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Standard Guide for Cleaning, Flushing, and Purification of Steam, Gas, and Hydroelectric Turbine Lubrication Systems[1]

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INTRODUCTION

Optimum turbine system reliability requires a well designed lubricating system and use of a good lubricant that is free of contaminants. Achieving this requires use of proper purification methods to ensure that the oil is free of detrimental contaminants. In addition, it requires an ongoing monitoring program to ensure that the oil quality is within specifications and that corrective action is taken to minimize contaminant generation and ingression. The benefits of purification of an operating lubrication system can be significantly reduced if the lubricating systems are not initially cleaned to a level that will prevent component damage on initial start up after manufacturing or rebuilding.

Care and thorough cleaning are required to minimize and remove contaminants during fabrication, rebuilding, or installation, or combination thereof. Because contaminants will remain from these processes, it is necessary to flush and purify the system to remove them prior to startup. Ongoing purification is required to maintain pure oil during operation. In new systems, the emphasis is on the removal of contaminants introduced during manufacture, storage, field fabrication, and installation. In operational systems, the emphasis is on the removal of contaminants that are generated or carried in during operation, and by malfunctions that occur during operation or contaminants that are introduced during overhaul, or both.

1. Scope

1.1 This guide covers types of contaminants, oil purification devices, contamination monitoring, contamination control during building or refurbishing of turbine systems, lubrication system flushing, and maintenance of pure lubrication oil.

1.2 To obtain maximum operating life and reliability, or lubricants and system, it is vital that the turbine lubrication system has pure oil. This guide is intended to aid the equipment manufacturer, installer, and turbine operator in coordinating their efforts to obtain and maintain clean lubrication and control systems. These systems may be on land or marine turbine generators and propulsion and mechanical drive equipment. This guide is generalized due to variations in the type of equipment, builder's practices, and operating conditions.

1.3 This guide primarily addresses petroleum based lubricating oil. For systems using nonpetroleum based fluids, this guide may not be appropriate. For nonpetroleum products, consult the equipment and fluid manufacturers.

1.4 This guide is applicable to both large and small lubrication systems. Some equipment specified herein, however, may not be appropriate for all systems. Moreover, in situations where specific guidelines and procedures are provided by the equipment manufacturer, such procedures should take precedence over the recommendations of this guide.

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

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

[1] This guide is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.C0.01 on Turbine Oil Monitoring, Problems and Systems.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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

D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
D664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration
D974 Test Method for Acid and Base Number by Color-Indicator Titration
D2272 Test Method for Oxidation Stability of Steam Turbine Oils by Rotating Pressure Vessel
D4241 Practice for Design of Gas Turbine Generator Lubricating Oil Systems (Withdrawn 2008)[3]
D4248 Practice for Design of Steam Turbine Generator Oil Systems (Withdrawn 2008)[3]
D4378 Practice for In-Service Monitoring of Mineral Turbine Oils for Steam, Gas, and Combined Cycle Turbines
D4898 Test Method for Insoluble Contamination of Hydraulic Fluids by Gravimetric Analysis
D6304 Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration
D6810 Test Method for Measurement of Hindered Phenolic Antioxidant Content in Non-Zinc Turbine Oils by Linear Sweep Voltammetry
D6971 Test Method for Measurement of Hindered Phenolic and Aromatic Amine Antioxidant Content in Non-zinc Turbine Oils by Linear Sweep Voltammetry
D7155 Practice for Evaluating Compatibility of Mixtures of Turbine Lubricating Oils
D7546 Test Method for Determination of Moisture in New and In-Service Lubricating Oils and Additives by Relative Humidity Sensor
D7647 Test Method for Automatic Particle Counting of Lubricating and Hydraulic Fluids Using Dilution Techniques to Eliminate the Contribution of Water and Interfering Soft Particles by Light Extinction
F311 Practice for Processing Aerospace Liquid Samples for Particulate Contamination Analysis Using Membrane Filters
F312 Test Methods for Microscopical Sizing and Counting Particles from Aerospace Fluids on Membrane Filters

2.2 *ISO Standards:*[4]
ISO 3722 Hydraulic Fluid Power—Fluid Sample Containers—Qualifying and Controlling Cleaning Methods
ISO 4021 Hydraulic Fluid Power—Particulate Contamination Analysis—Extraction of Fluid Samples from Lines of an Operating System.
ISO 4406 Hydraulic Fluid Power—Fluids—Method for Coding Level of Contamination by Solid Particles
ISO 4572 Hydraulic Fluid Power—Filters—Multi-pass Method for Evaluating Filtration Performance

2.3 *API Standard:*[5]
API 614 Lubrication, Shaft-Sealing, and Control-Oil Systems for Special Purpose Applications

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *adsorption, n*—removal of contaminants from oil by adhesion of the contaminant in an extremely thin layer of molecules to a fixed solid. The solid can be a fiber, a fine powder, or porous particles.

3.1.2 *centrifugation, n*—use of centrifugal force to separate contaminants from oils. Contaminants such as water and particulate are generally more dense than the oil and migrate to the outside of the centrifuge because of centrifugal force.

3.1.3 *cleaning, v*—direct removal of contaminant from any part of the system, generally with the system shut down or offline. Cleaning can include removal of contaminant by shoveling, sweeping, squeegee, vacuuming, wiping, displacing with clean, dry compressed air and can be done with the aid of cleaning solutions.

3.1.4 *cleaning solution, n*—fluid used to aid in the removal of sludge and particulate matter in a system. Cleaning solutions may be classified as chemical cleaners, solvent cleaners, or oil soluble cleaners.

3.1.5 *coalescence, n*—process of passing oil with free water through a fiber sheet, generally in a cartridge form, to cause smaller drops of water to join to form larger ones that can be more easily removed from the oil.

3.1.6 *coalescer, n*—device that uses coalescence to separate water from oil. A coalescer generally consists of a coalescing cartridge(s) and a hydrophobic barrier that hinders water from passing out with the oil. It may also contain a filter located upstream or downstream, or both, of the coalescing cartridge(s).

3.1.7 *displacement flush, n*—system flush using on-board turbine pumps designed to remove unwanted materials from installation or repair.

3.1.8 *displacement oil, n*—oil used to remove either a lighter grade flush oil or an oil that is highly contaminated with oil soluble material.

3.1.9 *filter, n*—device containing a screen or fiber depth medium that removes particles from oil by physically trapping them in or on the screen or mesh.

3.1.10 *flushing, v*—circulation of liquid through the lubrication system or a component, when the turbine is not operating, to remove contaminant.

3.1.11 *high-pressure water flush, n*—use of high-pressure water to remove heavy rust or fouling from lube system internals.

3.1.12 *high-velocity flush, n*—system flush using external pumps that generate three to four times normal operating system velocities and a Reynolds number over 4000.

[3] The last approved version of this historical standard is referenced on www.astm.org.
[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.
[5] Available from American Petroleum Institute (API), 1220 L. St., NW, Washington, DC 20005-4070, http://www.api.org.

3.1.13 *operating oil, n*—specific charge or chemistry of oil to be used as the final fill oil after the flush.

3.1.14 *oxidation, n*—chemical reaction of a lubricant at elevated temperatures between dissolved atmospheric oxygen and the base oil. Oxidation reaction will be accelerated by the presence of oxidation accelerators such as metallic contaminants and water.

3.1.15 *pure oil, n*—homogeneous lubricating oil containing stable additives and free of soluble or insoluble contaminants of concentrations that exceed the lubrication system specifications.

3.1.16 *purification, v*—removal of a contaminant present in the oil through a separation process.

3.1.17 *sacrificial flush oil, n*—charge of oil that is used in the flushing process and not used as the final operating oil.

3.1.18 *surface active flush, n*—system flush with the use of surface active cleaners to remove varnish and sludge.

4. Significance and Use

4.1 This guide is intended to aid the equipment manufacturer, installer, and turbine operator in coordinating their efforts to obtain and maintain clean lubrication and control systems.

4.2 The flushing and cleaning philosophies stated in this guide are applicable to both large and small lubrication systems.

4.3 Clean lubrication systems result from proper system design and good planning, execution, and communication by all involved during commissioning. No phase of these procedures should be undertaken without a thorough understanding of the possible effects of improper system preparation. The installation, cleaning, and flushing of the equipment should not be entrusted to persons lacking in experience.

4.4 Because of the knowledge and specialized equipment that is required, the operator may wish to employ an outside specialist contractor for the system flushing. Review of this guide can provide guidelines for discussion with prospective contractors.

5. Contamination Control Overview

5.1 Lubrication systems can become contaminated from a variety of sources. The main focus of this guide is on the minimization, monitoring, and control of contaminants: water and both soluble and insoluble (stationary and suspended) contaminants. A more detailed discussion of these types of contaminants is given in Appendix X1.

5.2 Contamination control is the complete program of obtaining and maintaining a clean lubricant and lubrication system. This includes proper construction and maintenance practices, appropriate purification equipment, and regular monitoring of contaminants. The contamination control program must be capable of identifying and measuring contaminants and controlling them at, or preferably below, component tolerances. In particular, the sensitivity of bearings, gears, seals, and proportional and servo valves should be reviewed. As described in X2.7.1, cleanliness levels for various system components are generally established by their manufacturers' specifications. These and recommendations of the fluid manufacturer must be considered when employing contamination control systems. In addition, there are insoluble contaminants (oxidation precursors) that are below machine tolerances, but as their volume amasses they create a potential for sludge and varnish creation as a normal consequence of oxidation reactions.

5.3 Contamination control considerations must begin with system design and continue through the manufacture, installation, flushing, operation, and maintenance of the system.

5.4 Design of the system must consider component contaminant sensitivity and provide points for sampling oil and methods for controlling contaminants. Contamination monitoring is discussed in Appendix X2 and contamination control methods in Appendix X3. Inclusion of filtration in steam and gas turbine lubrication systems is discussed in Practices D4248 and D4241 respectively.

5.5 The manufacturer must minimize the amount of built-in contaminant by minimizing ingression and by flushing components to achieve target cleanliness levels in the finished component.

5.6 Contamination control during installation and major maintenance of turbine systems is discussed in Section 6.

5.7 Proper heating is critical during flushing and routine operation to minimize oil degradation. Heating is discussed in Appendix X4.

5.8 Removal of contamination by flushing is discussed in Section 7.

5.9 Contamination control in operational systems and during routine maintenance is discussed in Section 8. Properly designed systems can normally control water and insoluble contaminants in operational systems. If, however, it is necessary to remove soluble contaminants other than water, an oil change and also possibly a flush may be required.

6. Contamination Control When Installing and Refurbishing Turbine Systems

6.1 *General:*

6.1.1 Exclusion or removal of contaminant, or both, in manufacturing or refurbishing, or both, are necessary for a subsequent successful flush and can be achieved only by the cooperation and diligence of many parties.

6.1.2 *Examples of Essential Precautions to Exclude or Remove Contaminant, or Both:*

6.1.2.1 The system should be designed to allow successful cleaning.

6.1.2.2 The pipe and other equipment must be properly cleaned and preserved.

6.1.2.3 All possible locations for the entrance of dirt (pipe ends) must be durably covered and secured for storage prior to shipment and loading. Shipment and unloading must take place without damage to these covers.

6.1.2.4 Inspection of pipe at the turbine site must be thorough to discover any damage or open covers and to have them repaired.

6.1.2.5 Storage prior to installation must be in a sheltered location, especially if the storage is to be for a long duration.

6.1.2.6 Inspection immediately prior to installation must be thorough, and the pipe must be cleaned if excessive rust or dirt is discovered.

6.1.2.7 Continuous monitoring of conditions during the complete turbine installation must take place to ensure that cleanliness related tasks are being accomplished. Dirt should not be introduced into the pipes and equipment.

6.1.2.8 Great care must be taken to prevent contaminant entry during any modifications.

6.1.2.9 The work area must be kept clean.

6.1.2.10 This list is not complete, but it does illustrate that the manufacturer, the shipper, the operator, and the installation contractor are all responsible for ensuring that no contaminants enter the lubrication system. These efforts to prevent the entrance of dirt will make the flushing procedure easier, safer, and shorter, and thus less costly.

6.2 *On-Site Contamination Control:*

6.2.1 *General:*

6.2.1.1 All components that are fabricated and assembled at a manufacturer's facility and received as a unit for installation in the system are defined as preassembled components.

6.2.1.2 The preassembled components should be inspected upon receipt to determine condition and degree of protection. All seals and caps intended to exclude moisture and dirt should be checked for integrity and replaced as required. If the initial or a subsequent inspection discloses dirt or rusting, the item should be immediately cleaned, represerved, and sealed, as required. Because of the variety of equipment and materials, details for each case cannot be given here. For painted (coated) components, the coating should be inspected for integrity and renewed as necessary. All components should be checked to ensure that all tape and temporary supports or restraints have been removed.

6.2.1.3 Undercover storage is recommended. Monthly inspections are recommended, and corrective steps must be taken when necessary. Care must be taken during inspections to minimize disturbance of equipment protection.

6.2.2 *Corrosion Protection:*

6.2.2.1 The application of various types of rust preventives is required to protect uncoated ferrous surfaces from corrosion during the storage and installation phases. Most preservatives today are oil soluble, and special procedures, such as hydraulic lancing, are often used to preserve gear cases, sumps, and tanks. The preservative compounds can normally be removed by flushing the system with regular lubrication oil or oil solvent, although hand cleaning of some components is also employed. If possible, however, the flush oil, operating oil, and preservative should be compatible to preclude foaming, the formation of emulsions, precipitates or the breakdown of lubrication oil additives. A system flush (displacement flush) with a sacrificial flush oil is often recommended to minimize operating oil contamination which could result in reduced performance. Product compatibility of the flush oil should be confirmed in accordance with Practice D7155 testing. Caution should be exercised in this regard. Compatibilities and limitations may generally be obtained from the oil suppliers. It is strongly recommended that preservative oil removal and preservative oil solubility in, and compatibility with, all subsequent oils, including the system oil, be reviewed at every step of subsequent processes. Review with the equipment manufacturer may also be beneficial. All oils added, including preservative oils, should be filtered as discussed in 7.6.

6.2.2.2 Once the rust preventative is removed, the ferrous surfaces are subject to rust unless care is taken to keep all surfaces oil-wetted. Corrosion of unwetted surfaces can be minimized by the use of vapor space inhibited oils to the maximum extent possible. The general procedure for the use of the vapor space inhibited oils is as follows:

(1) Wet all surfaces with vapor space inhibited oils after cleaning.

(2) Do not drain; add sufficient oil to provide a reservoir of the oil in the assembly.

(3) Seal the component to prevent loss of vapor phase protection and intrusion of contaminants.

6.2.2.3 These vapor space inhibited oils may be fully compatible with regular lubricating oils and flushing oils, and draining or removal may not be necessary. Compatibility testing in accordance with Practice D7155 is recommended to confirm compatibility. In addition, it has been shown that these oils may provide some residual protection to the system and minimize corrosion after the oils have been drained or displaced.

6.2.2.4 The vapor space inhibited oils are available in a range of viscosities. However, if an oil of significantly higher viscosity than the flushing oil is used, draining of the assembled system to limit the amount of the higher viscosity to 10 % is recommended to prevent significantly increasing the viscosity of the flushing oil.

6.2.3 *Gear Assemblies:*

6.2.3.1 When shipping gears, additional braces and tapes are frequently used to prevent movement of the elements and damage to the teeth and bearings. Upon receipt of the assembled gears at the installation point, an inspection should be conducted with the gear manufacturer's representative to determine whether any damage has occurred during shipment. At this time the gears should be thoroughly inspected for contamination, and if any is found, the manufacturer's recommendation should be followed for proper represervation. Periodic inspections, careful to minimize vapor space inhibition loss, should be made to ensure that proper preservation is maintained until the gear assembly is placed into regular operation. Upon installation, all temporary restraints, including tape, must be removed.

6.2.3.2 Speed reducers are normally shipped with a thin coating of preservatives applied to all internal machined surfaces that are in contact with lubrication oil, such as gear teeth, bearings, journals, interior housing surfaces, and oil piping. The preservative is oil soluble and is normally removed by the flushing program. Gear cases, protected by vapor space inhibited lubricating oil, should be inspected upon receipt for integrity of seals. Damaged seals should be replaced immediately. If the oil has been lost, the gear case and the gears should be pressure sprayed through the inspection openings with filtered vapor space inhibited oil or rust preventive oil at 55 °C to 57 °C (130 °F to 135 °F). Starting at the top of the case, the gear case and the gears should be thoroughly flushed down. After flushing, the oil level recommended by the gear manufacturer should be reestablished and the unit sealed.

6.2.4 *Valves, Strainer, and Coolers:*

6.2.4.1 Valves, strainers, and coolers, when received from the manufacturer, should be inspected to determine if there is contamination. If there is evidence of a hard film protective coating or contamination, the unit should be dismantled and all the parts thoroughly cleaned with filtered petroleum solvent. In all cases, use clean, lintless cloths (not waste cloths), a squeegee, or a vacuum cleaner.

6.2.4.2 Internal surfaces that cannot be reached should be flushed with an oil soluble cleaner or filtered petroleum solvent. Alkaline or acid cleaners should not be used.

NOTE 1—Petroleum solvents are flammable; care must be taken to prevent fires. Precautions must also be taken to ensure that workers do not inhale fumes from the solvent or come into contact with liquid solvents for prolonged periods. Filters can generate electric charges. Proper electrical connection of all equipment prior to transferring fluids or starting flushing is required.

6.2.4.3 After internal surfaces have been cleaned, they should be sealed or put into service as soon as possible. If the internal surfaces cannot be effectively sealed or put into service, they must be thoroughly air dried and coated immediately by spraying them with filtered and compatible rust preventive oil. After all surfaces have been coated, the equipment should be reassembled and all openings capped. This rust preventative coating may require removal with flush oil prior to equipment use.

6.2.5 *Sumps and Tanks*—Sumps, reservoirs, or tanks should be completely drained and thoroughly inspected. If present, rust, mill scale, weld spatter, loose paint, and so forth, should be manually removed. A coating of rust-preventive oil, or a vapor space inhibitor oil, should be applied, and all openings should be sealed. This rust preventative coating may require removal with flush oil. Repainting is not recommended.

6.2.6 *Bearings*—It is important that bearings be installed by qualified personnel. Extreme care should be taken to prevent accidental contamination of, or damage to, the bearings and journals. Bearing surfaces should be protected by rust-preventive oil that is readily soluble in flushing oil or vapor space inhibitor oil. All openings should be sealed.

6.2.7 *Control Devices*—Installation and contamination protection for oil-wetted control devices should be handled as carefully as that for bearings. Extreme care must also be taken to prevent accidental contamination of the associated piping during installation.

6.2.8 *Pumps*—Prior to assembly and installation, pumps should be inspected for the presence of hard film coatings or contaminants. If any are present, the pumps should be thoroughly cleaned, coated with rust-preventive or vapor-space inhibitor oil, and sealed.

7. Flushing

7.1 If the equipment manufacturer has supplied detailed flushing procedures, they should take precedence over these recommendations.

7.2 *Flushing Methods:*

7.2.1 *Displacement Flush*—For new systems and systems with service hours that do not typically require surface active cleaning or the improved cleaning of a high-velocity flush.

7.2.1.1 For a unit that is field assembled, keeping the lubrication and hydraulic control system piping clean enough so that flushing is not necessary is economically and practically impossible. Thus, it is generally recognized that an oil flush must take place after the piping has been installed and just before the turbine and its driven equipment go into operation. The success of this oil flush, however, depends to a large degree on the success of the efforts to keep dirt out initially and the proper conduct of the flush. A successful flush means that clean pipe and system components are obtained in a minimum of time and with a minimum of effort.

7.2.1.2 The cleaning and flushing of both new and used systems are accomplished by essentially the same procedure. In the new systems, the emphasis is on the removal of contaminants introduced during the manufacture, storage, system temporary rust protection, field fabrication, and installation. In used systems, the emphasis is on removal of contaminants that are generated during operation or are introduced to the system during overhaul.

7.2.1.3 A displacement flush utilizes a displacement flush oil of the same chemistry as the operating oil. System pumps and flow channels are utilized to circulate the displacement flush oil. Side stream filtration is recommended to improve flush effectiveness.

7.2.2 *High-Velocity Flush*—For new systems and systems with service hours that may not require surface active cleaning and will benefit from enhanced flushing compared to displacement flushing. High-velocity flushing provides improved cleaning of typically non-wetted surface areas like the lube oil return header.

7.2.2.1 The primary requirement for a successful oil flush is a high oil velocity at least three to four times normal system velocity, and a Reynolds number over 4000 within the system. Wherever possible, turbulent flow should be achieved in system pipes. Bearing jumpers are installed to elevate bearing supply and return flow rates and protect bearing surfaces from contaminants. System headers may be isolated to increase pipeline velocity. The use of outside pumps is typically required to achieve this flow.

7.2.3 *Surface Active Cleaner*—Flushing for in-service systems with varnish or sludge that require a cleaning solution for effective deposit removal.

7.2.3.1 Some turbine and associated hydraulic systems may require a surface active flush to clean inaccessible internal surfaces of varnish. The term varnish is being used to include all internal deposits, including sludge. Flushing with a surface active cleaner is typically reserved for gas turbines with combined hydraulic and turbine oil reservoirs. Minor levels of oil soluble cleaners or solvent cleaners may impact operating oil demulsibility, required in steam turbine operation. A subsequent displacement flush shall be conducted to effectively remove the surface active cleaning agent. Both the surface active flushing fluid and the following displacement flush fluid should not be reused as they may impact the performance of the final system operating oil. Hydraulic system flushing can be improved with the use of flushing blocks that are used to bypass the system servo valves.

7.2.4 High-pressure water flush for systems with service hours that have developed significant rust or fouling to the extent that less aggressive flushing methods are ineffective. High-pressure water is locally directed at fouled areas. Special care must be taken to remove all flush water at the completion of this flush.

7.2.5 *General Flushing Method Guidance:*

7.2.5.1 It may not be practical to flush through certain systems or devices that are assembled, cleaned, and sealed in the factory before shipment. Such equipment should be carefully protected against intrusion of contaminants, and in this flushing procedure, such equipment should be blanked off or bypassed until other systems are clean.

7.2.5.2 Even for assemblies that can be flushed through freely, the prescribed flushing procedure may not have the ability to flush out any and all conceivable kinds of contaminants. Much adverse experience testifies to this. Therefore, it is clear that great care should be exercised during the entire system installation to prevent unnecessary impurities from entering the oil systems that cannot be easily removed by flushing. Such contamination, when dislodged by turbine vibration or system operational effects, could cause problems in subsequent operations.

7.2.5.3 The knowledge that a system flush will be performed before startup should not be allowed to lead to the misconception that contaminants entering the oil system are not harmful because "they will all be removed by the flush."

7.3 *General Guidelines for Flushing of Operational Systems to Remove Contaminant:*

7.3.1 Guidelines for when to remove used oil or flush an operational system to reduce contaminant, or both, are given in 8.5.

7.3.2 The remainder of Section 7 should be reviewed and the applicable sections decided upon, after consultation of the equipment user with the appropriate suppliers, based on the condition of the system and used oil.

7.3.3 Sea water contamination requires special procedures. After removal of excess salt water, corrosion inhibitors specifically developed for this type of contamination might be used in the system.

7.4 *Preparation of System for Flushing:*

7.4.1 Prior to the flushing operation, all accessible areas of the lubricating oil system should be thoroughly inspected. If significant contaminant is encountered, it should be manually removed. Final inspection for welding splatter or materials that may break loose and contaminate the system with metallic particles should be made. If found they should be completely removed.

7.4.2 Any temporary humidity control devices (vacuum dehydrators, coalescing filters) placed in the system must be removed. The state of cleanliness of the system at this time is always questionable, and therefore, all lubricating oil manifolds and leads to bearings must be blanked off as closely as possible to the parts they serve. For high-velocity flushing, jumpers may be installed to bypass all bearings, but they should be so installed as to bypass as little of the piping and flow passages as possible. All other areas in the system that are not to be flushed should be blanked off with the use of numbered blanks. The numbered blanks must be removed from the system and accounted for on a checklist at the end of the flushing period.

7.4.3 Despite all efforts, some particles large enough to damage pumps may remain. In all systems, installing temporary strainers of 80 to 100 mesh on the suction side of the lubrication oil or flush pumps, or both, is recommended. In addition, install temporary fine mesh strainers on the discharge side of gravity and pressure systems. Fine screens of 100 mesh or finer should be installed at the inlet of all feed lines to the bearing pedestal. They should also be installed on the inlet headers of gear sets. Lintless bags, if available, may be used temporarily on the inside of the existing lubricating oil system strainers during the flushing period. Magnetic separating elements may be installed in the existing lubricating oil system strainers. Customary marine practice is to install these in the duplex strainers on the discharge side.

7.4.4 Whenever possible, use of full flow filters during the flush is recommended. Auxiliary filters may be used to provide higher filtered oil flow rates and finer filtration. All purification systems should be ready for operation as soon as the flushing oil is installed. It is generally desirable to purify the reservoir, pump, and purification systems before beginning to flush the rest of the unit. This has the advantage of providing clean oil to other parts of the system. In addition, when purified oil is used for flushing, the increased contaminant observed in the oil when additional sections are flushed gives some measure of flush effectiveness. If necessary, pipes and valves for recirculation to the reservoir should be installed. If this piping is temporary, valves at the reservoir and purification device should be provided to allow removal of the temporary piping.

7.4.5 Frequently, sampling points installed for monitoring oil cleanliness during routine operation are not adequate to monitor the cleanliness of components and the progress of the flush. Sampling points must be installed as necessary, as described in X2.2.2. If the lubricating oil heater has not been installed, or if it is inadequate, heat may be supplied to the flushing oil in several ways. The best method is to pass hot water through the cooler; this can be generated by bubbling low-pressure steam through the water somewhere outside the cooler. The cooler must be vented to the atmosphere to prevent pressure build up. Low pressure steam may also be used; however, the cooler should be checked against the manufacturer's recommendation. Great care must be taken to ensure that not over 34 kPa (5 psig) steam is admitted to the cooler so that the cooler is not damaged and the flushing oil is not overheated. Electrical heaters may also be used. The cautions outlined in Appendix X4 must be observed to avoid overheating the oil.

7.4.6 A lance attached to a clean hose should be used for hot oil spraying of gearing or other hard to reach areas. It can be attached to the cooler (currently being used as a heater) or an oil pump discharge strainer. For safety, the hose, lance, and any other fittings used must be pressure rated for the full flush pump outlet pressure. Precautions must also be taken to protect personnel from the hot oil spray. Extreme fire and spark protection precautions must be taken. Even less hazardous lubricants can ignite if heated and sprayed; conventional mineral oils may form explosive mixtures under such conditions.

7.5 *Selection of Flushing Oil:*

7.5.1 The oil selected for flushing of the system can be either the system operating oil or flushing oil that is compatible with the operating oil and of similar viscosity. The selection of the type of flushing oil to be used should be based on the judgment of experienced personnel after thorough inspection of the lubricating oil system. Residual flush oil may impact system operating oil performance. To minimize oil contamination, delivery should only be made in clean containers with clean or flushed hoses, pumps and manifolds. For large quantities, use of stainless steel or aluminum tank trucks or tank cars and cleanliness certification are required.

7.5.2 *System Operating Oil*—In applications where an existing unit is being flushed, the previous turbine lubricating oil may be used as flushing oil or subsequently as the operating oil, or both. In this case, the oil has been stored in a storage tank. When the system operating oil is used for flushing, it should not be used for operation unless it has been tested and shown to be suitable for system operation following flushing. This precaution is necessary because oil-soluble contaminants picked up during the flush may be incompatible with system components or cause foaming, emulsification or reduced oxidation resistance, or combination thereof.

7.5.3 *Flushing Oil Selection:*

7.5.3.1 Any operator who uses a flushing oil assumes responsibility to ensure its mechanical and chemical compatibility with the entire lubricating oil system and all turbine equipment exposed to this oil, including, but not limited to:

(1) All components of the lubrication and flushing systems.

(2) Final charge of lubricating oil.

(3) Permanent or temporary flushing hose lining at temperatures up to 88 °C (190 °F), including those to boiler water feed pump turbine systems.

(4) Rust preventive paints used in pedestal and guard piping.

(5) Preservatives used to protect pipes during shipping, storage, and installation that normally may not be removed prior to flushing.

(6) Residual oil impact on performance of system operating oil.

7.5.4 *Surface Active Cleaner Selection*—Varnish removal is greatly accelerated with the use of cleaners but there can be negative impact from cleaner residue on the system operating oil and equipment components. Cleaners are segmented as follows:

7.5.4.1 *Oil Soluble Cleaners*—Typically naphthenic based with detergents, dispersants, and corrosion inhibitors.

7.5.4.2 *Solvent Cleaners*—Typically hydrocarbon-based like alkylated benzene.

7.5.4.3 Water-based chemical cleaners are not recommended as the water and chemical residue can cause significant damage to the system operating oil and equipment components.

7.6 *Supplying Flushing Oil to Reservoir*—When filling the turbine lubricating system, oil should be filtered with as fine or finer filters as the system operating or flushing filters. In addition, in the flushing process, it is generally advisable to filter the oil between transfers. This allows single pass filtration that prevents the purified oil from mixing with the contaminated oil. Filtration of oils while warm will improve element life. Filter ratings on transfers to holding tanks can vary with oil temperature and oil contaminant levels. The reservoir should be filled to the minimum operating level to ensure that the system lubricating oil pump(s) are always submerged and operate properly.

7.7 *Flushing Procedure:*

7.7.1 Elevated oil temperature, oil temperature cycling and vibration contribute to the success of an oil flush. Hammering or vibration at pertinent points will promote loosening of solids in the system. Once solids are loosened, they will settle by gravity in the main oil tank, eventually be caught by temporary screens, or removed by filtration.

7.7.2 *Monitoring of Contaminant During Flushing:*

7.7.2.1 Monitoring of contaminant, especially particulate, is commonly performed during the flush and is strongly recommended. These analyses ensure that clean oil is being used for the flush and provide the best measure of the flush's progress.

7.7.2.2 The analyses for particulate may be performed on site using a particle count method or field analysis of contaminant from a sample drawn through an analysis membrane as discussed in X2.5.2 or performed in a laboratory as discussed in X2.6. If the analysis is performed on site, the person performing the analysis should be completely familiar with the operation and limitations of the apparatus. If the analyses are to be performed by a laboratory, the schedule must be established before the flush commences to provide timely results.

7.7.2.3 Flushing decisions based on sample cleanliness should only be made by personnel familiar with both the flush dynamics and the significance of the sample cleanliness. For system components, some manufacturers will require full flow analysis for large particles, typically larger than 125 µm. This generally entails filtering all return oil through strainers of the appropriate mesh. If required, these analyses should be performed with the appropriate throughput and by personnel familiar with the procedure.

7.7.3 *Maintenance of Purification Apparatus During Flushing*—Experience in flushing lubricating oil systems has shown that almost all of the foreign matter is collected in the filters or temporary strainers during the first few hours of flushing. During this time, whenever a noticeable increase in the pressure drop across the strainers is observed, the strainers should be cleaned and bags renewed. This may occur as frequently as 15 min intervals. The lubrication oil contamination control devices must be inspected and cleaned frequently.

Auxiliary filters, when used, should be operated within the pressure drop limits as specified by the manufacturer.

7.7.4 *Startup*—If appropriate, the lubricating oil pump(s) should be started. Oil circulation in the reservoir should be begun and purification started. The oil should be gradually heated to 65 °C to 71 °C (150 °F to 170 °F) by use of the purifier oil heater and, if necessary, by methods described in 7.4.5. Circulation and purification should be continued as long as it is necessary to flush the system. When heating the oil, the guidelines given in Appendix X4 should be followed to avoid overheating the oil. Purification of the reservoir should continue until the oil reaches the desired cleanliness level as determined by taking a reservoir sample or sample immediately upstream of a purification device as discussed in Appendix X2.

7.7.5 Flushing times of 12 h to as much as several days may be necessary to reach the desired level of cleanliness. Periodic sampling and analysis, as discussed in 7.7.2, is recommended to monitor the progress of the flush. Throughout the flushing period, the oil in the system should be maintained at 65 °C to 71 °C (150 °F to 170 °F), except when rotating the equipment. This temperature is necessary to maintain fluidity of the flushing oil in the system and to dissolve oil soluble materials and to aid in loosening adherent particles. General practice is to allow the oil temperature to drop 28 °C to 32 °C (50 °F to 60 °F) for 2 h to 3 h during flushing to allow for pipe contraction. This procedure aids in removing any scale that may be on the pipe.

7.7.6 *Flushing of Coolers*—Each lubricating oil cooler should be cleaned separately to provide maximum oil velocity in the cooler to optimize contaminant removal.

7.7.7 *Flushing of Gravity Tanks*—If there is more than one gravity tank in a gravity system, circulation of the flushing oil should be alternated through each of the gravity tanks for a minimum of 12 h or more for each tank.

7.7.8 *Flushing of Lubricating and Auxiliary Pumps*—Each lubricating oil pump and auxiliary pump should be used during the flushing period.

7.7.9 *Flushing of Piping*—During the early phases of the flushing period, the piping, particularly at joints and flanges, should be vibrated or hammered to dislodge any scale or weld splatter that may have adhered to the surface. The absence of contaminants, such as lint, welding beads, or other extraneous matter, on strainers or bags and accessible parts of the system indicates that the system is clean. The final decision to flush additional parts of the system, however, should be based on cleanliness criteria specified by the equipment manufacturer or established prior to the flush. After these criteria have been met, other parts of the lubricating oil system should then be flushed by removing blanks and jumpers.

7.7.10 *Flushing of Gears:*

7.7.10.1 At this point in the flush, if the unit being flushed is a geared unit, the gear case should be opened and sprayed with oil cooled to 55 °C to 60 °C (130 °F to 140 °F). All accessible points, including the upper surfaces of the casing, should be included. This flushing should be done through the inspection openings on the gear housing. The gears should be jacked progressively to new positions to permit thorough cleaning. Jacking should not be continuous and should not be done if the oil temperature is in excess of 60 °C (140 °F). Upon completion of the flushing by hose, the inspection covers should be secured and oil circulation continued, while gradually heating the oil to 65 °C to 71 °C (150 °F to 170 °F). The flushing procedure should be continued until the entire system is thoroughly cleaned. At this point, a representative sample should be taken for verification of cleanliness.

7.7.10.2 All oil strainers adjacent to gear oil spray nozzles should be examined and cleaned as necessary. When no evidence of contaminants appears in the strainers, bags, or auxiliary filters or from oil analysis, oil circulation to these gears should be stopped. If practical, representative bearings should be inspected and their condition should be used as a guide to whether further flushing is necessary. Bearing inspection may not, however, be practical or recommended, especially in packaged gas turbine systems.

7.7.11 *Flushing of Turbine Main Bearings and Sumps:*

7.7.11.1 The turbine main bearings will be one of the most sensitive components to particulate that moves through the system as a result of a flush. The turbine manufacturer's guidelines for flushing turbine bearings areas (bearings or bearing sumps, or both) should be used whenever available. When not available, the following should be considered.

7.7.11.2 Bearing areas should be flushed with clean fluid only. This may be accomplished either by isolating the bearing areas and flushing all upstream components, including valves and piping, to a specified cleanliness level and then redirecting the flow of clean fluid through the bearing area or by placing a screen or bag filter immediately upstream of the bearing area to ensure that particulate freed within the system does not flow through the bearing.

7.7.11.3 Monitoring fluid cleanliness at the first accessible location downstream of the bearing area being flushed gives the most reliable indication of bearing cleanliness. Some manufacturers may require full flow monitoring of the fluid coming from these areas for relatively large particles using screens. Experience indicates that if these are used, screens and analysis procedures should be designed to eliminate the influence of environmental contaminant that could unnecessarily prolong the flush.

7.7.12 *Flushing Procedures Specific to Surface Active Flushing:*

7.7.12.1 Confirm in-service oils suitability for use as to support surface active cleaner and insoluble system contaminants. In-service oil solubility and contaminant testing, like ultra-centrifuge or membrane patch colorimetry, may be suitable. The surface active cleaner shall be added in concentrations and circulated based oil suppler recommendations. Side stream filtration is recommended, during the flush. Flushing may be considered complete based on time and or system before and after test coupon cleanliness. A test coupon is an area or part of the lubrication system that has deposit formation (varnish/sludge) that can be used for validation during the surface active flush using photo or boroscope documentation.

7.7.12.2 At the flush completion the flush oil, containing surface active cleaners, should be completely drained. Particular attention should be paid to low point draining. A subsequent flush oil should be used to remove cleaner residue that may impact the performance of the final fill operating oil. At the completion of this flush the oil should be drained and the system prepared for confined space entry cleaning.

7.7.13 *Flushing Procedures Specific to High-Velocity Flushing:*

7.7.13.1 Bearing and hydraulic section jumpers are required to provide for increased flow rate or three to four time nominal lube oil header flow rates to obtain a minimum Reynolds number of 4000. External pumping done through isolated turbine sections offers elevated flush velocities. Turbine sections are isolated and flushed in sequences that provide for optimum system cleaning. (**Warning—**Fluid temperature may increase due to internal friction. It is recommended to monitor and appropriately control the temperature within safe operating levels.)

7.7.14 *Terminating the Flush*—When all contaminated sections of the system have been flushed and sample evaluations indicate that operating cleanliness requirements for all components have been met, including any manufacturer or user cleanliness requirements, terminate the flush.

7.8 *Draining of Oil Used for Flushing*—If the oil is to be drained when the flushing procedure is complete, it should be drained as soon as practical and safe. Allowing the oil to cool will leave more contamination in the system than if drained while it is still hot. Oil lines should be opened at the lowest points and the oil allowed to drain. Breaking of flanges and the use of a vacuum will improved drain effectiveness. The oil should then be removed from sumps, tanks, and coolers. The sump and all tanks and accessible surfaces should be manually cleaned with lint-free rags to remove all traces of residual contamination and as much oil as possible. The flushing oil, after purification, may be used for flushing another installation, after it has been determined that the product is free of contaminants and still contains solvency and rust inhibiting properties. After the flushing oil has been drained and surfaces cleaned, the lubricating oil system should be again thoroughly inspected for evidences of contamination. The system should then be completely rechecked to determine if it is secure for operation.

7.9 *Displacement Oil*—If very light oil is used for flushing, or if there are quantities of special flushing oil left in the system, displacement oil must be used. Another reason for the use of displacement oil is to remove flushing oil or cleaners, or both, that are highly contaminated with oil soluble materials. A displacement flush is also recommended when changing the type of oil in a system. Displacement oil should be compatible with and approximately the same viscosity as the operating charge to be installed. To minimize the impact of the displacement flush oil on the operating oil it is recommended that these oils be of the same chemistry. Strainers and filter housings and other large vessels should be drained, strainers cleaned, and all filter elements replaced. Pump the displacement oil into the system as soon as possible. The circulating pumps and turning or jacking gear, if present, should be started, the oil heated to 60 °C to 70 °C (140 °F to 160 °F), and circulated for a minimum of 2 h with purification. Circulation of the oil should be continued for 12 h to 24 h or until inspection of the strainers and filter bags shows no evidence of contaminants. The displacement oil should be drained while warm to improve flow. Low points and isolated areas should be drained or vacuumed clean.

7.10 *Interim Corrosion Protection*—With respect to corrosion, one of the most critical times for a lubricating oil system is the long idle period that may exist between flushing and regular operation. Proper scheduling of the flushing operation will minimize this idle period. The use of oil with a vapor space inhibitor will protect the system from corrosion by condensation. If a corrosion inhibitor is used, consult with the oil supplier on compatibility with the system oil. Confirm compatibility with Practice D7155. During this period, the system should be inspected frequently for signs of corrosion, particularly the upper portions of the gear case where the newly charged oil has not come into contact with the case and gear surfaces. It is in this region that moisture will condense into droplets of water and start the corrosion process and contaminate the new oil. If corrosion is taking place, it can be minimized by hand lancing these portions of the housing. Corrosion on the gear teeth can be prevented by rotating the bull gear a turn and a quarter every week with the lubrication oil system operating, thereby coating all of the teeth with a new protective film of oil. Cold oil, approximately 38 °C (100 °F), should be used for this purpose and when hand lancing to obtain best adhesion.

7.11 *New Oil Charge*—A full charge of new turbine oil should be installed in the system as soon as possible. This charge should be introduced through filters, purified and certified as clean before circulating.

8. Contamination Control In Operational Units

8.1 *Contamination Control During Operation*—Contamination control systems should be in operation as long as the lubricating oil system is in service. These systems should maintain oil purity at levels discussed in X2.7. Additional guidelines for contamination monitoring in operating systems are given in Practice D4378. The oil contamination levels and the operation of all purification devices should be constantly monitored to ensure that they are performing adequately and to determine the need for maintenance. In addition, all openings from the system to the atmosphere, such as breather vents, should be regarded as sources of contaminant. Whenever practical, these should be provided with particle and moisture control devices. When making inspections or working on or around a turbine, care must be taken to prevent contaminants from entering the lubrication system. When extraneous work that may generate contaminants is being performed in the vicinity of the lubrication system, precautions should be taken to ensure that system components are not exposed and all access points closed or protected, prior to beginning the work.

8.2 *Contamination Control During Oil Transfer:*

8.2.1 There are several reasons why oil may be transferred out of all or part of the lubrication system. These include preparation for repair of a system component, system overhaul, or replacement because the oil no longer meets specifications. In the first two cases, the oil will probably be returned to the system, while in the third case, it will probably be discarded.

8.2.2 If the oil is to be retained, it should be transferred to a clean container. Before transferring the lubricant, inspect the storage tank for particulate and water and clean if necessary. Residues from previous fills are contaminants and should be removed if practical.

8.2.3 When the oil is being transferred from the system, care should be taken to remove all the oil. Heaters, coolers, and purification devices can contain large amounts of oil that contain contaminants. In addition, this prevents inadvertent spillage later.

8.2.4 Purification of the oil during transfer or temporary storage is also recommended if analyses indicate it is required. If the entire system is drained, contractors with large portable purification apparatus may be employed to purify the oil. These contractors should be able to provide a certificate of analysis indicating the fluid meets the established cleanliness criteria. On completion of system repairs, the oil should be returned in the same manner as indicated for new oil in 7.11.

8.3 *Contamination Control During Repairs:*

8.3.1 The discussions in this section and the following section are pertinent for repairs that intrude into the lubrication system but where a full system flush will not be performed. Guidelines for deciding whether to perform a full system flush, including that for removing oil-borne contamination system-wide, are given in 8.5.

8.3.2 Whenever maintenance or repair is performed on a part of the lubrication system or a lubricated component, care should be taken to prevent contamination.

8.3.3 *Major Precautions to Prevent Contamination During Repairs:*

8.3.3.1 Cover/close the area being worked on to prevent ingression of abrasives, weld slag, and dust.

8.3.3.2 Use clean, lintless wipes.

8.3.3.3 Inspect each space before access is limited to ensure that all wipes, cords, tapes, tools, and other materials have been removed.

8.3.3.4 Use only clean, oil compatible cleaners and preservatives. Remove as much cleaner as possible, if used.

8.3.3.5 Take any steps necessary to prevent rust and other corrosion.

8.3.3.6 Install gears bearings and seals properly to prevent future wear, which will generate wear particles when operating.

8.3.3.7 For components that are particularly sensitive to particulate, order replacement parts that have appropriate cleanliness standards.

8.3.3.8 Do not use untested coatings to protect bearing surfaces during rotor handling.

8.3.3.9 For a more thorough discussion, a review of Section 6 is recommended.

8.4 *System Cleaning and Coating*—After draining, all accessible parts of the system should be cleaned using the appropriate method(s), followed by wiping with lint-free material. Particular attention should be given to reservoirs, where most deposits are usually found. Deposits accumulated during service should be examined to determine the source, and steps taken to eliminate the cause. If it is necessary to repair or recoat surfaces, they should be thoroughly cleaned before being recoated with an oil compatible durable coating. Caution should be employed if using a coating that may come off the surface, releasing either chips or pigment particles. It may be more advantageous to clean the surface and allow the inhibitors in the oil to protect the surface. Cleaning by flushing with oil after wiping and hand cleaning is recommended. The same general procedures given for cleaning systems in the preceding sections should be followed. Chemical cleaning is not recommended. Such chemicals could cause serious degradation of the operating oil and could damage system components. The use of hot water or steam could result in rusted surfaces and is not recommended.

8.5 *Flushing:*

8.5.1 Except under unusual circumstances, such as after major repairs or overhaul, an operational lubrication system should not be flushed. Only by a complete inspection of the system and analysis of the oil can the necessity for flushing be determined.

8.5.2 The condition of the oil and the system should both be taken into consideration when deciding whether to flush the system following repairs. The presence of soluble contaminants that can not be removed by purification and the degradation of the oil's additives or base stock may be reasons for flushing the entire system. Laboratory analyses of the used oil should be performed if these types of oil degradation are suspected. Consultation with the oil supplier is recommended.

8.5.3 The condition of the system, however, is generally more significant. It is of particular importance to consider the sensitivity of the section being repaired to contaminant and the sections of the system that would be directly exposed to contaminant from this system. Without full flow purification, for example, some of the contaminant from this component will probably reach other components before it can be removed by settling or side-stream purification. The cleanliness level of replacement parts, the types of built-in contaminants, and the type of contaminants introduced in the repair work (abrasive grit, weld slag, fibers, solvents, and so forth) should also be considered. If a full flush will not be done, consideration should be given to flushing the component and the pipes connected to it with heated, filtered operating oil. Monitoring of the cleanliness of the flush oil during this flush is recommended. Details on flushing individual components are given in 7.7.6 – 7.7.11.

8.5.4 If, after consideration of the factors above, the operator and lubricant supplier agree that a full flush is required, the appropriate flushing procedure in Section 7 should be used.

9. Keywords

9.1 centrifugation; cleanliness; coalescence; contamination; dehydration; filtration; flushing; purification; turbine lubrication

APPENDIXES

(Nonmandatory Information)

X1. WATER, OIL SOLUBLE CONTAMINANTS OTHER THAN WATER, AND OIL INSOLUBLE CONTAMINANTS

X1.1 Water

X1.1.1 Water is present in oil in solution and possibly also in the free or emulsified form. Ingression of salt water will also result in the deposition of salts if the water is evaporated. All free and emulsified water and any salts should be removed from turbine lubrication before placing the turbine in operation.

X1.1.2 Water can exist in solution at varying concentrations depending on the compounding of the oil, the temperature, and so forth. For example, oil may hold 50 ppm of water at 21 °C (70 °F) and 250 ppm at 71 °C (160 °F). In general, under normal operating conditions, dissolved water has no significant adverse effect on lubricating properties of the oil and does not cause significant corrosion in these systems. Dissolved water has, however, been reported to cause bearing damage. In addition, when oil passes through a cooler, some water may come out of solution and become free water in the form of droplets. Free water can have adverse effects on the lubricating properties of the oil and cause other system problems.

X1.1.3 Many contaminants inhibit the separation of free water from the oil by forming a stable emulsion. In turbine oils, the emulsion may impair oil circulation, interfere with lubrication, and adversely affect contamination control equipment. Emulsions may be prevented by removing water. If water can not be eliminated, it is recommended that methods for controlling emulsions be discussed with the equipment or oil supplier. If severe emulsification with water occurs, it may be desirable to raise the oil temperature to around 82 °C (180 °F) to facilitate breaking of the emulsion to form larger drops of free water. The guidelines given in Appendix X4 should be followed to avoid overheating the oil.

X1.1.4 Water contamination can be classified as either fresh or seawater, as encountered in land or marine systems. Fresh water may enter the lubricating system through turbine gland seals, in moist air through improperly located or improperly protected vents, or both, and through leaks in coolers and steam heaters. Seawater, in marine lubrication systems, enters through leaks in coolers, faulty manhole gaskets, faulty sump tank seals and improperly located vents. Sea and brackish water may also present a problem when used as a coolant in land based units. Even fresh water from leaking coolers may contain significant amounts of solids or materials that may react with oil additives. Water contamination in lubricating and control oils tends to: promote oil oxidation, reduce oil stability, promote sludge and varnish, promote foaming, form emulsions, promote rusting and corrosion, reduce additive concentration, adversely affect lubricating properties, alter oil viscosity, reduce filter element life and may cause bacterial growth.

X1.1.5 The circulation in most lubrication systems today is such that there is little settling. For leaks and some solids ingression, the operation of the purifier or contamination control device, if present, is usually sufficient to remove contaminants.

X1.1.6 In the case of severe salt water contamination, where the water is accompanied by a substantial quantity of salts, it may be necessary to remove the operating oil and clean and flush the lubricating systems.

X1.2 Oil Soluble Contaminants Other than Water

X1.2.1 Soluble contaminants in lubricating or control systems may include gases, fuel oils, cleaning chemicals, solvents, most rust preventatives, lubricants incompatible with system components, flushing oils, extraneous oils, gasket sealant, degradation by-products, and assembly lubricants. Oil soluble contaminants may change the oil viscosity, alter the flash point, change the color, result in sludge and varnish deposits, initiate additive-water interaction (which can cause emulsification, possible additive loss, instability, and impaired purification equipment performance, foaming, and air entrainment), and accelerate oxidation. If a soluble contaminant is present, the oil supplier and the equipment manufacturer should be consulted regarding the advisability of continued use of the oil or replacing it with a new charge. Most of these contaminants cannot be removed by conventional oil contamination control equipment, although there is some evidence that degradation by-products such as acids can be removed through some ion exchange technologies in API Group II and III lubricants. Gases and some light solvents can also be removed by vacuum dehydration methods. Normally, a new charge of oil is required to correct the problem.

X1.3 Oil Insoluble Contaminants

X1.3.1 Insoluble contaminants normally encountered are metallic and nonmetallic materials of all types and sizes, including fibers, airborne solids, sand, soaps, and some rust preventatives. These contaminants are often the result of inappropriate or careless manufacturing, shipping, storage, installation, operation, or maintenance practices. Some of the effects of solid contamination are abrasive wear of bearings and seals, faulty control functioning, plugged oil lines, reduced oil stability, sludge and varnish formation, reduced filter element life, increased foaming tendency, stabilized water-oil emulsions, and accelerated oxidation by the catalytic effect of metal particles. Harmful insolubles may exist in the lubrication oil system as stationary or suspended matter. Normal operation causes insoluble contaminants. Evaluating particle concentration, type and build-up rate can indicate possible system problems. Particle counting however, usually does not indicate the sludge and varnish potential of the fluid, since the insoluble contaminants responsible for sludge and varnish are typically below 1 µm in size, which is below the detection limits of most particle counting technologies.

X1.3.2 *Stationary Contaminant:*

X1.3.2.1 In new systems, prior to any flushing, most of the contaminants will be stationary. In a new or refurbished system, contaminants can include abrasive grit, metal filings, weld slag, rust, dirt, and paper and cloth fibers. In operating systems, contamination can settle out in parts of the system where there is no, low, or intermittent flow. These areas can include the reservoir, lubricant pipes with low flow rates, dead end pipes, or pipes with closed valves and bearing cases where there is low oil flow. There are frequently lubricant pipes that are not completely full. In these pipes, gravity is the driving force of the flow and the flow rate and oil levels in the pipe are strongly dependent on the oil viscosity, which is a function of temperature. Stationary contaminants in operating systems can include wear metals, seal debris, rust, dirt, cloth or paper debris, and materials generated by various chemical reactions. Oil that has been exposed to elevated temperatures can form higher molecular weight degradation products that help to bind the stationary contaminant together.

X1.3.2.2 Unless this stationary debris is removed, it may become dislodged during startup or during system operation. These contaminants should be dislodged by high flow rates, vibration, hydraulic lancing, or high-pressure water flushing. Experience, good judgment, and careful inspection by the installation supervisor must be relied upon to determine when such debris has been satisfactorily removed. If a high-pressure water flush is performed, provisions must be made to ensure that all water has been removed.

X1.3.3 *Suspended Contaminants*—Both new and in-service oil can contain suspended contaminants. The amount they contain will depend on the extent of prior purification. Contaminants suspended in the oil can be from system operation or generated during a flush by loosening stationary contaminant from pipes, pedestal castings, tank walls, and so forth. Suspended debris can be measured, as described in X2.5 and X2.6. To prevent the level of suspended debris from getting beyond acceptable limits and to prevent contamination of cleaner areas, all units should be provided with contamination control systems as described in Appendix X3.

X1.4 *Temperature Dependant Contaminants*—Some turbine oil degradation products will transition in and out of solution based on oil temperature.

X2. OIL CONDITION MONITORING

X2.1 In operating systems, the lubricating oil should be sampled and evaluated at frequent intervals (see Practice D4378) or as recommended by the manufacturer or oil supplier) during operation. Practice D4378 also recommends daily visual inspection for free water. These observations and sample analyses will serve as a guide to the condition of the oil and will determine the effectiveness of the oil maintenance program. Data from all inspections and analyses should be recorded, and a log of oil makeup should be maintained. The rate of change in the properties of the oil can be as significant as the absolute values. In system flushes, samples should be taken and analyzed at appropriate frequencies to monitor flush progress. A log of all samples taken and the results of all analyses should also be maintained for flushes.

X2.2 Sampling Points

X2.2.1 *Location in Operational Systems*—The three most common locations for sampling are from the center of the reservoir and upstream and downstream of a purification device. Whenever possible, obtain a sample from a flowing stream of fluid. A reservoir sample or sample upstream of a purification device gives information about contaminant entering or being generated by the system. In a full flow contamination control system, a sample downstream of the purification device reflects the cleanliness of the oil going to the turbine. Because of contaminant settling, the oil sample obtained from the reservoir drain valve is not representative of the system oil. Sampling from the drain valve is not recommended.

X2.2.2 *Additional Sampling Points to Monitor Flush*—Selecting the proper sample location and properly interpreting the results of the analyses, particularly particle counts, is critical to ensure a successful flush. If the flush piping or blanks allow, sampling the oil immediately upstream or downstream of the bearing or component that is being flushed and that is farthest from the oil supply gives the most direct indication of the cleanliness of the components being flushed. If the flush bypasses the bearings, or if samples at the bearings cannot be obtained, then a return oil sample will give the most direct indication of the cleanliness of the components being flushed. Return oil samples are frequently difficult to obtain because of their location or their low line pressure, or both. If samples can not be taken elsewhere, samples are frequently taken from the reservoir or immediately upstream of the purification device. In this case, the dilution effect of the reservoir must be considered, particularly when the reservoir initially contains very pure oil. In general, samples taken downstream of a purification device, usually a filter, that supplies oil directly to the components being flushed indicate the cleanliness of the flushing oil, not how much contaminant is being removed from the system. Frequently, samples are taken from several locations.

X2.2.3 In monitoring operational systems and flushing, sample locations recommended by the turbine manufacturer should be given preference.

X2.2.4 *Configuration*—Samples should be taken from locations that are representatives of the oil going to the system. Thus, for full flow contamination removal systems, the preferred location is downstream of the contamination control device. For systems with bypass contamination control or when a sample cannot be taken from a point downstream of a supply pump, a sample may be taken from the center of the reservoir. Because contaminants can settle, sampling from the bottom of the reservoir is not recommended. Design sampling points for obtaining samples from a fluid line following the principles are outlined in Section 4.1 of ISO 4021. Use ball valves with polytetrafluoroethylene (PTFE) seats in sample points used for taking samples for particulate analysis. As much as possible, sampling hardware should be placed in protected positions to prevent accidental breakage and loss of fluid. Samplers for obtaining reservoir samples, particularly those for particle counts, should follow the principles given in Section 4.2 of ISO 4021.

X2.3 Oil Sampling Techniques

X2.3.1 The taking of several samples in break-resistant, 250 mL (8 oz) glass bottles with screw on caps and plastic liners is preferred. A representative sample must be analyzed. Metal cans with press-on lids or containers with rubber or ground glass stoppers are not acceptable if particle concentrations are to be evaluated. However, metal cans are acceptable for other types of testing. Cleanliness in the handling of the sample and container is critical. Each container should be cleaned and kept clean. The following is a recommended cleaning procedure for used glass sample containers: (*1*) wash thoroughly in hot water and detergent; (*2*) rinse with soft, hot tap water; (*3*) rinse with filtered distilled water; (*4*) rinse with filtered isopropyl alcohol; (*5*) final rinse with filtered acetone; (*6*) dry with clean air. Caps should be isolated from the bottle contents by a liner of clean plastic that is compatible with the system fluid. Precleaned bottles may also be obtained from commercial sources. If particulate concentrations are to be evaluated, it is recommended that the cleanliness of selected sample bottles be evaluated per ISO 3722 to ensure that they are clean enough so as not to contribute significant particulate to the sample. It is recommended that the required cleanliness level be set at a maximum of 10 % of the upper limit of the lowest ISO Code likely for each size.

X2.3.2 The collection of samples for evaluating contamination control should be made from a system operating at the rated flow. The sample line should be thoroughly flushed by the oil, passing at least 500 milliliters of fluid or five times the volume of the sampling line and valve, whichever is greater. Since the flush volume can affect the sample particle concentrations, whatever flush volume is used, it should be used consistently. Without changing the sample valve setting, the sample container should be rinsed with the system oil and the oil discarded. When the needed volume has been collected, the plastic film and cap should be immediately replaced. The container, with its cover tightened, may be wiped clean on the outside and then transported promptly to a particle counter or a lab for analysis. All containers should be properly identified with respect to type of product, source, tests required, etc. Additional guidelines for obtaining samples for particle counts are given in ISO 4021.

X2.3.3 Retained samples should be stored in a cool, dark place.

NOTE X2.1—Unless the above detailed precautions are followed, contaminant introduced by the sample container or sampling technique may cause false values and may result in needless attempts to correct an apparently contaminated system that is in good condition.

X2.4 Manual Inspection

X2.4.1 Frequent observations (daily) should be made through the flow sight glass (bull's eye) of the oil flow in the lines to or from the various parts of the unit to check changes in the oil conditions. A noticeable change in appearance is an indication of contamination, particularly water, air, or sediment. Small samples should be taken periodically in properly cleaned glass containers and compared visually with new oil and previously retained samples. Inspection includes a check of cloudiness (free water or gases), sediment, and odor.

X2.5 On-Site Analysis

X2.5.1 Commercial test apparatus exists for on-site lubricating oil evaluation. Portable automatic or online particle counters, or both, that have the accuracy of laboratory units are available. Relative to an off-site laboratory particle count, they have the advantage of reduced turnaround time. In addition the online counter has the advantage that it can be connected directly to the system, eliminating the possibility of contamination from the environment or sample containers, or both. As with all testing and measurement equipment, the manufacturer's procedures must be followed. Testing must be carried out by a knowledgeable and experienced individual. Particle counts can provide useful guidance during a flush that the desired level of cleanliness has been reached. During a flush, it may be advisable to have a final laboratory analysis to ensure that the desired cleanliness has been reached.

X2.5.2 There is also equipment available to draw a sample of oil through an analysis membrane for examination of the contaminant. The membrane is then rinsed with filtered solvent and examined with a microscope. This allows a semi-quantitative determination of the contaminant concentration and allows for visual determination of the types of contaminant present. Use of a clean filter funnel and filtered solvent are critical to minimize outside contaminant. This method will also give an indication of when a section has been adequately flushed. A sample should also be provided to a lab for a final particle count.

X2.5.3 Instruments are commercially available for measuring water and viscosity. These instruments employ a variety of techniques, and the user should be familiar with their limitations. These instruments can offer guidance for critical decisions. Again, however, ongoing sampling and laboratory measurements are recommended.

X2.6 Laboratory Analysis

X2.6.1 Samples of lubricating or control oils should be submitted periodically for laboratory analysis during system operation or when a visual inspection indicates an abnormal condition. Additional guidelines can be found in Practice D4378. Analyses that should be included in the laboratory evaluation are given in Table X2.1.

X2.7 Oil Cleanliness Criteria

X2.7.1 The equipment manufacturer is responsible for establishing the recommended degree of cleanliness. The turbine manufacturer is responsible for assigning cleanliness levels and

TABLE X2.1 Laboratory Analyses for Turbine Lubrication Oil

NOTE 1—Tests should include some measure of oxidation stability reserve or antioxidant concentration, such as FT-IR, voltametric measurements, or Test Methods D2272, D6810, or D6971 to determine remaining antioxidant life. Consult with the oil supplier when selecting methods and acceptance criteria for oxidation stability reserve or the measurement of antioxidant concentrations.

Characteristic	Test Method
Appearance	-
Odor	-
Viscosity	D445
Water	D6304, D7546
Sediment	F311 or D4898
Acid Number	D664, D974
Particle Count	F312 or D7647

sampling and analysis methods. In all cases, the criteria specified by the turbine manufacturer should supersede those found in this practice. Recommendations vary depending on the configuration of the turbine lubrication and hydraulic systems.

X2.7.2 Particulate limits are generally expressed in terms of counts or cleanliness codes. During either a manual or automatic particle count, each particle is assigned to one of several size ranges and the total number of particles in each size range per volume of fluid recorded. The well known ISO 4406 method uses a code to reference the number of particles larger than 4 µm/mL, 6 µm/mL, and 14 µm/mL of oil. ISO 4406 assigns integer values to denote a range of particles per millilitre whose upper limit doubles with each successive number. Manufacturers' turbine lubrication oil cleanliness recommendations typically vary from ISO 16-/14/11 to ISO 18-/16/13.

X2.7.3 It is recommended that the concentration of the water in a lubricating system be maintained at or below the saturation level at the lowest temperature in the system. This prevents water from condensing out of the oil to form free water that could settle in areas with low flow. It also allows the oil to eventually remove free water that might have settled. The saturation level of the oil as a function of temperature should be obtained from the oil manufacturer. When non-mineral oil such as a phosphate ester fluid is used, the manufacturer's recommendations should be followed.

X3. CONTAMINATION CONTROL

X3.1 Methods

X3.1.1 The contamination control system should be capable of maintaining particulate matter and water contamination below limits established for the system by the equipment manufacturer. The type of system installed, the configuration it is installed in, flow rate through the purification system, and the contaminant ingression or generation, or both, rate all affect the concentration of the contaminant in oil going to the turbine's components. Not all methods described below may be appropriate for all systems.

X3.1.2 *Gravity Settling*—Gravity settling separates contaminants that are heavier than the oil and requires slowly flowing or quiescent oil. Gravity settling of water and solids has generally been supplanted by more active methods of purification, especially for operating systems. It may be employed, particularly off-line, as a method for reducing the contaminant load on other purification devices. The rate of separation is dependent on the viscosity of the oil, the size and specific gravity of the contaminants, and lack of turbulence of the oil. Tanks or reservoirs that use gravity settling generally have a sloped bottom or a sump, or both, for removing contaminant. Careful control of oil transfer between the turbine lubrication reservoir and the settling tank is necessary to ensure that the oil level in the reservoir does not go above or below its designed limits. Unless gravity settling tanks are cleaned thoroughly, there is also the possibility of reintroducing contamination from previous oil. Free water collected by gravity separation should be drained periodically to avoid the growth of organic material. This material may accumulate in piping, flow control, or monitoring devices or purification devices and reduce lubricating oil flow to critical machine components.

X3.1.3 *Centrifugation:*

X3.1.3.1 Centrifugation is a means of removing some insoluble fluids and solid contaminants from fluids by utilizing the centrifugal force developed by rotating the fluids at a high speed. For contaminants suspended in oil, the degree of separation is dependent upon the flow rate through the centrifuge, the viscosity of the oil, and the difference in the density of the contaminants and oil. Commercial units are sized to attain a specific level of separation. Clean oil and separated water are continuously discharged automatically by the centrifuge. Sludge and solid contaminants remain in the centrifuge bowl and are periodically removed manually or, in a self-cleaning type centrifuge, automatically. These units may be referred to as purifiers or clarifiers.

X3.1.3.2 It has been reported that centrifuges can remove particles as small as 5 µm or smaller. With favorable conditions of low oil viscosity and appropriate throughput, centrifuges have been reported to reduce water to less than 0.5 %. Most emulsions can be prevented by the removal of water. It has been reported that emulsions may be broken in centrifuges.

X3.1.4 *Filtration:*

X3.1.4.1 Mechanical filters remove solid contaminants by passing fluid through restrictions that trap the solid particles. Depending upon the choice of filter medium, mechanical filters can remove particles as small as 1 µm. As contaminants are removed and collected on the filter element, the pressure drop across the filter increases, ultimately requiring replacement or cleaning of the element.

X3.1.4.2 Instrumentation such as a differential pressure gage should be provided with the filters to enable the operator to monitor the contamination control system to ensure that it is functioning properly and to signal or indicate the necessity for changing or cleaning the filter elements. This is particularly important in automated systems.

X3.1.4.3 *Filter Ratings:*

(1) The absolute rating represents complete removal of all spherical test contaminants equal to or larger than the absolute particle size rating. In the rating test, a specified volume of a specified fluid with a specified concentration of spherical contaminant with a defined size distribution is passed through the test filter at a specified temperature and flow rate. The effluent is filtered through an analysis membrane and the membrane inspected. All particles on the membrane must be smaller than the specified rating.

(2) The nominal rating of a screen or filter represents the removal in a circulating system of 98 % of the contaminants equal to or larger than the nominal rating. For a nominal rating to be meaningful, the test method and contaminant used must be specified.

(3) The beta rating represents a ratio of particles of a given size *x* (in microns) that enter a filter to those that leave the filter in a multipass test. The multipass test is performed in accordance with ISO 4572. Filters will have different beta ratings for different particle sizes. Use of beta filter ratings is recommended over absolute or nominal ratings.

X3.1.4.4 Screens have a meaningful removal rating only when evaluated with contaminant comprised solely of spherical particles. They have good retention of particles but fairly low dirt capacity because all dirt is collected on the surface. By comparing the rating of the screens used in the lubricating system during flushing with the allowable contamination level, it will be evident that only coarse particles can be retained by these screens.

X3.1.5 *Depth Media Filters*—The removal of fine particles must be done by the bypass or full flow contamination control system, as well as the filters through which the oil is passed when the system is drained and refilled. Filters in these systems are often depth filters; that is, a bed of material (metal, or organic or inorganic fiber) with narrow irregular passages. Such filters have no meaningful pore size, and even a relatively coarse depth filter will usually remove a large amount of fine particles, especially after successive passes (recirculation). Depth filters have high dirt capacity due to their relatively large void volumes. Cleaning, however, is difficult, or even impossible; used cartridges usually have to be replaced with new ones.

X3.1.6 *Electrostatic Separators*—Electrostatic separation is a technology that allows very small insoluble particles to be collected and removed. Whereas mechanical filters can only remove particles down to 1 mm in size, electrostatic separation can remove particles as small as 0.01 mm in size. Since the majority of contaminants in turbine oils are under 1 µm in size, and these contaminants eventually form deposits, electrostatic separation is useful in preventing sludge and varnish. The technology works by sandwiching dielectric contamination collectors between electrodes. High, direct current voltage is applied to the oil as it flows through the media, electrically charging the insoluble particles. The charged particles are then attracted to either the anode or cathode, depending upon their charge, and captured in a collector. Electrostatic separators are also said to remove sludge and varnish that has already precipitated out of the fluid and formed on the internals of the system. Electrostatic separators are set up on a bypass loop off of the reservoir, and require several passes to clean the fluid. The technology requires a nonconducting fluid and its performance is therefore affected with high amounts of water contamination. Beta ratios are not useful for determining technology performance.

X3.1.7 *Charge Agglomeration*—A process where sub-micron particles are charged with electrostatic forces and then allowed to agglomerate in size. These sub-micron particles agglomerate to sizes that can be removed by conventional mechanical filtration.

X3.1.8 *Coalescence*—Purification by coalescence makes use of special fiber cartridges similar to filter elements to coalesce small dispersed water droplets to larger ones. The oil is then passed through special hydrophobic barrier screens that prevent passage of the large water droplets. These then drop to the bottom of the coalescer and are removed. Depending on oil additive package, throughput, viscosity, and temperature, coalescers can provide oil with outlet water concentrations to as low as 100 ppm. Particles trapped in the coalescer cartridges may interfere with coalescence and will reduce cartridge life. It is therefore generally necessary to protect the coalescer by use of a prefilter. Typical solid concentrations should be considered prior to use of a coalescer system.

X3.1.9 *Vacuum Dehydration*—Vacuum dehydration is a method by which water is removed from the oil by application of heat or air stripping and vacuum. Wet oil is introduced into a chamber with a vacuum of 693 mm to 870 mm (272 in. to 340 in.) of water where it is distributed over a large surface or sprayed at temperatures of 38 °C to 82 °C (100 °F to 180 °F). Elevated oil temperatures may impact oxidation stability. The water is removed in the form of a vapor and may be condensed before rejection from the system. Care must be taken that the combined effect of temperature and vacuum will not remove some of the lower vapor pressure oil components. Depending on oil additive package, throughput, viscosity, and temperature, vacuum dehydrators can provide oil with outlet water concentrations to as low as 45 ppm. The oil supplier can provide the necessary information on this point. If salt water is present, an after filter may be required for the removal of salt crystals. Vacuum purification equipment frequently also includes a filter for removing particulate to provide cleaner oil. In addition, without appropriate filtration, solids may collect in the purification chamber. For these reasons, typical solids concentrations should be considered prior to use of a vacuum purification system. Vacuum dehydration also offers the advantage that it removes air from the system.

X3.1.10 *Adsorption*—Adsorption (surface attraction) purification utilizes active-type media, such as Fuller's Earth, or activated alumina to remove oil oxidation products by their attractive or adherence to the surfaces of these materials. Adsorption agents with highly active surfaces may also remove additives from inhibited oils and alter chemical composition of the base stock. This method of purification should only be used with agreement and consultation between the user and the lubricant supplier. When fire resistant type fluids such as phosphate esters are used, as in hydraulic governor control systems, bypass purification with an adsorption medium may be used for acid removal. Devices using adsorbents can provide fluids with as low as 10 ppm of water at their outlet.

X3.1.11 *Resin Based Filter Technologies*—Some filtration technologies utilize a resin matrix that is designed to remove oil degradation products that are either in solution or in suspension.

X3.1.12 *Vent Protection*—Vents should be protected with breather filters. When ingression of atmospheric moisture would be the primary source of water in a system, a vent drier may also be used.

X3.2 Contamination Control Method Limitations

X3.2.1 Centrifuges are gravity related, and effectiveness is dependent upon particle size, density, and gravitational force developed. Mechanical type filters are ineffective for water removal and insoluble contaminants less than 1 µm in size. Coalescers are designed primarily for water removal and are limited by the solid contamination, viscosity, and surfactant in the oil. Neither centrifuges or coalescers will remove dissolved water. Electrostatic separators cannot remove moisture and have reduced performance in the presence of water contamination. Vacuum dehydrators have low single-pass water removal efficiency and can impact the oils oxidation stability if over exposed to elevated temperatures. Adsorbents can affect chemical composition and are generally not recommended. Thus a combination of devices is often needed.

X3.2.2 To ensure that the oil being used is compatible with system filtration, the oil supplier should be consulted before purification is specified for turbine lubrication and hydraulic systems. System purification requirements should be included in the discussion when considering turbine lubrication or hydraulic system oils.

X3.3 Contamination Control Configurations

X3.3.1 Contamination control employs one or more of the following configurations to ensure the most efficient removal of contaminants.

X3.3.2 *Full Flow Contamination Control*—The most effective means of maintaining clean oil is by full flow treatment while the oil is being circulated during flushing and subsequent operation of the unit. In this configuration, all fluid being pumped to the system is purified first. Because of the high flow rates involved, this configuration is generally restricted to filtration.

X3.3.3 *Bypass Contamination Control:*

X3.3.3.1 In the bypass mode, also frequently referred to as a kidney loop, a portion of the oil is continuously withdrawn from the reservoir, the contaminants are removed, and the oil then returned to the reservoir. Continuous bypass purification, although less effective than full flow, has the advantage that oil purification can continue in operation even when the lubricated oil equipment has been shut down. Bypass systems are frequently easier to install for retrofits. When a centrifuge or coalescer with pre-filtration is used, both water and solid contaminants are removed.

X3.3.3.2 The required capacity of the bypass system will vary with the rate of contaminant ingression and type, efficiency, and capacity of the purification apparatus. The higher the efficiency of the purification system, the cleaner the system oil will be. For a given efficiency, the higher the purification rate relative to the system volume, the cleaner the system oil will be. Higher bypass rates are recommended for dirty environments, such as coal-fired plants. Recommended bypass purification flow rates are typically 10 % to 75 % of the system volume hourly.

X3.3.4 *Batch Contamination Control:*

X3.3.4.1 Batch methods are generally employed for purifying oil when it is being transferred between a storage system and the lubrication system reservoir. To minimize the risk of contamination from outside sources, oil should be transferred directly from a purifier (filter, centrifuge, dehydrator, and so forth) into the lubrication or hydraulic system. Batch contamination control is not generally used with operating systems because it is labor intensive, may not be able to keep up with contaminant ingression, and risks contamination from the holding tank.

X3.3.4.2 If the oil storage tank is in a cold environment, heating may be required to obtain a viscosity suitable for operation of the pumps and purification system. When heating the oil, the guidelines given in Appendix X4 should be followed to avoid overheating.

X3.4 Contamination Control System Connections

X3.4.1 In designing contamination control system connections, the following criteria should be considered. The connections should contribute to providing the purest oil practical to the turbine, to providing maximum protection against turbine damage due to purification system equipment or piping failure, and to maximizing the life of purification cartridges (filter elements, coalescer elements, or adsorbent cartridges). Connection design variables include the position of the purification system inlet and outlet in the turbine lubrication system and the sizing and configuration of associated tubes, pipes, valves, and so forth on the purification system.

X3.4.2 Many older turbine lubrication systems were designed for gravity settling or deaeration, or both, and as a result may have a complex system of baffles in the reservoir or auxiliary settling tanks that should be considered when evaluating purification connection locations. To an increasing extent, mechanical devices have taken over the function of removing water and solids. In newer systems, the reservoir and purification system connections have probably been designed for use with mechanical purification and the connections have been optimized.

X3.4.3 To avoid introducing contamination when adding oil to the system, it is recommended that a separate connection be provided for filling the system. To avoid contamination with the wrong oil, it is also recommended that the proper lubrication oil's manufacturer, oil name, and viscosity grade be clearly indicated at this connection. Provision should be made so that oils can be transferred to and from holding tanks and settling tanks with purification. All purification devices and associated hardware should be cleaned to levels comparable to the main turbine lubrication system prior to installation or use. Clear labeling and good record keeping of the contents of transfer vessels will aid in preventing use of the wrong oil.

X3.4.4 All connections should be appropriately sized to prevent undue pressure drops at the rated flow of the purification device. With all contamination control devices, including settling tanks, care must be taken to prevent loss of lubricant from the system. All drain valves that lead out of the system should be locked closed when not in use. Any pressure relief valve drains should be piped back to the reservoir. All purification device inlets must be low enough in the tank to ensure an adequate oil supply to prevent air entrainment.

X3.4.5 The pressure rating of pumps supplying the purification devices must be considered. It is generally recommended that all hardware downstream of such a pump be rated to the full output pressure of the pump. If that is not practical, fail safe pressure relief must be provided and all hardware rated to the relief setting. Wherever practical, valves and other fittings should be designed to be strong enough to resist breakage by being struck accidentally or being stepped on. For permanent installation of purification devices, pipes are recommended instead of hoses.

X3.4.6 For water removal devices, provision must be made to allow the water removed from the lubrication oil to be disposed of in an environmentally acceptable manner.

X3.4.7 If gravity settling is employed as a purification method, it is necessary to have a drain at the bottom of the tank or tank sump to remove the settled contaminant. It is generally recommended that the material be drained from the bottom of the tank or tank sump to a waste oil tank and the waste oil disposed of in an environmentally acceptable manner. The oil may also be purified and reused; however, the sensitivity of the purification device to contaminant should be considered. Because fine filters, coalescers, and vacuum dehydrators are relatively sensitive to settled contaminant, particularly sludge and surfactants, it is generally not recommended that the drain be connected to these devices. If oil from a settling tank is to be purified by one of these devices, the tank outlet to the purification device should be above the level where significant concentrations of settled contaminant would be encountered.

X3.4.8 If the system is being retrofitted with a full-flow purification device, it is most likely that this device will be installed immediately downstream of the lubricant pump. In this case, the effective inlet and outlet of the purification device are already defined. An oil flow bypass must be provided when maintenance on the device is required while the turbine is operating. In the case of filters, this is frequently accomplished by providing multiple housings that allow one or more to be bypassed while the elements are changed.

X3.4.9 *Bypass Purification:*

X3.4.9.1 If a retrofit bypass purification system is being installed, it is recommended that the operator review reservoir drawings and obtain guidance from the turbine manufacturer and manufacturer of the purification device. Both the inlet and the outlet should be connected to the reservoir, with no connection to the main lubrication piping. It is generally recommended that the inlet and the outlet be placed as far apart as possible in the reservoir; however, possible reduction of deaeration and contaminant removal through settling by flow bypass through the device should be considered. As discussed in X3.4.7, contaminant settling and device contaminant sensitivity should be considered in determining the level of the lubrication system reservoir outlet to the purification system.

X3.4.9.2 In general, with a bypass system, the higher the flow through the bypass system, the purer the fluid will be going to the turbine. If bypass contamination control is to reduce the contamination load on a full flow purification device, such as a pressure line filter, the bypass removal efficiency times the flow rate should be at least equal to, and preferably several times greater than, the removal efficiency times the flow rate for the full-flow device.

X3.4.10 If portable purification is used, there are several additional precautions to be observed. All connections on the lubrication system and purification device must be clearly labeled. A label on the purification device must indicate current contents to avoid cross contamination. All hoses and connections must have appropriate pressure ratings. Where connections with valves are used, the valves on the turbine lubrication system should be locked closed when not in use. Use of a pressure relief device on the purification device is recommended should flow be accidentally started to a connection with a closed valve. When not in use, hoses and valves should be capped to prevent accidental leakage and contaminant ingression. Before connecting to the lubrication system, the purification device should be at least as clean as the lubrication system.

X4. HEATING

X4.1 Flushing frequently involves heating the oil, as do some methods of contamination control. To avoid degradation, the lubricant manufacturer should be consulted to assist in selecting appropriate heating and caution should be exercised in heating the oil. At all times, heating elements must be totally immersed. An oil level control will provide adequate protection.

X4.2 In circulating oil systems, maintain heater skin temperatures below 121 °C (250 °F) and ensure that oil circulating pumps are operated during heating. Steam heating pressure should be no higher than 34 kPa (5 psig). API 614 specifies a maximum watt density for electrical heaters of 2.3 W/cm^2 (15 $W/in.^2$) for mineral based products. Higher watt densities of up to 3.6 W/cm^2 (23 $W/in.^2$) have been recommended with adequate circulation to avoid exceeding the allowable heater skin temperatures indicated above. Controls should be installed to maintain these maximum levels.

X4.3 To heat noncirculating oil, heater skin temperatures should be maintained at or below 66 °C (150 °F). Temperature monitoring devices should be installed on the heater skin for this purpose, and temperature control devices employed.