Designation: D4174 – 17

Standard Practice for Cleaning, Flushing, and Purification of Petroleum Fluid Hydraulic Systems[1]

This standard is issued under the fixed designation D4174; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This practice covers aid for the equipment manufacturer, the installer, the oil supplier and the operator in coordinating their efforts towards obtaining and maintaining clean petroleum fluid hydraulic systems. Of necessity, this practice is generalized due to variations in the type of equipment, builder's practices, and operating conditions. Constant vigilance is required throughout all phases of design, fabrication, installation, flushing, testing, and operation of hydraulic systems to minimize and reduce the presence of contaminants and to obtain optimum system reliability.

1.2 This practice is presented in the following sequence:

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

[1] This practice is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of D02.N0 on Hydraulic Fluids.

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

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

1.5 *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]

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

D1774 Test Method for Elastic Properties of Textile Fibers (Withdrawn 2000)[3]

D2709 Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge

D4006 Test Method for Water in Crude Oil by Distillation

D7042 Test Method for Dynamic Viscosity and Density of Liquids by Stabinger Viscometer (and the Calculation of Kinematic Viscosity)

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

F313 Test Method for Insoluble Contamination of Hydraulic Fluids by Gravimetric Analysis (Withdrawn 1988)[3]

2.2 *ANSI Standards:*

B93.2 Glossary of Terms for Fluid Power[4]

B93.19 Method for Extracting Fluid Samples from the Lines of an Operating Hydraulic Fluid Power System (for Particulate Contamination Analysis)[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *nominal filtration rating*—an arbitrary micrometre value indicated by a filter manufacturer. Due to lack of reproducibility this rating is deprecated. (ANSI B93.2)

4. Significance and Use

4.1 Proper fluid condition is essential for the satisfactory performance and long life of the equipment. Prerequisites for proper lubrication and component performance are: (*1*) a well-designed hydraulic system, (*2*) the use of a suitable fluid, and (*3*) a maintenance program including proper filtration methods to ensure that the fluid is free of contaminants. These prerequisites are meaningless unless the hydraulic system is initially cleaned to a level that will prevent component damage on initial start up or when debris may be dislodged by any system upset.

4.2 The cleaning and flushing of both new and used systems are accomplished by essentially the same procedure. In new systems, the emphasis is on the removal of contaminants introduced during the manufacture, storage, field fabrication, and installation. In used systems, the emphasis is on the removal of contaminants that are generated during operations, from failures that occur during operation; or contaminants introduced during overhaul. Both new and used systems may benefit from high velocity flushing to remove materials that can collect in hard to drain pockets or normally non-wetted surfaces.

4.3 While the flushing and cleaning philosophies stated in this practice are applicable to all primary and servo hydraulic systems, the equipment specified herein does not apply to compact systems that use relatively small volumes of fluid unless they are servo systems where it is economically justified.

4.4 It should be emphasized that the established procedures to be followed for flushing and cleaning the hydraulic systems should be accomplished through the cooperative efforts and agreement of the equipment manufacturer, the installer, the flushing service vendor, the operator, and the fluid supplier. No phase of these procedures should be undertaken without a thorough understanding of the possible effects of improper system preparation. The installation and cleaning and flushing of the equipment should not be entrusted to persons lacking in experience.

5. Types of Contamination

5.1 *General*—Hydraulic systems can become contaminated from a variety of sources. Generally, there are five categories of contamination: (*1*) water, (*2*) fluid soluble material, (*3*) fluid insoluble material, (*4*) erroneous fluid additions, and (*5*) hydraulic fluid deterioration. Properly designed systems can normally control water and insoluble contaminants; however, when it is necessary to remove soluble contaminants, a fluid change and flush are required.

5.2 *Water*—Water is almost always present in hydraulic fluids. It may be present in solution or in a free or emulsified form. Water can exist in solution at varying concentrations depending on the nature of the fluid, the temperature, and so forth. For example, hydraulic fluid may hold 50 ppm of water

[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.

[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.

at 21 °C (70 °F) and 250 ppm at 71 °C (160 °F). The water in solution has no adverse effect on lubricating properties of the fluid and causes no corrosion; however, when fluid passes through a cooler some water may come out of solution and become free water in the form of finely dispersed droplets. Many contaminants hinder the separation of this free water from the fluid by settling and may cause an emulsion. In hydraulic fluids, the emulsion impairs circulation, interfere with lubrication and adversely affect contamination control equipment.

5.2.1 Water contamination can be classified as either fresh or sea water, as encountered in land or marine systems. Fresh water enters the hydraulic system from moist air as condensation, through improperly located vents, leaks in coolers, and steam heaters, and because of improper operation. Sea water, in marine hydraulic systems, enters through leaks in coolers, faulty manhole gaskets, faulty sump tank seals and improperly located vents. Sea and brackish water can also present a problem when used as a coolant in land-based units. Water contamination in hydraulic fluids can:

5.2.1.1 Promote fluid oxidation.

5.2.1.2 Reduce fluid stability.

5.2.1.3 Promote sludge.

5.2.1.4 Promote foaming.

5.2.1.5 Form emulsions.

5.2.1.6 Promote rusting and corrosion.

5.2.1.7 Cause additive depletion and drop-out.

5.2.1.8 Adversely affect lubricating properties.

5.2.1.9 Promote bacteria growth.

5.2.1.10 Alter fluid viscosity.

5.2.1.11 Adversely affect fine filtration (that is, excessive back pressure).

5.2.1.12 Promote cavitation.

5.2.2 In the case of severe salt water contamination, it is necessary to remove the operating fluid and clean and flush the hydraulic systems.

5.3 *Soluble Contaminants:*

5.3.1 Soluble contaminants in hydraulic systems include cleaning chemicals, solvents, rust preventives, incompatible lubricants, flushing oils, extraneous oils, oxidation products, gasket sealants, and assembly lubricants. These contaminants cannot be removed by conventional fluid contamination control equipment. Normally, a new charge of fluid accompanied with a displacement flush oil is required to correct the problem. Fluid soluble contaminants can:

5.3.1.1 Change the fluid viscosity.

5.3.1.2 Alter the flash point.

5.3.1.3 Change the color.

5.3.1.4 Result in sludge deposits.

5.3.1.5 Attack elastomeric seals.

5.3.1.6 Initiate additive-water interaction that can cause emulsification, possible additive loss, instability, impaired purification equipment performance, foaming, and air entrainment.

5.3.1.7 Accelerate oxidation.

5.3.2 When a soluble contaminant is present, the fluid supplier and he equipment manufacturer should be consulted regarding the advisability of continued use of the fluid or replacing it with a new charge.

5.4 *Insoluble Contaminants:*

5.4.1 Insoluble contaminants normally encountered are metal particles (including rust) of all types and sizes, fibers, airborne solids, sand, and other nonmetallic particles. These contaminants are often the result of improper manufacturing techniques, improper shipping and storage practices, and careless installation of hydraulic systems. Some of the effects of solid contamination are:

5.4.1.1 Abrasive wear or sticking of components such as: control valve poppets, cylinders, piston rods, and seals.

5.4.1.2 Faulty control functioning, particularly plugged fluid lines/filter plugging.

5.4.1.3 Reduced fluid stability.

5.4.1.4 Sludge formation.

5.4.1.5 Increased foaming tendency.

5.4.1.6 Stabilized water-oil emulsions/accelerated oxidation by catalytic effect of metal particles.

5.4.2 Harmful contamination can exist in the hydraulic system in two forms:

5.4.2.1 *Lodged Contamination*—These contaminants may become dislodged by high fluid flows and temperature differentials or by induced vibration during flushing. Contamination can be lodged in unflushed pockets or settled on the bottom of tanks. Unless this contaminant is removed, it becomes dislodged during startup or during system upsets. Experience, good judgement, and careful inspection by the installation supervisor must be relied upon to determine when such dirt has been satisfactorily removed.

5.4.2.2 *Suspended or Loose Contamination:*

5.4.2.3 Contaminants suspended in the fluid can be generated by particles coming loose from pipe, hose, hydraulic components, tank walls generally caused by high fluid velocity, wear debris, and vibration. Suspended contaminant can be measured, as described in 11.3 and 11.4. To prevent the level of suspended contaminant from getting beyond acceptable limits, hydraulic system filtration can be augmented with a bypass contamination control system (fluid filter or centrifuge). Preferably a full flow filter or a full flow filter plus bypass purification is provided. When a full flow filter is used, a bypass purification system may not be required.

5.4.2.4 The bypass or full flow system, or both, can be in operation during the flush operation as well as on a continuous basis during hydraulic system operation. High-velocity flushes will require appropriately sized full flow filters. The rated flow capacity per hour of a bypass system should be 10 to 20 % of the total system fluid volume.

6. Contamination Control

6.1 *General*—Contamination control in a hydraulic system is the complete program of monitoring and maintaining a clean fluid. Contamination control must begin with the design, manufacture, and installation of the hydraulic system and continue throughout the life of the system. When making inspections or working in or around a unit, care must be taken to prevent contaminants from entering the system. When work that generates contaminants is being performed in the vicinity of the hydraulic system, the system components must be protected even to the extent of suspending operations, and requiring system components to be sealed until the contaminating activity has ceased. The contamination control system must be capable of removing water and particulate matter consistent with contamination tolerance and system cleanliness requirements.

6.1.1 *Initial Filling*—When initially filling the hydraulic system, fluids are to be filtered through filters rated from 3-µm to 10-µm (as needed) with a beta ratio >1000 as they are being transferred into the reservoir. The contamination control system is ready for operation prior to the hydraulic system fill and is operating throughout flushing. See Section 9.5 for new installation flushing details.

6.1.2 *In-Service Units*—The contamination control system is in operation as long as the hydraulic system is in service. Its operation is frequently and regularly monitored to assure that it is performing adequately and to determine the need for its maintenance.

6.1.3 *Connection of Contamination Control System*—The external fluid take-off from the circulating system to the contamination control system is from the lowest point of the fluid sump or reservoir, to facilitate removal of solid contaminants and water.

6.1.3.1 Piping between the reservoir and the contamination control system is designed to minimize the potential for the loss of fluid that results from piping or equipment failure. This means short runs and the fewest possible joints. Piping is sized so as to provide sufficient flow velocity to carry water and dirt to the contamination control system.

6.1.3.2 The fluid return line to the reservoir is located as far removed as possible from the take-off for the contamination control system. The return line must contain suitable means to prevent back flow or siphoning and terminate below the fluid level. To prevent loss of fluid through back flow, auxiliary connections are provided for oil supply from and to station storage tanks. Fluid sampling valves with suitable locking devices are provided before and after the filtration system.

6.1.3.3 Instrumentation such as a differential pressure gage and an alarm is provided with the filters to enable the operator to determine if the contamination control system is functioning properly and also to signal or indicate the necessity for changing or cleaning various filter elements. This is particularly important in automated systems.

6.1.3.4 Filters that never increase differential pressure can be as much as concern as a high differential pressure. This could indicate improper installation or damaged filter allowing bypass.

6.1.3.5 When severe emulsification with water occurs, raise the fluid temperature for a limited time (less than 2 h) to a maximum of 82 °C (180 °F) to facilitate breaking of the emulsion. Prolonged operation above 82 °C (180 °F) may prematurely oxidize the hydraulic fluid.

6.1.3.6 Overheating of the hydraulic fluid can cause cracking that can result in severe viscosity reduction. This can be prevented by maintaining heater skin temperatures below 121 °C (250 °F), and ensuring that fluid hydraulic pumps are operated during heating. Ensure that the steam heating pressure is less than 34.5 kPa (5 psig). Experience has shown that a safe watt density for electrical heaters is 0.77 W/cm^2 (5 $W/in.^2$). Higher densities up to 3.1 W/cm^2 (20 $W/in.^2$) have been used with adequate circulation to avoid exceeding the allowable heater skin temperatures indicated above. Temperature controls are installed to maintain these maximum levels. At all times, heating elements must be totally immersed, a fluid level control will provide adequate protection. Control heating of the oil so as not to go below the minimum in fluid viscosity recommended for the pumps.

6.1.4 *Piping or Tubing Contamination Control System*—The interconnecting piping or tubing and contamination control system must be as clean as the initial hydraulic system. The bypass contamination control system, when present, is piped separately with no connection to the hydraulic fluid piping or tubing. It should be designed so that the contamination control system can take suction from and discharge to any of the following: (Safeguards are provided to prevent fluid being drained below minimum fluid level in the sump).

6.1.4.1 Main hydraulic reservoir.

6.1.4.2 Storage tank.

6.1.4.3 Auxiliaries, see details in following section.

6.1.5 Bypass contamination control system suction and discharge piping or tubing size is sized for turbulent flow at all times and based on the capability of the filtration device. Piping includes: bypass around fluid heater, pressure relief valves on inlet and outlet pumps, sample cocks on fluid inlet and outlet, and check valves and stop valves as required. A drain line is installed from the water removal equipment to a sludge tank or dirty fluid tank.

6.1.6 The suction lines from any reservoir or tank are situated at the lowest point to facilitate removal of solid contaminants and water. Piping between systems should be designed to minimize fluid loss by sloping the lines in the direction of flow for proper drainage.

6.1.7 Fluid return lines to reservoirs should be as far as possible from the take off line and discharge below the normal fluid operating level. The lines contain a sight flow glass near the reservoir.

6.2 *Contamination Control Procedures*—Contamination control systems normally employ one or more of the following procedures to assure the most efficient removal of water and solid contaminants.

6.2.1 *Full-Flow Contamination Control*—The most effective means of maintaining clean fluid is by full flow treatment while the fluid is being circulated during flushing and during normal operation of the unit. This method is capable of removing solids rather than water since the equipment is a full flow (filter/strainer). When water contamination is present, it can normally be controlled by a bypass type system.

6.2.2 *Bypass Contamination Control:*

6.2.2.1 In a bypass mode, a portion of the fluid is continuously withdrawn, the contaminants are removed and the fluid then returned to the reservoir. Continuous bypass although less efficient than full flow, is preferred over batch filtration because the system can continue in operation even though the hydraulic system has been shut down. When a centrifuge, dehydrator, or coalescer is used, both water and solid contaminants are removed although the presence of particulate matter will reduce the water removal effectiveness of the coalescer. Thus, the bypass system is the primary system considered over batch purification.

6.2.2.2 The capacity of a bypass system is at least 10 % to 20 % of the total fluid circulation flow rate.

6.2.2.3 The contamination control system should be capable of maintaining particulate matter and free water contamination below limits established for the system by the equipment manufacturer.

6.2.3 *Batch Contamination Control:*

6.2.3.1 Batch methods are generally employed for filtering fluid in the storage system. However, when severe fluid contamination is observed in a storage tank, appropriate valving for the use of a continuous bypass device (perhaps portable) is recommended. The source of contamination in the system is located and corrected.

6.2.3.2 When the fluid storage tank is likely to encounter low temperatures, a prescribed heater will be required. This is to heat the fluid to obtain a suitable viscosity for the filtration system and for operation of the hydraulic pumps. (**Warning—** Proper controls must be provided to avoid overheating of noncirculated fluid.).

6.3 *Contamination Control Processes*—The basic methods for removal of contaminants are gravity, centrifugation, and mechanical filtration.

6.3.1 *Gravity:*

6.3.1.1 Gravity purification can only separate out contaminants that are heavier than the fluid. The rate of separation is dependent on viscosity of the fluid, particle size and specific gravity of the contaminants, and quiesence of the fluid. Gravity separation is often accomplished during quiescent fluid storage and must be supplemented by one or more of the other contamination control methods.

6.3.1.2 A method for reducing the contaminant load on filters is to heat the fluid in a tank and allow the solids and the water to settle. This settling tank should be equipped with low-pressure steam heating coils or low-watt density electrical resistance heaters of designated size and a drain that terminates in a waste fluid tank. The settling tank is connected to the contamination control system suction and discharge lines. This settling tank is equipped with a drop line to the hydraulic sump, or reservoir and the valve on this line is locked closed. The capacity of the settling tank should be sufficient to hold the entire operating charge. Settled material can be more readily removed from gravity tanks, when the tanks are provided with sloped, conical, or vee bottoms.

6.3.2 *Mechanical:*

6.3.2.1 *Centrifuge*—Centrifugation is a means of separating fluids of different density and removing solid contaminants from fluids by utilizing centrifugal force developed by rotating the fluids at a high speed. For hydraulic fluid, the degree of separation is dependent upon the flow rate, viscosity of the fluid and the density of the solids and specific gravity of the fluid contaminants. Commercial units are sized to attain a specific level of separation. Clean fluid 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 automatically, as in the self-cleaning type centrifuge. These units are commonly called purifiers or clarifiers. With centrifugal purifiers, the solids and water are removed so they are no longer in contact with the fluid that reduces the self catalyzing effects on oxidation.

6.3.2.2 *Filters*—Mechanical filters remove solid contaminants by passing fluid through restrictions that trap the solid particles. Depending upon the choice of filter media, particles as small as or less than one micrometre can be removed. As contaminants are removed and collected on the filter element, the pressure drop across the filter increases, ultimately requiring replacement or cleaning of the elements.

6.3.3 *Supplementary Methods*—Supplementary methods for contamination control are coalescers, vacuum dehydration, and adsorption (for descriptions of these methods see 12.3, 12.4, and 12.5). Contamination control by the preceding methods can, under certain conditions, deplete the hydraulic fluid additives.

6.3.4 *Limitations of Contamination Control Devices*—Centrifuges are gravity related and effectiveness is dependent upon particle size and density and gravitational force developed. Most mechanical-type filters are ineffective for water removal. Coalescers are designed primarily for water removal and are limited by the solid contamination, viscosity, and surfactants in the fluid. Vacuum dehydrators and air stripping have low single-pass water removal efficiency. Certain types of adsorbents can affect the fluid's chemical composition and should only be used after verification.

7. Storage

7.1 *General:*

7.1.1 During storage, protect all components from rust, contaminants, and damage as much as possible. Undercover storage with proper vent breather filers is recommended. Monthly inspections are recommended, and corrective steps must be taken when found necessary. Take care during inspections to minimize disturbance of equipment protection.

7.1.2 The protection of all uncoated components requires that an application of some type of rust preventive be used to protect ferrous surfaces from corrosion during the storage and installation phases. Remove the preservative compounds by flushing the system with regular hydraulic fluid or oil solvent, although hand cleaning of some components is also used. However, the flush oil and preservative must be compatible to preclude foaming, the formation of emulsions, or the breakdown of hydraulic fluid additives. Once the rust preventive is removed, the ferrous surfaces are subject to rust unless care is taken to keep all surfaces oil-wetted. To lessen these undesirable effects vapor space inhibited (VSI) oils can be used. The general requirements for the use of the vapor space inhibited oils are:

7.1.2.1 Wet all surfaces with vapor space inhibited oils after cleaning.

7.1.2.2 Do not drain but add sufficient oil to provide a reservoir of the oil in the assembly.

7.1.2.3 Seal the component to prevent loss of vapor phase protection and intrusion of contaminants.

7.1.3 Most of these VSI oils are fully compatible with regular hydraulic fluids and flushing oils, and draining or removal may not be necessary. However, follow the oil manufacturer's recommendation. In addition, it has been shown that these oils will provide some residual protection to the system and lessen corrosion after the oils have been drained or displaced.

7.1.4 These VSI oils are available in a range of viscosities. However, when 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 VSI oil to 10 % is recommended to prevent significantly increasing the viscosity of the flushing oil.

8. Inspection

8.1 *General:*

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

8.1.2 Inspect the preassembled components upon receipt to determine condition and degree of protection. All seals and caps intended to exclude moisture and dirt are checked for integrity and replaced as required. When the initial or subsequent inspection discloses dirt or rusting, the item is immediately cleaned, represerved, and sealed as required. Due to the variety of equipment and materials, details to cover each case cannot be specified. For painted (coated) components, the coating is inspected for integrity and renewed as necessary.

8.2 *Systems Components:*

8.2.1 *Valves, Strainers, and Coolers*—Inspect valves, strainers and coolers, when received from the manufacturer, for contamination. When there is evidence of hard film protective coating or contamination, the unit should be dismantled and all the parts thoroughly cleaned with a petroleum solvent or oil soluble cleaner. In all cases, use clean rags (not waste cloths).

8.2.1.1 Internal surfaces that cannot be reached are flushed with a petroleum solvent or oil soluble cleaner. (**Warning—** Combustible. Skin irritant on repeated contact. Aspiration hazard.)

8.2.1.2 After internal surfaces have been cleaned, they must be thoroughly dried with moisture-free air. All cleaned surfaces are coated immediately by spraying them with an oil supplier approved rust-preventive oil, vapor space inhibitor, or suitable lube oil. After all surfaces have been coated, reassemble the equipment and cap all openings.

8.2.2 *Sumps and Tanks*—Thoroughly inspect sumps, reservoirs, or tanks. Manually remove rust, mill scale, weld spatter, loose paint, etc. Apply a coating of rust-preventive oil, or a vapor space inhibited oil, and seal all openings. Repainting is not recommended.

8.2.3 *Control Devices*—It is important that control devices be installed by qualified personnel. Extreme care is taken to prevent accidental contamination to these devices. Prevent accidental contamination of the associated piping during installation.

8.2.4 *Pumps*—Prior to assembly and installation, inspect pumps for the presence of hard film coatings or contamination. When such coatings or contaminants are present, thoroughly clean and coat the pumps with rust preventive or vapor space inhibited oil.

9. Flushing Program

9.1 *General*—For a unit that is field assembled, keeping the hydraulic system piping or tubing 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 or tubing has been installed but before the system goes into operation. However, the success of this oil flush depends on: (*1*) the success of the efforts to keep dirt out initially, and (*2*) the proper conduct of the flush (the subject of this procedure). A successful flush means that clean pipe and system components are obtained with minimum time and effort. The cleaning and flushing of both new and used systems are accomplished by essentially the same procedure. New systems will often benefit from high velocity flushing. In new systems, the emphasis is on the removal of contaminants introduced during the manufacture, storage, field fabrication and installation. In used systems, the emphasis is on the removal of contaminants that are generated by failures that occur during operation, or introduced during operation or overhaul. Do not flush through valves, bearings, or other critical components. Use inspected clean bypasses. Tight clearances in the system and any flow orifice should always be removed to promote turbulent flow conditions, allowing faster flushing time.

9.1.1 A successful flush should keep the dirt out is achieved by the cooperation and diligence of many parties. Examples of these efforts are listed as follows:

9.1.1.1 Design system to allow successful cleaning.

9.1.1.2 Properly clean and preserve the piping or tubing and other equipment.

9.1.1.3 Durably cover and secure for storage prior to shipment and loading all possible locations for the entrance of dirt (pipe or tubing ends). Shipment and unloading must take place without damage to these covers.

9.1.1.4 Inspect pipe or tubing at the installation site thoroughly to discover any damaged or open covers and have them repaired.

9.1.1.5 Store prior to installation in a sheltered location especially when the storage is to be for long duration.

9.1.1.6 Inspect thoroughly immediately prior to installation, and clean the pipe or tubing when excessive rust or dirt is discovered.

9.1.1.7 Continuously monitor conditions during the complete hydraulic system installation to assure that cleanliness-related tasks are being accomplished. Take measures not to introduce dirt into the pipes or tubing and equipment.

9.1.1.8 Prevent contaminant entry during any modifications.

9.1.1.9 Keep work area clean.

9.1.2 The list is not complete but it does illustrate that the manufacturer, the shipper, the installer and the operator all have a hand in ensuring that contaminants generated or entering the piping or tubing is minimal. These efforts to prevent the entrance of contaminants will make the flushing procedure easier, safer, and shorter and thus less costly.

9.1.3 The success of oil flushing also depends on the ability of the hydraulic pump to provide a large flow rate (high velocity flush) thus giving a turbulent flow within the system (see 9.1.5, Note 1). The use of outside pumps is recommended when necessary, to achieve this flow. Oil temperature, oil temperature cycling, vibration, etc., all contribute to the success of an oil flush. However, high oil velocity (two to three times normal system velocity) utilized in a correctly sequenced flush, is by far the most important ingredient to a successful flushing procedure as prescribed in this practice.

9.1.4 Loosening of solids will be promoted by hammering or vibration, at pertinent points in the system. Once the solids are broken loose, they will either settle in the main oil tank, be caught by temporary screens, or filtered out by the user's bypass or full-flow filtration system.

9.1.5 However, it is impractical to flush through certain systems or devices that are assembled, cleaned and sealed in the factory before shipment. Protect such equipment carefully against intrusion of contaminants, and in this flushing procedure, blank off or bypass such equipment until the other systems are clean.

NOTE 1—A turbulent flow in a long tube will be maintained when the Reynolds number is in the 4000 to above 20 000 range, depending on OEM recommendations.

9.1.6 Even for the assemblies that can be flushed thoroughly, the prescribed flushing procedure does not have the ability to flush out any and all conceivable kinds of contaminants. Much adverse experience testifies to this. Therefore, during the entire system installation process, take preventive measures to exclude impurities that cannot be easily removed by the flushing of the fluid systems.

9.1.7 Such contamination when dislodged by system vibration or operational effects will cause problems in subsequent operations.

9.1.8 The knowledge that an oil flush will be performed before startup must not be allowed to lead to the concept that contaminants entering the fluid system are not harmful because "they will all be removed by the flush."

9.1.9 Secondary bypass filtration is recommended to circulate on system reservoir during a high velocity flush and at time of start-up.

9.2 *Preparation of System for Flushing:*

9.2.1 *Inspection*—Prior to the flushing operation, thoroughly inspect all accessible areas of the hydraulic system. When the slightest evidence of contamination is encountered, it should be removed manually. Make final inspection for welding spatter or material that may break loose and contaminate the system with metallic particles. If found they should be completely removed. It must be emphasized that if thorough inspection of all surfaces shows contamination, it must be removed prior to charging the system with flushing oil.

9.2.2 The system should be inspected and any temporary humidity control devices that may have been placed in the system for interim protection before flushing should be removed. The state of cleanliness of a system is always questionable, and therefore, all leads to cylinders and motors must be blanked off as closely as possible to the parts they serve. Jumpers have to be installed to bypass all actuators but install them as to bypass as little of the piping and flow passages as possible. Blank off all other areas in the system that are not to be flushed with the use of numbered blanks. Remove the numbered blanks from the system and account for them according to a check-off list at the end of the flushing period.

9.2.3 Install temporary strainers of 80 to 100 mesh on the suction side of the pump. In addition, install temporary fine mesh strainers (no finer than 100 mesh) on the discharge side of gravity and pressure systems. Use lintless bags temporarily on the inside of the existing hydraulic system strainers, when available, during the flushing period. Install magnetic separating elements in the existing hydraulic system strainers. However, some experience indicates that they are of limited value.

9.2.4 Use auxiliary filters of the nonreactive type to increase the rate of filtration, and to decrease the maximum particle size of contaminants in the hydraulic fluid.

9.2.5 When a hydraulic fluid heater has not been installed, or when it is inadequate, supply heat to the flushing oil with the help of electrical heaters in the tanks. Hot water passed through coolers is recommended; however, when low-pressure steam is used, make sure it complies with manufacturer's recommendation. Ensure that 34.5 kPa (5 psig) is the maximum pressure of the steam admitted to the cooler so that the cooler is not damaged and the flushing oil is not overheated. A preferable method is to pass hot water through the cooler and bubble low-pressure steam through the water somewhere outside the cooler. Vent the cooler to the atmosphere to prevent the buildup of pressure.

9.2.6 Clean all accessible surfaces not previously wiped down with clean rags. Make a final inspection prior to filling the system with flushing oil.

9.3 *Fluid Heating Prior to Flushing* (New and In-Service Units)—Heat the fluid to 60 °C to 82 °C (140 °F to 180 °F) either by means of low-pressure steam 34.5 kPa (5 psig) maximum on the water side of the oil cooler, when it is designed for such service, or by electrical resistance heaters in the purifier or main tank. Circulate the fluid during this period.

9.4 *Selection of Flushing Oils*—The oil selected for flushing of the system can be either the system operating fluid or a special flushing oil. 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 hydraulic system.

9.4.1 *System Operating Fluid*—When the system operating fluid is used for flushing, it is not used for operation unless it has been tested and shown to be of suitable quality for system operation. This precaution is necessary since incompatible oil-soluble contaminants picked up during the flush may cause foaming, emulsification, and reduced oxidation resistance.

9.4.2 *Special Flushing Oil*—Use rust inhibited oils of lower viscosity (less than 32 cSt at 40 °C (150 SSU at 104 °F) or special flushing oils for flushing. The flushing oils are special blends with good solvency, containing rust inhibitors and additives for the removal of system contaminants such as rust-preventive compounds and sludges. Flushing oils blended with halogenated petroleum solvents, and solutions containing water, caustic compounds or other active materials *must not* be used. The flushing oil must be compatible with all seals and hoses and with the hydraulic pumps, when used for flushing.

9.4.3 *Flushing Oil Selection Guide*—If the operator uses flushing oils, he assumes responsibility to ensure its compatibility with the entire hydraulic system and all equipment exposed to this oil, including, but not limited to, the following:

9.4.3.1 All components of the hydraulic system.

9.4.3.2 Final charge of hydraulic fluid.

9.4.3.3 Permanent or temporary flushing hose linings at temperatures up to 88 °C (190 °F).

9.4.3.4 Rust preventive paints used in reservoirs.

9.4.3.5 Preservatives used in the pipes or tubes for shipping and installation that normally are not removed.

9.5 *Flushing Procedure for New Systems*—Establish the proper piping configuration to bypass the servo values, and so forth before filling with the flushing oil charge.

9.5.1 *Flushing Oil Charge*—Fill the reservoir with flushing oil to the minimum operating level so that the hydraulic system pump(s) inlets are always submerged below the reservoir oil level and operate properly. Start the pump(s), and circulate the oil. Since system pumps cannot generally give adequate fluid velocity for effective flushing, use external pumps at two to three times system pump flow rate. Start the purifier and heat the oil gradually to 65 °C to 71 °C (150 °F to 170 °F) by use of the purifier oil heater and, when necessary, by the use of the cooler as outlined above (see 8.2). Continue this circulation as long as it is necessary to flush the system.

9.5.1.1 A flushing time of at least 12 h is typically necessary to ensure proper system cleanliness. System size and complexity will dictate the extent of flush time and cleaning procedures. (Section 8 details oil sampling techniques and analysis procedures required to determine level of cleanliness.) Throughout the flushing period maintain the oil in the system at 65 °C to 82 °C (150 °F to 180 °F). 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 or tube contraction. This procedure aids in removing any scale on the pipe or tube.

9.5.1.2 Reduce system pump discharge pressure for flushing purposes by lowering the relief valve or compensator settings to prevent possible damage.

9.5.2 *Cleaning of Filtration Devices*—Experience in flushing hydraulic systems has shown that almost all of the foreign matter is collected in the 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 hydraulic oil purifier and 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.

9.5.3 *Cleaning of System Components*—Clean each hydraulic fluid cooler separately by maintaining maximum oil velocity in the cooler in order to flush out any contamination. When there is more than one gravity tank in a gravity system, alternate circulation of the flushing oil through each of the gravity tanks for periods of at least 12 or more hours for each tank. Use each hydraulic oil pump during the flushing period.

9.5.4 *System Flushing and Flush Acceptance Criteria:*

9.5.4.1 During the early phases of the flushing period, vibrate or hammer the piping or tubing, particularly at joints and flanges, to dislodge any particulate debris such as scale or weld spatter that may have adhered to the surface. When inspection of the strainers or bags and accessible parts of the system shows that there is no evidence of contaminants such as lint, welding beads, or other extraneous matter, then the system is considered clean; however, use of the cleanliness criteria as described in 11.5 are recommended.

9.5.4.2 After inspection of the strainers or bags and temporary filters discloses that there is no evidence of contaminants, flush other parts of the hydraulic system by removing blanks and jumpers. Continue the flushing procedure until it is considered that the entire system is thoroughly cleaned. At this point take a sample for verification of cleanliness (11.5).

9.5.4.3 Replace all inspection plates on openings except those in use. When no evidence of contaminants appears in the strainers or bags and auxiliary filters, stop oil circulation, and inspect representative components for cleanliness. The condition of these components as well as oil analysis ISO particle count is used as a guide as to whether further flushing is necessary.

9.5.4.4 Flush acceptance criteria may be ISO Cleanliness codes 17/16/14 to 16/14/11 acceptable particulate range and/or 100-mesh strainer or bag with no particles detectable by naked eye for two consecutive 1 h or 2 h runs.

9.5.5 *Draining of Flushing Oil*—When flushing is completed, continue circulating the oil and cool to approximately 48 °C (120 °F). When this temperature is reached, remove the flushing oil from the system. Open fluid lines at lowest points and allow the oil to drain. The oil is then stripped from sumps, tanks, and coolers. The sump, all tanks, and accessible surfaces should be manually cleaned with clean rags to remove all traces of residual contamination and as much oil as possible. The flushing oil can be reused, after it is purified, for flushing another installation, provided it has been determined that the oil is free of contaminants. After the flushing fluid has been drained and surfaces cleaned, the hydraulic fluid system is again thoroughly inspected for evidence of contamination. The system is then completely rechecked to determine if it is suitable for operation.

NOTE 2—All used or waste oils are disposed of in accordance with appropriate regulations.

9.5.6 *Displacement Oil*—When hydraulic fluid is used for flushing, no displacement oil is required,but re-use of this flush oil for system operation should only be permitted when the oil analysis results are acceptable (9.4). When a very light oil is used for flushing or when there are quantities of special flushing oil left in the system, a displacement oil must be used. Another reason for the use of a displacement oil is to remove flushing oil that is highly contaminated with oil-soluble materials. It is also necessary when changing fluid in a system. Displacement oil should be compatible and have approximately the same viscosity as the operating fluid charge to be installed. Clean strainers and replace all filter bags; pump the prefiltered displacement oil into the system as soon as possible. The circulating pumps are started, the oil heated to 60 °C to 71 °C (140 °F to 160 °F) and circulated for a minimum of 2 h. Continue circulation of the oil for at least 24 h or until the strainers and filter bags visually show no evidence of contaminants. Displacement oil can be used for unit trials prior to regular system operation. When a decision is made to use an operating charge, pump the displacement oil out and drain all low points. The sumps and tanks are cleaned and a final inspection made. The system is now ready for new fluid.

9.5.7 *Interim Corrosion Protection*—One of the most critical periods during the service life of a hydraulic system with respect to corrosion is the long idle period that can exist after flushing and prior to regular operation. The use of oil with a vapor space inhibitor can protect the system from corrosion by condensation. During this period, inspect the system frequently for signs of corrosion.

9.5.8 *New Fluid Charge*—Install a full charge of prefiltered new hydraulic fluid in the system as soon as possible. This charge is introduced through 3-µm to 10-µm beta ratio >1000 filters and purified before circulating.

9.6 *Flushing of Used Systems:*

9.6.1 *General Guidelines*—In cases of minor contamination, follow applicable portions of 9.4. These are selected after review of the circumstances, by the equipment operator and fluid suppliers. For example, under certain circumstances it is necessary to use only the displacement oil procedure outlined under 9.5.6. In cases of severe contamination, not including sea water, follow the procedures outlined in 9.4. Modification of the flushing time and the circulating temperature may be required depending upon the circumstances of the contamination. Sea water contamination requires special procedures for handling. After removal of excess salt water, corrosion inhibitors specifically developed for this type of contamination must be used in the system. Careful cleaning procedures must be followed to obtain a satisfactory condition in the hydraulic system. Following this, the procedures as outlined in 9.4 are applicable.

9.6.2 *Procedures*—When the necessity for cleaning an hydraulic system is shown by inspection or tests, drain the fluid completely from the system, including retention points such as coolers and strainer body. When the fluid is suitable for further service, it is stored in such a way as to protect against contamination. After draining, clean all accessible parts of the system by wiping with clean rags. Give particular attention to reservoirs, where most deposits are usually found. Examine deposits accumulated during service to determine the source, and take steps to eliminate the cause. When it is necessary to repair or recoat surfaces, degrease thoroughly and clean them before recoating with an oil compatible durable coating. Cleaning by flushing with oil after wiping and hand cleaning is recommended. Follow the same general procedures given for cleaning new systems in 9.5. Oil soluble cleaners are recommended but compatibility with the operating oil fill should be confirmed. Water-based chemical cleaning is not recommended. Such chemicals cause serious degradation of the operating fluid and could damage system components. The use of hot water or steam results in rusted surfaces and is not recommended.

10. System Maintenance

10.1 Except under unusual circumstances, such as after major repairs or overhaul, do not flush the hydraulic system during operation. Only by a complete inspection of the system and analysis of the fluid can the necessity for flushing be determined.

10.2 *Preinstallation*—The bypass system is in operation during the flush on a continuous basis. The rated flow capacity per hour of such a system is numerically equal to 10 % to 20 % of the total volume of fluid. Check all fluid, even that being directly supplied by the fluid vendor, for cleanliness before being added to the system. Filter all operating fluid charged to the system through 3-µm to 10-µm beta ratio >1000 filters before being added to the main fluid tank because experience has shown that a clean hydraulic system can be contaminated with a dirty fluid charge. To minimize fluid contamination, delivery of large quantities is made only in certified clean tank trucks or tank cars.

10.3 *In-Service Units*—The contamination control system is operational whenever the hydraulic fluid is circulating in the main hydraulic system. When the system is not in operation pump the hydraulic fluid into a settling tank where the fluid is heated to approximately 55 °C (130 °F) to promote the settling. Since the fluid can be contaminated in the settling tank or the interconnecting piping or tubing, it is recommended that the fluid be passed through the contamination control system prior to being returned to the system.

10.4 *Decision to Flush In-Service Hydraulic Systems*—Factors in deciding whether or not flushing is done after service or overhaul are as follows:

10.5 *Condition of Fluid*—When there is any indication of the operating charge being degraded due to deterioration or contamination, make an appropriate analysis of the fluid.

10.6 *Condition of the System*—Conduct a complete inspection of the system to find deposits.

10.7 *Replacement of Components*—Consideration is given to the possibility that the replacement components can result in an increase in system contamination level. When the operator and fluid supplier agree that flushing is required after consideration is given to these factors, use the flushing procedure in Section 9.

11. Fluid Condition Monitoring

11.1 Follow the usual practice of periodically submitting fluid samples to a laboratory for analysis. In addition, sample the hydraulic fluid and observe at frequent intervals (200 h initially and every 3 to 6 months thereafter or as recommended by manufacturer) during operation. These observations and sample analyses will serve as a guide to the condition of the fluid and determine the effectiveness of the fluid maintenance program. Record data from all inspections and analyses and maintain a log of fluid make-up. The rate of change in the properties of the fluid can sometimes be more significant than absolute values.

11.2 *Fluid Sampling Techniques*—To avoid settling and stratification, the clean sample container must be of the proper size. The taking of several samples in break-resistant, 250 mL (8 oz) 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 when particle cleanliness level testing is required. However, metal cans are acceptable for other types of testing. Cleanliness in the handling of the sample and container is critical. When more precise particle count data is required, a triple flush of the bottle and lid with the hydraulic oil to be tested is recommended. The sample container should be rinsed with the system fluid. When the needed volume has been collected, remove the container. The cap is immediately replaced. Clean hands and clean rags are essential while collecting samples. The container with its tight cover, can be wiped clean on the outside and then transported promptly to a particle counter or a lab for analysis. Identify all containers properly with respect to type of product, source, tests required, etc. See ANSI B93.19 for details of sampling procedure.

NOTE 3—Unless the above detailed precautions are followed, dirt introduced by the sample container or sampling technique can cause false values and result in needless attempts to correct an apparently contaminated system that is in good condition.

11.3 *Visual Inspection:*

11.3.1 Make frequent observations through the sight glass (bull's eye) of the fluid flow in the lines to or from the various parts of the unit to check changes in the fluid conditions. A noticeable change in appearance is an indication of contamination, particularly water, air or sediment. Take small samples periodically in properly cleaned glass containers and compared visually with new fluid and previously retained samples. Store retained samples in a cool, dark place. Inspection incudes a check of the following:

11.3.1.1 Color change,

11.3.1.2 Cloud (free water),

11.3.1.3 Sediment, and

11.3.1.4 Odor.

11.3.2 Commercial test kits are available for on-site visual hydraulic fluid evaluation. These kits are intended only as a general guide for determining the condition of the fluid and should not be considered as a substitute for laboratory analysis.

11.4 *Laboratory Analysis*—Submit samples of hydraulic oils periodically for laboratory analysis during system operation or when a visual inspection indicates an abnormal condition.

11.4.1 Tests include the following:

Characteristics	Test Method
Appearance	...
Odor	...
Viscosity	D445 or D7042
Water	D1774, D4006, D7546
Sediment	D2709, F311
Neutralization number[A]	D664, D974
Particle count and distribution[B]	D7647, F312, F313

[A] While normally used to determine acidity, can in the case of vapor space inhibited oils be used to monitor loss of additive.

[B] Automatic particle counting can be used instead of manual counting. Automatic counters must be standardized by the method specified by the instrument manufacturer. Results can be misleading when entrained water or air is present in the fluid. Particle counts are not necessary on all units. Follow equipment builders recommendations.

11.5 *Fluid Cleanliness Criteria:*

11.5.1 The equipment manufacturer (in cooperation with user) is responsible for establishing the recommended cleanliness level. Fluid cleanliness is usually defined by weight, number, and size of particulate contamination, or can be summarized by achieving ISO Particle count targets, like 16/14/11.

11.5.2 As with particle size, quantity of particles also can be misleading. Particulate contamination quantity is defined as weight/unit volume of fluid. The density of contaminating materials present can vary greatly. Therefore, the quantity by weight is highly dependent on the density of materials and amount of each material present. This leads to the often reported anomaly of high particle counts with low weight and low counts with high weight. Therefore, it can be seen that particle size and weight of contaminant must be used with caution for establishing tolerances in actual systems. Particle counts by use of an automatic counter can be helpful in providing relative improvement as the flushing progresses. Particle count methods are superior to gravitational methods.

12. General Information

12.1 The following information is material offered to supplement the general text. In flushing a system, consider the contained volume of a cylinder versus the contained volume of the hydraulic lines between a directional valve and the cylinder. It is necessary to force the fluid to exhaust for proper flushing.

12.1.1 The nominal rating (see 3.1.1) of a screen or filter is defined by the manufacturer but typically represents the removal in a circulating system of 98 % of the contaminants equal to or larger than the nominal rating in laboratory tests using "standard" contaminants. This definition does not apply to system "dirt."

12.1.2 Screens have a meaningful surface rating for near spherical particles; they have good retention of particles but low dirt capacity because all dirt is collected on the surface.

12.1.3 By comparing the rating of the screens, used in the hydraulic system during flushing, with the allowable contamination level, it will be evident that only coarse particles can be retained by these screens. 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 fluid is passed when drained and refilled. Filters in these systems are often depth filters; that is, a bed of compound (metal, paper, fiber) with narrow irregular passages. Such filters have no fixed pore size and even a relatively coarse depth filter will usually remove a surprising amount of fine particles especially after successive passes (recirculation). Depth filters have high dirt capacity due to their relatively large void volumes. However, cleaning is difficult, or even impossible, and cartridges usually have to be replaced.

12.2 *Centrifuge Ratings:*

12.2.1 Purification performance is achieved by removing particulate matter down to ten micrometres or less by selective removal and by removing all free water (water not in solution). Selective removal means that the separation is done by using a centrifugal process.

NOTE 4—Additives are soluble in the fluid and will not be removed by centrifugal force.

12.2.2 Purifiers can handle free water under emergency conditions.

12.2.3 Most emulsions can be prevented by the removal of water, but even very stubborn emulsions can usually be broken in centrifugal purifiers. Most important is that purifiers offer constant efficiency.

12.3 *Coalescence*—Purification by coalescence makes use of special filter cartridges and surfaces to coalesce small dispersed water droplets into larger ones. The larger water droplets are separated by a barrier screen and fall to the bottom of the filter while the dry fluid passes through the filter. This method, because it involves fine filtration surfaces also separates particulate matter in the coalescer by the mechanical filtration principle. Therefore, in "dirty" systems it is necessary to protect the coalescer separator by the use of prior mechanical filtration of particulate matter. Verification of these system effects are ascertained prior to use of coalescer separators.

12.4 *Vacuum Dehydration*—Vacuum dehydration is a method by which water, entrained gases/air, and volatile solvents are removed from the fluid by application of heat or air stripping and vacuum. Wet fluid is introduced into a chamber, typically operating at 510 mm to 640 mm (20 in. to 25 in.) of vacuum where it is distributed over a large surface or sprayed at temperatures of 38 °C to 60 °C (100 °F to 140 °F). The water is removed in the form of a vapor and sometimes condensed before rejection from the system. Above vacuum and pressure conditions are gentle enough for most hydraulic fluid to not cause any damage. Temperature should be limited to 71 °C (160 °F) to minimize premature oxidation of the hydraulic fluid. The fluid supplier can provide the necessary information on this point. When salt water is present, an after filter may be required for the removal of salt crystals.

12.5 *Adsorption*—Adsorption (surface attraction) purification utilizes active-type media such as fullers earth (clay) to remove fluid oxidation products by their attraction or adherence to the large internal surfaces of the fullers earth. Adsorption agents with highly active surfaces can possibly remove additives from inhibited fluids. Use this method only with agreement and consultation between the operator and the fluid supplier.

13. Keywords

13.1 contamination; filter/filtration; flushing

SUMMARY OF CHANGES

Subcommittee D02.N0 has identified the location of selected changes to this standard since the last issue (D4174 – 15) that may impact the use of this standard. (Approved December 1, 2017.)

(1) Added Test Method D7042 to 2.1 and 11.4.1.