions contain information intended to help the purchaser of a General Electric gas turbine and the lubricant supplier to select the proper grade and quality of lubricating oil for the turbine application.

For those turbines that utilize a load gear and anti-wear additives, please refer to GEK 101941, "Lubricating Oil Recommendations with Antiwear Additives for Gas Turbines with Bearing Ambients above 500°F (260°C)."

These recommendations apply to General Electric's Heavy Duty Gas Turbines only. For lubrication recommendations for equipment other than General Electric, refer to the instructions provided by the manufacturer of that equipment.

The successful operation of the gas turbine and its driven equipment is vitally dependent upon the lubrication system. Therefore, it is necessary for all factors contributing to correct lubrication to be present and for the entire system to be maintained in good order.

The life of the equipment depends upon a continuous supply of lubricant of proper quality, quantity, temperature, and pressure.

This being the case, the life and quality of the lubricant is of prime importance to the user. Experience has shown that certain fluid monitoring and condition maintenance is required. Hence, the following recommendations are made.

II. VARNISHING PROPENSITY

Base Oil Types and Characteristics

The two most important properties of base oils used in the formulation of turbine oils are:

1. Inherent thermal and oxidation stability
2. Solubility characteristics of the base oil towards additives

There are significant differences in performance of different base oils in these respects:

A. Group I Base Oils

Base Oils are known generally to exhibit excellent solubility characteristics towards additives and degradation byproducts and are therefore more likely to keep degradation products in solution compared to Group II base stocks.

However, standard Group I base oils suffer limitations in the area of thermal and oxidation stability and are unlikely to achieve the high levels of thermal and oxidation performance required by modern high performance gas turbine lubricants, as defined in this specification, without the need to heavily fortify them with antioxidants. This approach can lead to the formation of excess levels of degradation byproducts, mainly breakdown products of the antioxidants, further resulting in varnishing problems despite the superior solubility characteristics of the base oil.

B. Group II Base Stocks

Base Stocks generally exhibit excellent inherent thermal and oxidative stability and typically give better performance response to antioxidants, which means the required thermal, and oxidation characteristics required in a high performance gas turbine lubricant can be achieved with lower dosage rates of antioxidants. This combination tends to offer products, which are initially cleaner in service - i.e. form lower levels of degradation product.

However, Group II base oils are known generally to exhibit reduced solubility characteristics compared to Group I base stocks with the result that degradation products, when formed as the oil ages, tend to fall out of solution more readily and therefore have an increased tendency to form varnish.

Group V Polyalkylene Glycol (PAG) base stocks are known to exhibit excellent thermal and oxidative stability as well as provide superior solubility characteristics as compared to Group I and Groups II-IV base oils. PAGs, by nature are relatively polar when compared with the relatively non-polar nature of Group I mineral oil, or with the increasingly non-polar Group II-IV base oils. Since PAG degradation compounds are polar, they will remain soluble and will not fall out of solution.

By their nature PAG oils prevent the occurrence of varnish by eliminating the formation and accumulation of insoluble degradation products. Consequently non-varnishing Group V PAG based formulations are highly superior in thermo-oxidative stability.

There is often a trade-off between thermal and oxidation stability and the solubility characteristics of the turbine oil. Therefore careful the selection of base oil is important in order to achieve an optimum result.

III. RECOMMENDED PHYSICAL PROPERTIES

For this purpose, the lubricating oil should be a rust and oxidation inhibiting petroleum lubricating oil or synthetic hydrocarbon with greater high temperature oxidation stability than conventional lubricating oils, and that minimizes deposits harmful to bearings or hydraulic control systems.

Table 1 lists recommended properties of new oil and include the ASTM test method and the recommended value; these methods should act as a reference for details of tests. The oil is International Standards Organization Viscosity Grade 32 (ISO VG 32) Oil. The properties listed are typical of turbine lubricating oils except for the oxidation test requirements.

Note that he values in Table 1 are only recommended values. Oil shown to perform successfully in the field may still be used, even if it does not comply with the values in Table 1.

When non-varnishing Group V PAG based synthetic fluid is used, the recommended used limits are defined in Table 5.

For several years there have been investigations to decide on appropriate (New Fluid) laboratory tests, which could distinguish between fluids, which give satisfactory long-term service in a turbine, and those which did not. To date, there has not been complete correlation between laboratory testing and field experience.

ASTM TEST METHOD NO.	TEST	CURRENT RECOMMENDED VALUE
D287	Gravity (° API)	29-39
D1500	Color	2.0 (max.)
D97	Pour Point (°F/°C)	+10/-12 (max.)
D445	Viscosity 40°C (centistokes)	28.8-35.2
D974	(TAN) Total Acid Number	0.20 (max.)
D665	Rust prevention - A	Pass
D93	Flash point (COC) (°F/°C)	420/215 (min.)
D130	Copper corrosion	1B (max.)
D892	Foam	50/0 (max.) 50/0 (max.) 50/0 (max.)
D943	Turbine oil oxidation test (hrs.)	5,000 (min.)
D2272	Oxidation Stability by Rotating Pressure Vessel (min.)	500 (min.)
D2272	Oxidation Stability by Rotating Pressure Vessel (modified)	85% (min.) of time in unmodified test
D3427	Air Release	5 (max.)
D2270	Viscosity Index (VI)	95 (min.)

See APPENDIX A for test method descriptions

Table 1. Recommended Properties of high-temperature Lubricating Oil for Gas Turbines (New Oil)

ASTM TEST METHOD NO.	TEST	CURRENT RECOMMENDED VALUE
D4052	Specific Gravity	Report
D1500	Color	2.0 (max.)
D97	Pour Point (°F/°C)	-40/-40 (max.)
D445	Viscosity 40°C (centistokes)	23-26
D974	(TAN) Total Acid Number	0.20 (max.)
D665	Rust prevention — A	Pass
D93	Flash point (COC) (°F/°C)	446/230 (min.)
D130	Copper corrosion	1B (max.)
D892	Foam	25/0 (max.) 0/0 (max.) 0/0 (max.)
D2893B	Oxidation Characteristics 212 °F/ 100 °C Viscosity Change @121 °C,13 days	3.0% (max.)
D2272	Oxidation Stability by Rotating Pressure Vessel (minutes)	500 (min.)
D2272	Oxidation Stability by Rotating Pressure Vessel (modified)	85% (min.) of time in unmodified test
D3427	Air Release	1.0 (max.)
D2270	Viscosity Index (VI)	125 (min.)
PLTL-73	Thermal Conductivity,40C,watts/m °K	0.1 (min)

Table 2. Recommended Properties of high-temperature, non-varnishing, PAG-Based Fluid for Gas Turbines (New Oil)

IV. LUBRICATION SYSTEM

The lubrication system is configured to provide an ample supply of filtered lubricating oil at the proper temperature and pressure for operation of the turbine and its associated equipment.

1. Protective devices are incorporated into those systems where it is necessary to protect the equipment against low lube oil level, low lube oil pressure, and high lube oil temperature. The protective devices generate an alarm or shut down the unit if any of these conditions occur.

2. The particular arrangement of the system, the protective devices, and the system settings are shown on the schematic piping diagram for the specific gas turbine. Other information on the lubrication system is found in the service manual and includes the system's operation, maintenance, and instructions for the various pieces of equipment used in the system.

V. OPERATING TEMPERATURES

Lubricating oil is exposed to a range of temperatures as it is circulated through the gas turbine. For reliable circulation of oil before starting, the oil temperature should be 75˚F (24˚C) to obtain the appropriate viscosity.

1. The nominal bearing inlet oil temperature is 130˚F (54˚C). However, actual operating conditions may vary due to:

   a. Customer requirements,

   b. Ambient conditions, and/or

   c. Coolant temperature.

2. The lubricating system cooling equipment is configured to maintain the nominal 130˚F (54˚C) bearing inlet oil temperature when a large volume of plant raw water is available for cooling. However When radiator systems are involved, it should be noted that while the nominal 130˚F (54˚C) bearing header will be maintained for a high percentage of the operating time, the sizing is such that for the maximum recorded and reported ambient temperature at the site, the bearing header temperature may be 160˚F (71˚C). The minimum recommended oil inlet temperature is 90˚F (32˚C). The gas turbine bearings are configured to operate satisfactorily at these inlet oil temperatures. In special cases, other configured header temperatures are used as dictated by the load devices.

3. Operating bearing temperature rises are discussed in appropriate sections of the service manual. Typically, the lubricant temperature rise from bearing inlet to drain is in the 25˚F to 60˚F (14˚C to 33˚C) range. If a reduction gear is involved, this temperature rise may be 60˚F (33˚C).

4. In some gas turbines have bearing housings are located in an area of high ambient temperature. This ambient and the sealing air may be over 500˚F (260˚C). The bearing housing is sealed with labyrinths and positive airflow such that the bearing drain spaces are at approximately atmospheric pressure. A portion of the lubricating fluid will be mixed with a small quantity of hot sealing air and will wash metal surfaces at a temperature between the bearing housing ambient and the oil drain temperature.

5. The lubricant temperature in the tank will be 25˚F to 40˚F (14˚C to 22˚C) above the bearing header. Thus, the bulk temperature will be 155˚F to 200˚F (68˚C to 93˚C) during operation. When non-varnishing Group V PAG fluid is used, turbine bearings will typically operate at 5oF to 10oF lower temperature. This is due to the higher thermal conductivity of Group V PAG fluid versus Group I or Group II-IV oils.

VI. CORROSION — PREVENTATIVE MATERIALS

Manufacturing procedures are conceived such that all metal surfaces in contact with the lubricating oil in the lubrication system are protected from corrosion by proscribed cleaning and treating.

1. The inside walls of the lubricating oil tank are processed at the factory using an oil-resistant paint.
2. The inner surfaces of all lubricating oil piping, bearings, hydraulic control devices, and other apparatus whose surfaces will be in contact with the turbine lubricating oil are coated with a vapor space rust- inhibited (VSI) lubricating oil which is used as a combination test and shipping oil.
3. In addition, 50 gallons of this oil is put in the reservoir at shipment and the system openings are closed. The oil and its vapors provide corrosion protection during shipment and installation.
4. At installation this oil should be removed and the reservoir manually cleaned. The remaining VSI oil should be removed with a displacement flush.
5. Vapor phase rust inhibitors are polar in nature and can impact the water separation and foaming characteristics of turbine oil. It is essential that they be completely flushed from the turbine before the new turbine oil added. It is strongly recommended that flush oil be disposed of and not re-used as operating oil. Non-varnishing Group V PAG fluids which are also polar in nature may dissolve residual amounts of VSI oil and will provide increased cleaning efficiency during the displacement flush.
6. If necessary, lubricant suppliers may obtain information on the specific VSI oil used via contact with GE Engineering.

VII. CLEANING REQUIRED AT INSTALLATION

The reliable operation of hydraulic controls and machine bearings is dependent upon the cleanliness of the lubricating oil system. During manufacture, considerable care has been taken in processing, cleaning, and flushing this system to maintain the cleanliness. Further, full flow filters are included in the system thereby filtering all of the fluid before its use.

NOTE

For guidance in flushing and cleaning, refer to ASTM Standard D 6439 "Standard Guide for Cleaning, Flushing, and Purification of Steam, Gas, and Hydroelectric Turbine Lubrication Systems." This ASTM standard should be followed.

Most of General Electric Company gas turbines are package power plants that require a minimum of flushing and cleaning at installation.

NOTE

It is strongly recommended that the flush/displacement fluid be of the same properties as the proposed in service fluid, also that the flush/displacement fluid be discarded after use, and that it not be reused for long-term turbine lubrication.

1. If the installation is of a non-package type requiring field pipe fabrication of intricate shapes, then complete cleaning and flushing is required.
2. From the ASTM standard for a package power plant the minimum practices include the following:
3. Upon arrival of the equipment at the site, a general visual inspection should be made to become familiar with the equipment, to observe any shipment damage, and to determine that the lubrication and control systems are sealed from contamination. Take corrective action as necessary from these observations. It is important that the systems subject to contamination or corrosion remain sealed as much as possible during the installation period.
4. The field interconnections of the piping must be clean at installation. This piping is of simple configuration to permit visual inspection and manual cleaning.
5. During the installation, any soft or hard film temporary corrosion protective material must be manually removed.
6. A displacement flush should be performed. Install and circulate the operating lubricant for a 24- to 36-hour period (or longer as necessary) at a temperature of 130˚F to 150˚F (54˚C to 66˚C). The auxiliary lubricant oil pump may be used. Remove and dispose of this displacement fluid.
7. After satisfying the above items, the reservoir should be manually cleaned. The parties involved should be satisfied that the operating lubricant is clean and free of water and that it meets the manufacturer’s recommendations. The actual final fill should be made through a suitable strainer or filter, as a precaution against the accidental ingress of solid foreign objects.
8. After filling, circulate the lubricant through the system to confirm that satisfactory flow has been established. Verify there are no leaks in the system.

VIII. OPERATOR RESPONSIBILITY

A. After the unit is installed, and prior to its initial starting

The operator should take all precautions to ensure:

1. The lubricating system has been thoroughly flushed and is clean.
2. The supply of turbine oil is ample for operation of the unit.
3. The type of oil is in accordance with this instruction.

B. During operation of the unit

The operator should establish a routine inspection procedure to ensure that:

1. The temperature and pressure levels of the lubrication system are within the limits specified by the service manual and the piping schematic diagrams.
2. No leakage is observed throughout the systems.
3. The oil purity is maintained by adhering closely to the recommendations set forth by the oil vendor for sampling, purifying, and replenishing the lube oil supply or inhibitors. Water in-leakage can be checked via sampling of tank bottoms.

C. Recommendations regarding oil storage and reservoir top-up:

1. The operator should store oil per the oil vendor instructions and local regulatory specifications.

   Most vendors recommend storing oil barrels in a covered environment. Oil barrels may not be air-tight. Therefore, in order to prevent ingress of ambient contaminants, some vendors recommend storing the barrels at an angle, such that the level of fluid in the barrel remains higher than the drum access ports.

2. The particle count of the oil tends to increase from the time of production, to delivery, and through the storage period on site.

   Prior to topping up the reservoir with additional oil, it would be prudent to analyze a sample to confirm the physical condition has not deteriorated beyond the oil vendor recommendations. Additionally, the oil should be added through a filter to the reservoir inlet port. The added oil should not deteriorate the overall reservoir oil cleanliness beyond the recommended cleanliness level.

   The recommended oil cleanliness level documentation is referred to in the lubricating oil schematic piping diagram for the gas turbine unit. If the oil vendor cannot specify a filter that would deliver the oil to the reservoir within the cleanliness limits, refer to the flushing instructions for the unit.

NOTE

Always follow the equipment vendor instructions for maintaining hardware or piping that comes into contact with the lubricating oil.

Prior to using any external agent (such as a detergent or chemical) in cleaning these, consult with the hardware and oil vendors on the compatibility or possible side effects of the agent on the oil or hardware.

IX. OIL VENDOR RESPONSIBILITY

It is generally recognized that turbine lubricating fluid should be a petroleum derivative or synthetic hydrocarbon or be a Group V polyalkylene glycol (PAG) based turbine fluid. All fluids should be free from sediment, inorganic acids, or any material which, in the service specified, would be injurious to the oil or the equipment. For the case of petroleum derivatives or synthetic hydrocarbons the lubricating fluid should also be free of water, whereas for Group V PAG based turbine fluids, as much as 7500 ppm of water can be tolerated.

NOTE

The responsibility of supplying the proper oil for the lubricating system to meet this instruction rests with the oil vendor and the Customer.

The oil vendor is expected to make recommendations to the turbine operator concerning compatibility with the VSI oil and operational sampling and testing. Further, they are expected to cooperate with the manufacturer and the operator by providing the support necessary to ensure satisfactory performance of the lubricant, such as examination of oil samples and recommendations for corrective action, if required.

If necessary, lubricant suppliers may obtain information on the specific VSI oil used via contact with GE Engineering.

X. MONITORING

Lubricant condition must be monitored for reliable operation of the gas turbine. ASTM Standard D4378, “In-Service Monitoring of Mineral Turbine Oils for Steam and Gas Turbines" provides guidance for selecting sampling and testing schedules. This document recommends sampling the oil after 24 hours of service and then suggests nominal intervals depending on hours of operation.

The sampling and testing schedule should be adjusted for site-specific conditions, to account for the severity of operating conditions as well as oil condition. ASTM Standard D4378 provides information that can be useful in making this determination.

Oil analysis has been in a state of change over the past 10 years. Traditional tests that have been used for decades have been somewhat ineffective at predicting the remaining useful life or deposition tendencies of newer turbine oil formulations. As such, new tests have been introduced which are proceeding through the ASTM approval process. Some of those tests will be referred to in this document revision. It is important to understand that clear communication needs to take place between the turbine operator, the fluid supplier and the test lab when interpreting test results and implementing actions based on those results.

A. Sampling

The proper sampling techniques are important when taking lubricant samples. In order for a sample to be representative, it must be obtained either from a free flowing line or an agitated tank.

1. The preferable sampling method is sampling from a Line.

The lubricating fluid, in the line should be free-flowing and not deadheaded. For instance:

a. The lines in the bearing header, the active filter and active heat exchanger are free flowing; the lines to the gauge cabinet are deadheaded.

b. In a machine with dual filters or heat exchangers, the inactive filters or heat exchangers do not have flowing fluid and, therefore, are not suitable sampling points.

When using a sampling line, make sure that the line has been thoroughly flushed before taking a sample. Adequate amount of flushing will depend on sampling line dimensions, length and diameter.

2. Secondary sampling methods are:

a. Tapping from the Tank or Reservoir:

As described above, the lubricant fluid must be thoroughly agitated in the reservoir (via operation of the main lube pump(s)) and the tap line flushed before a sample can be taken.

The tapping point should be located at a level between ½ and ¾ up from the bottom of the tank. In order to ensure a representative sample, fluid should never be drawn from the drain point.

b. Dipping from the Tank:

Where neither of the above facilities is available the lubricant fluid sample must be taken by dipping from the tank. Lubricant should be thoroughly circulated (with one or more lube oil pumps) before the sample is taken.

The sample should be taken from a level between ½ and ¾ up from the bottom of the tank. Care should be taken to avoid, so far as possible, collecting any contaminant from the surface layer of the oil. Thorough agitation during the sampling process will help to minimize this; the use of a sampling "thief" will avoid introducing any fluid from the surface layer.

3. A fluid sample is probably not representative if:

a. The fluid in the system is hot while the sample is cold.

b. The fluid in the system is one color or clarity in a sight glass while the sample is a different color or clarity.

c. The viscosity of the reservoir fluid is different than the sample when both are at the same temperature.

d. It should be noted that on occasion a sample may be requested that will not be representative of the overall system. At that time, sampling instructions, as specified by the requestor, must be followed. For example, a sample might be taken off the top or the bottom of a tank to check for contamination. In such a case, the sampling point should be clearly marked on the sample container.

e. When a sample is taken, care should be used to ensure that all available headspace in the container is used. In other words, the container should be as full as possible to ensure that any free oxygen is minimized.

4. Samples should be taken in a "suitable" container.

To be "suitable", the container should be:

a. Clean. If in doubt about its cleanliness, use another container. If this is not possible, flush it out with the fluid to be sampled.

b. Resistant to the material being sampled. For instance, the fire resistant phosphate ester fluids and some fuels will dissolve certain plastics. This includes the liner in bottle caps. To verify the container's resistance, if time permits, allow the sample to sit in container and observe its effects. Aluminum foil makes a good, resistant cap liner.

c. Appropriate for whatever handling is required. Containers with leaking tops and glass containers improperly protected are not suitable for shipment. Note that stringent packaging requirements must be followed if shipment is to be made by air.

d. Of sufficient size. An extensive chemical analysis, if that is why a sample is required, cannot be done on the contents of a container that is too small. Normally one pint is sufficient unless a larger quantity is requested.

e. Opaque. Certain chemical reactions can be initiated or accelerated by exposing the sample to sunlight.

f. Lubricant suppliers may provide sample containers that meet the above-mentioned requirements. These should be used whenever possible. If frequent samples are taken, an adequate supply of containers should be kept.

5. A sample should be properly marked.

Markings should include at least the following information:

1) Customer name,
2) Site Name,
3) Site Location,
4) Turbine serial number,
5) Turbine fired hours,
6) Turbine fired starts,
7) Date sample taken,
8) Type of fluid sampled,
9) Sampling point, and
10) Approximate number of total hours the fluid has been in service.

a. Samples from the initial fill

These should be forwarded to the lubricant supplier and/or a laboratory for extensive tests; these test results will be used as a base line and the results kept for the life of the fluid. This sample should be taken at least 24 hours after the system has been placed in normal operation to ensure it is representative of oil that will be in use for long-term service.

b. The frequency of other samples

Frequency depends upon the service; results of previous samples should be consistent with the oil supplier's recommendations. Sufficient tests and sample intervals are necessary to establish trends and to prevent significant lubricant operational problems. Sharing the test results among the user, oil supplier, contracted laboratory and General Electric Company Gas Turbine Division can be helpful.

c. Clean

Bottles for particle count analysis should be certified clean to NAS 3 (max) to avoid introducing contaminant which could potentially affect the cleanliness level result of samples being reviewed.

NOTE

Test result trending is critical. Making decisions based on single data points is not recommended. If test results do not follow a logical trend, re-sampling and testing would be recommended.

B. Oxidation

Oxidation is the primary mechanism responsible for turbine oil degradation. As such, it is critical to understand the Oxidation stability of any proposed new oil and oils that are in service/use.

Historically, test method ASTM D2272 (Standard Test Method for Oxidation Stability of Steam Turbine Oils by Rotating Pressure Vessel) has been widely accepted as way for monitoring degradation due to oxidation.

This test, along with TAN (Total Acid Number) and Viscosity have been very effective in providing a complete picture for monitoring oil condition and allowing reasonable projections for the remaining useful life of the fluid.

More recently, with the introduction of special, highly refined Group II and Group III base stocks and the use of complex, multi-component antioxidant systems for turbine oil formulations, this test has been proven to be less representative of used oil condition.

In particular, the ASTM D2272, test when used for some modern oil formulations, has been shown to be susceptible to variation caused by the oxidation inhibitors used. ASTM D2272 is also influenced by the presence of certain additive components other than antioxidants, such as anti-wear additives, metal passivators and corrosion inhibitors, providing a misleading picture of the oxidative stability of the fluid.

For this reason, and due to its poor precision, it is falling from favor as a condition monitoring technique for oils in service. Care should be taken if this test is being used for condition monitoring.

For oils formulated with a standard Group I base stock and conventional antioxidant system, the ASTM D2272 test is still valid and should be continued as is recommended in Table 1.

C. Synthetic Oils

Synthetic oils are currently being successfully utilized in many different kinds of equipment, including heavy-duty gas turbines. Due to the very specific nature of synthetic formulations, it may be possible that the recommended values shown in Table 1 are not consistent with the values of synthetic oil being considered for use in a GE gas turbine. As was stated previously, the values in Table 1 are only recommended values. Oil that has been shown to perform successfully in the field may still be used even if all values in Table 1 have not been satisfied.

Among the synthetic oils currently being successfully utilized, Group V PAG formulations offer several unique attributes that provide advantages for turbine operators; these include reduced friction, increased heat transfer, faster air release, increased water tolerance, improved solubility characteristics, and as described previously in Section II, of this document are inherently non-varnishing. When using Group V PAG based turbine fluid, the recommended values indicated in Table 2 should be consulted.

XI. USE LIMITS- GROUP I OILS WITH CONVENTIONAL ANTIOXIDANT ADDITIVES

The lubricant supplier will have recommended use limits. However, General Electric Company also has recommendations that are stated in this section. The object of the use limits is to prompt action before turbine operational problems develop because of the condition of the oil. Recommended use limits are given in Table 3 and discussed below.

ASTM D445	Viscosity at 40˚C (104˚F)	35.2 centistokes (max.) 28.8 centistokes (min.)
ASTM D974	Total Acid Number	0.2-0.3 rise from initial (see table 1) Max not to exceed 0.4 mg KOH/gm.
ASTM D6971	Measurement of Hindered Phenolic and Aromatic Amine Antioxidant Content in Non-zinc Turbine Oils by Linear Sweep Voltammetry	25% (min) of new oil value
ASTM D2272	Rotating Pressure Vessel Oxidation Test (RPVOT)	25% (min.) of new oil value (see table 1)
*Membrane Patch Colorimetry (MPC)		Trend

(*Currently undergoing ASTM approval)

Table 3. Recommended Use Limits- Group I Oils with Conventional Antioxidant Additives

In the event that any of these limits is exceeded, the lubricating oil needs to be changed. The steps for such a change include:

1. Draining the old oil,
2. Manually mopping out the tanks,
3. Filling and displacement flush (as described in Section VII),
4. Draining flush oil,
5. Manually mopping out the tank, and
6. Filling the tank with the new charge of oil...

XII. USE LIMITS- HIGHLY REFINED GROUP I & GROUP II-IV OILS WITH COMPLEX ANTIOXIDANT ADDITIVES

The introduction of oil formulations, which utilize a Group II base stock and a combination (Phenol and Amine) anti-oxidation system has shown that the traditional parameters monitored for Group I formulations (Viscosity, Acid and Oxidation) are not as effective in trending and predicting the remaining useful life of the oil. However, it is still recommended that these 3 parameters be monitored, along with the additional tests shown in Table 4.

As mentioned previously, new tests are currently being evaluated to assist turbine operators with monitoring the condition of oils formulated with Group II-IV base stocks and mixed Phenol/Amine anti-oxidation additives. In order to receive ASTM approval, these new analytical tests must pass a rigid testing protocol and are currently pending. They are being referenced in this document to assist turbine operators in the absence of any available approved tests and should be utilized in close coordination with the oil suppliers and testing labs.

The lubricant supplier will have recommended use limits. However, General Electric Company also has recommendations that are stated in this section. The object of the use limits is to prompt action before turbine operational problems develop because of the condition of the oil.

ASTM D445	Viscosity at 40˚C (104˚F)	35.2 centistokes (max.) 28.8 centistokes (min.)
ASTM D974	Total Acid Number	0.2-0.3 rise from initial (see table 1) Max not to exceed 0.4 mg KOH/gm.
ASTM D6971	Measurement of Hindered Phenolic and Aromatic Amine Antioxidant Content in Non-zinc Turbine Oils by Linear Sweep Voltammetry	25% (min.) of new oil value
*Membrane Patch Colorimetry (MPC)		Trend
ASTM D5452	Standard Test Method for Particulate Contamination in Aviation Fuels by Laboratory Filtration	Trend
ASTM D7214	Standard Test Method of Determination of the Oxidation of Used Lubricants by FT-IR Using Peak Area Increase Calculation	Trend

(*Currently undergoing ASTM approval)

Table 4. Recommended Use Limits

XIII. USE LIMITS- NON-VARNISHING PAG BASED FLUIDS (WITH SUPERIOR ANTIOXIDANT ADDITIVES)

ASTM D445	Viscosity at 40˚C (104˚F)	31.0 centistokes (max.) 20.0 centistokes (min.)
ASTM D974	Total Acid Number	Max not to exceed 2.0 mg KOH/gm.
ASTM D6971	Measurement of Hindered Phenolic and Aromatic Amine Antioxidant Content in Non-zinc Turbine Oils by Linear Sweep Voltammetry	25% (min.) of new oil value
ASTM D 6304	Water	7500 ppm (max)
ASTM D 3427	Air Release	2.0 (max)
*Membrane Patch Colorimetry (MPC)		Trend
ASTM D5452	Standard Test Method for Particulate Contamination in Aviation Fuels by Laboratory Filtration	Trend
ASTM D7214	Standard Test Method of Determination of the Oxidation of Used Lubricants by FT-IR Using Peak Area Increase Calculation	Trend
*Currently undergoing ASTM approval		

Table 5. Recommended Use Limits

With any one of these measurements out of limits (if applicable), the lubricating oil needs to be changed, the steps for such a change include:

1. Draining the old oil,
2. Manually mopping out the tanks,
3. Milling and displacement flush (see Section VII),
4. Draining flush oil,
5. Manually mopping out the tank, and
6. Filling the tank with the new charge of oil.

XIV. COMMENTS

As the turbine manufacturer, the following comments are offered.

A. Oil Purifying or Conditioning Systems

Oil conditioning systems, configured in a "side stream" or "kidney koop" arrangement have been shown to be effective, however the main concern when considering such an arrangement is the effect it may have on specific additives to and performance of the finished oil. For example centrifuges are not recommended because of their potential for removing oil additives. The fluid supplier should be consulted when utilization of one of these systems is being considered.

Full-flow filtration is included in the lubrication system; it should be noted that these filters have been sized for bearing protection. Attempting to reduce the pore size may result in complications and is not recommended.

An operating gas turbine is an excellent dehydrator; thus water removal systems are normally not necessary. Water contamination is limited to condensation and cooler leaks. It is recommended that the cooling water pressure be maintained below lube fluid pressure, so that the chance of water leakage into the lubrication system is minimized.

Clay filters are not recommended for cleaning of turbine oils meeting these instructions.

B. Use of Additives

As a general guideline customers should not incorporate any additives into the fluid. This prohibition particularly refers to the use of

1. "Oiliness additives,"
2. "Oil dopes,"
3. Preservative oils,
4. Anti-oxidants, and
5. Engine Oils.

Past experience indicates that these fluids have been introduced to the system during installation and maintenance; extra care should be taken during those times to prevent this from occurring.

If oiling the bearing is required to facilitate rolling of the shaft during maintenance, the oil from the lubricant oil tank should be used.

In some cases, the addition of certain additive components to in-service turbine oils can correct fluid performance issues. Extreme care should be taken if considering this practice and undertaken only with the cooperation of the fluid supplier. Third party additive products are not recommended.

C. Diagnostics Programs

Diagnostic programs such as wear metal analysis (e.g., Spectrographic Oil Analysis Program (SOAP)), may be used as part of oil sampling and analysis. General Electric makes no recommendation with regard to use of these programs. There are, however, several reservations. These programs should be used for establishing trends; a single point in time value is not meaningful. Unlike aircraft jet engines and piston engines, there have not been and are not any studies correlating the "spot" results of these programs with performance of a gas turbine. With the type of bearings used in a gas turbine, impending bearing failure is most likely to be predicted by analysis of mechanical vibration.

D. PAG Compatibility

As a general guideline turbine operator should not mix different lubricating turbine fluids in the system. A small amount, less than 2 % by volume, of mineral oil or synthetic hydrocarbons can only be tolerated in PAG based synthetic fluid . However contamination by a larger amount of petroleum or synthetic hydrocarbon based oil will compromise the functionality of the PAG based synthetic fluid and the turbine lubrication system itself, and must be avoided. Operators who desire to switch to a new type of oil should consult with the oil vendor and should adhere to the steps defined in Section VI regarding the cleaning of VSI oil during initial installation.

XV. APPENDIX A – TEST METHOD

For detailed information concerning the various test methods, please refer to the parent published documents. The discussions below are simply intended to help explain various tests and properties and are provided for informational purposes only.

A. Viscosity

The viscosity of a fluid is its resistance to flow. Viscosity is commonly reported in stokes which has the units of cm/sec. Centistokes (one hundredth of one stoke) are most commonly used for convenience. The viscosity in centistokes is also called the kinematic viscosity. The absolute or dynamic viscosity is expressed in poise (more commonly centipoise). It is the kinematic viscosity in stokes (or centistokes) at a given temperature multiplied by the density of the fluid at this temperature expressed in grams/cm3.

The viscosity in centistokes is determined per ASTM D445, “Viscosity of Transparent and Opaque Liquids (Kinematic and Dynamic Viscosities).” The viscosity is calculated from the time required for a fixed volume of fluid at a given temperature to flow through a calibrated glass capillary instrument using gravity flow.

Centistoke viscosities can be converted to Saybolt and vice-versa using the tables and formulas given in ASTM 2161 “Conversion of Kinematic Viscosity to Saybolt Universal Seconds.”

1. The viscosity limits provided above are consistent with the guidelines presented in ASTM D4378 “Standard Practice for In-Service Monitoring of Mineral Turbine Oils for Steam and Gas Turbines.” High viscosity is most likely the result of oil oxidation. Low viscosity is probably the result of contamination with fuel or a lower viscosity lubricant or other fluid.
2. Viscosity Index (VI) is an arbitrary number used to characterize the variation of kinematic viscosity with temperature. A higher VI indicates a smaller decrease in kinematic viscosity with increasing temperature or in other words, the higher the VI, the more resistant to viscosity change the oil is.

B. Pour Point

Pour point is the lowest temperature at which a fluid is observed to flow and is determined per ASTM D97 “Standard Test Method for Pour Point of Petroleum Products.” It is reported in increments of 5˚F and is determined as the temperature at which fluid, contained in a tube with an inside diameter of 30 to 33.5 mm, will not flow within five seconds of rotating the tube 90 degrees from the vertical to the horizontal position.

The pour point is reported more as a matter of information. Of practical concern in the configured of lubrication systems is the viscosity at which the lubricant fluid becomes too viscous to be pumped. For General Electric gas turbines the viscosity should be less than 173 centistokes for proper circulation of the fluid before starting.

C. Total Acid Number (Neutralization Number)

The total acid number is the milligrams of potassium hydroxide (KOH) required to neutralize the acidic constituents in a gram of sample. It is determined per ASTM D974, “Neutralization Number by Color Indicator Titration.” The total acid number (TAN) is sometimes called the neutralization

D. Flash and Fire Point

Flash and fire points are determined per ASTM D93 “Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester”

Flash and Fire Points are an indirect measure of both the volatility of the fluid and the flammability of these volatiles. Since there are more accurate ways of determining these (for instance, distillation to determine volatiles, this test is mainly of value as a quality control test.

E. Oxidation Tests

1. ASTM D943: “Standard Test Method for Oxidation Characteristics of Inhibited Mineral Oils" is the traditional oxidation test for turbine oils.
   a. In this test, a sample of oil is placed in a container of water along with pieces of steel and copper wire that have been coiled together. The container is maintained at a temperature of 203˚F (95˚C) and oxygen is passed through it.
   b. The test measures the time in hours for the acidity to reach 2.0 milligrams of potassium hydroxide per gram of sample.
2. ASTM D2272: “Standard Test Method for Oxidation Stability of Steam Turbine Oils by Rotating Pressure Vessel”
   a. This test is included as a screening test for new oils. It is normally used for quality control of particular new oil formulation.
   b. Although over time this test has been adopted widely as a condition monitoring test for oils in service, it has a number of disadvantages in this application. In particular,
   c. The result is susceptible to variation caused by certain contaminants present in the oil, and
   d. Results can be influenced by the effect of additive components other than antioxidants, such as anti-wear additives, metal passivators and corrosion inhibitors.
   e. In the latter case, it has been found that the volatility of inhibitors can have a significant effect on the results of this test when applied to oil in service.

   In screening new oils, the ASTM D2272 test should be run in the normal way and compared to the result of a second test run on oil which has been treated to remove volatiles:

   a. ASTM2272 Modified
      1) This pretreatment is done by putting the oil to be tested in a test tube 38 mm ID× 300 mm L. (This is the same tube used for the International Harvester BT-10 oxidation test.)
      2) This tube is immersed in a bath maintained at 250˚F (l21˚C). Clean, dry nitrogen is then bubbled through the heated oil for 48 hours at the rate of 3 liters per hour.
      3) The treated oil is then tested per ASTM D2272.
      4) The value obtained in the test of the treated oil should be no less than 85% of that obtained for the untreated.

b. The ASTM D2272 is an oxygen absorption test.

Oil, water, and copper catalyst coil, contained in a covered glass container, are placed in a vessel equipped with a pressure gauge. The vessel is charged with oxygen to a pressure of 90 psi (620 kPa), placed in a constant temperature oil bath set at 302˚F (150˚C), and rotated axially at 100 rpm at an angle of 30 degrees from the horizontal.

The time for the test oil to react with a given volume of oxygen is measured, with completion of the time being indicated by a specific drop in pressure.

3. Modified ASTM D-2893 B Oxidation Test Method for PAG-based Synthetic Turbine Fluid:

   a. The test lubricant (300ml) in a borosilicate glass tube is heated to 249.8 °F (121°C) in dry air for 312 hours (13 days).

   b. Both before and after the test, the kinematic viscosity of the fluid at 212°F (100°C) (KV100) is recorded according to ASTM D7042 and the percentage change recorded.

   c. A visual inspection of the fluid before and after the test is also made and any deposit formation recorded.

F. Anti-Oxidant Additive Levels

The ASTM D6971, "Standard Test Method for Measurement of Hindered Phenolic and Aromatic Amine Antioxidant Content in Non-zinc Turbine Oils by Linear Sweep Voltammetry" is gaining popularity as an effective method of quantifying the remaining antioxidant levels of oils in service and therefore giving a measurement of remaining useful life.

The method is essentially a comparator technique evaluating antioxidant levels in the sample under test against the initial levels present in a new oil sample.

G. Foaming Tendency

The ASTM D892 "Standard Test Method for Foaming Characteristics of Lubricating Oils" specifies three sequences of bubbling air through oil. First, it is done at 75˚F; second, it is done with a new sample of oil at 200˚F; and third, the oil from the second sequence is used but operated at 75˚F.

H. Rust Prevention

The rust prevention characteristics of the lubricant are determined per ASTM D665 "Standard Test Method for Rust-Preventing Characteristics of Inhibited Mineral Oil in the Presence of Water."

1. In many instances, such as in the gears of a steam turbine, water can become mixed with the lubricant and rusting of ferrous parts can occur.
2. This test indicates how well inhibited mineral oils aid in preventing this type of rusting.
3. This test method is also used for testing hydraulic and circulating oils, including heavier-than-water fluids.
4. It is used for specification of new oils and monitoring of in-service oils.

I. Air Release

D3427 “Standard Test Method for Air Release Properties of Petroleum Oils” describes the method for determining air release properties of petroleum oils.

1. Compressed air is blown through oil heated to a specified temperature. The length of time required for the air entrained in the oil to reduce to 0.2% is recorded as the air release time.
2. Air release provides a measure of the oil’s performance in hydraulic systems because entrained air results in the fluid becoming a compressible medium, which can lead to sponginess and sluggish response in hydraulic systems.
3. Entrained air can adversely affect the lubrication properties of the oil and also reduces the density of the fluid, which can lead to malfunction of critical systems.

J. Insolubles

1. MPC

This is the new test method for the measurement of lubricant generated insoluble color bodies in in-service turbine oils using membrane patch Colorimetry.

Turbine oil degradation products lead to deposits and have color bodies that can be measured in this test.

a. The MPC test extracts insoluble contaminants from 50ml of in-service turbine oil mixed with 50ml of petroleum ether onto a 0.45 nitro-cellulose membrane.

b. The color of the patch is then measured by a spectrophotometer. The darker the membrane, the higher potential the fluid has for generating deposits in the turbine oil system. T

c. The results of this procedure are reported as a Delta E value, within the CIELAB scale, representing the total color of the patch.

NOTE

The above test is in the ASTM validation phase and is being referenced here to assist turbine operators with oil condition monitoring.

2. FTIR

FT-IR - ASTM D7214 “Standard Test Method for Determination of the Oxidation of Used Lubricants by FT-IR Using Peak Area Increase Calculation.”

Oxidation, measured by FTIR fixed path length, will indicate level of general thermo oxidative degradation. Measurement can also indicate the presence of degradation mechanisms such as dieseling and electrical spark discharge.

Spectroscopy is often employed for wear metal analysis. A number of physical property tests can complement wear metal analysis and are used to provide information on lubricant condition. Molecular analysis of lubricants and hydraulic fluids by FT-IR spectroscopy produces direct information on molecular species of interest, including additives, fluid breakdown products and external contaminants, and thus complements wear metal and other analyses used in a condition-monitoring program.

FT-IR can be used to monitor additive depletion, contaminant buildup and base stock degradation. Contaminants monitored include water and incorrect make up oil. Oxidation can be monitored as evidence of degradation of the base stock.

Warning or alarm limits are currently not available, and test results should be trended and used in conjunction with a correlation to equipment performance to establish whether actions are necessary. Consultation with the oil supplier and/or test lab is required.

K. Water Content

The presence of water in the lubricating fluid is not indicative of decomposition but in the case of Group I and Group II-IV formulations, water can, however, promote the decomposition of the lubricating oil by reacting with additives in the oil.

1. Water may also promote corrosion, which in turn may cause filter plugging.
2. The presence of water may indicate a problem with the turbine system such as a leaking heat exchanger.
3. The source of water should be determined and corrected. For PAG-based turbine fluids, as much as 7500ppm of water can be tolerated.

L. 15. Particulates

ASTM D5452 – (Standard Test Method for Particulate Contamination in Aviation Fuels by Laboratory Filtration)

1. This method details how to measure particulates in fluids by measuring the change in weight of a membrane filter after a known volume of fluid has been passed through it. Although the test was configured with aviation fuels in mind, the procedure is also suitable for measuring the mass of contaminants in turbine oils.
2. It is advisable to use a 0.45-micron nitro-cellulose membrane filter and approximately 100 ml of fluid. The particulate contamination is determined by measuring the increase in mass of the test membrane relative to the control membrane filter and the results are expressed as mg/L.
3. This is a complimentary test to particle counting and membrane patch colorimetry and provides a more complete contamination profile of the fluid.
4. As stated above, the oil supplier may have other tests to determine oil conditions. These tests and any associated limits should be included in the oil-monitoring program.

XVI. APPENDIX B - GENERAL

The American Petroleum Institute (API) classifies base stocks as one of five categories.

GROUP I	Mineral oil derived from crude oil, produced via solvent refining or de-waxing.
GROUP II	Mineral oil derived from crude oil, produced via hydro processing.
GROUP III	A highly refined mineral oil derived from crude oil, with a VI >120 made via hydro cracking. (In North America this group is considered synthetic oil, for marketing purposes.)
GROUP IV	All Polyalphaolefin (PAO) oils. These are synthetics.
GROUP V	All base stocks not in Groups I-IV (naphthenics, re-refined, non-PAO Synthetics including polyalkylene glycols (PAGs), and esters

Table 6. API Base Stocks

Oil formulators may also combine base stocks to create hybridized formulations.

GE Power & Water

General Electric Company
www.ge-energy.com