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Standard Specification for Phosphate Ester-Based Fluids for Turbine Lubrication and Steam Turbine Electro-Hydraulic Control (EHC) Applications[1]

This standard is issued under the fixed designation D4293; 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 specification covers the minimum requirements for phosphate ester-based fluids for turbine lubricants and electro-hydraulic control fluids, as delivered.

1.2 The use of this type of fluid is restricted to turbine systems designed or modified to accommodate phosphate ester fluids.

1.3 This standard does not cover the minimum requirements for in-service phosphate ester fluids for the turbine electro-hydraulic control (EHC) fluid. These requirements are provided in Guide D8323.

1.4 The values stated in SI units are to be regarded as standard. For convenience, other units of measurement are provided in brackets.

1.5 *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.*

1.6 *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]

D92 Test Method for Flash and Fire Points by Cleveland Open Cup Tester
D97 Test Method for Pour Point of Petroleum Products
D130 Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test
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
D892 Test Method for Foaming Characteristics of Lubricating Oils
D974 Test Method for Acid and Base Number by Color-Indicator Titration
D1169 Test Method for Specific Resistance (Resistivity) of Electrical Insulating Liquids
D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
D1401 Test Method for Water Separability of Petroleum Oils and Synthetic Fluids
D2422 Classification of Industrial Fluid Lubricants by Viscosity System
D3427 Test Method for Air Release Properties of Hydrocarbon Based Oils
D4057 Practice for Manual Sampling of Petroleum and Petroleum Products
D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants
D6304 Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration
D7546 Test Method for Determination of Moisture in New and In-Service Lubricating Oils and Additives by Relative Humidity Sensor
D8112 Guide for Obtaining In-Service Samples of Turbine Operation Related Lubricating Fluid
D8323 Guide for Management of In-Service Phosphate Ester-based Fluids for Steam Turbine Electro-Hydraulic Control (EHC) Systems

[1] This specification 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**

2.2 *EN Standards:*[3]

EN 14832 Petroleum and Related Products—Determination of the Oxidation Stability and Corrosivity of Fire-resistant Phosphate Ester Fluids

EN 14833 Petroleum and Related Products—Determination of the Hydraulic Stability of Fire Resistant Phosphate Ester Fluids

2.3 *IEC Standard:*[4]

IEC 60247 Insulating Liquids—Measurement of Relative Permittivity, Dielectric Dissipation Factor (tan d) and d.c. Resistivity

2.4 *Energy Institute Standard:*[5]

IP 510 Energy Institute Standard—Petroleum Products—Determination of Organic Halogen Content—Oxidative Microcoulometric Method

2.5 *ISO Standards:*[6]

ISO 760 Determination of Water—Karl Fischer Method (General Method)

ISO 2160 Petroleum Products—Corrosiveness to Copper—Copper Strip Test

ISO 2592 Determination of Flash and Fire Points—Cleveland Open Cup Method

ISO 3016 Petroleum Products—Determination of Pour Point

ISO 3104 Petroleum Products—Transparent and Opaque Liquids—Determination of Kinematic Viscosity and Calculation of Dynamic Viscosity

ISO 3170 Petroleum Liquids—Manual Sampling

ISO 3448 Industrial Liquid Lubricants—ISO Viscosity Classification

ISO 3675 Crude Petroleum and Liquid Petroleum Products—Laboratory Determination of Density—Hydrometer Method

ISO 4259 Petroleum Products—Determination and Application of Precision Data in Relation to Methods of Test

ISO 4406 Hydraulic Fluid Power—Fluids—Method for Coding the Level of Contamination by Solid Particles

ISO 6072 Rubber—Compatibility Between Hydraulic Fluids and Standard Elastomeric Materials

ISO 6247 Petroleum Products—Determination of Foaming Characteristics of Lubricating Oils

ISO 6614 Petroleum Products—Determination of Water Separability of Petroleum Oils and Synthetic Fluids

ISO 6618 Petroleum Products and Lubricants—Determination of Acid or Base Number—Colour Indicator Titration Method

ISO 6619 Petroleum Products and Lubricants—Neutralization Number—Potentiometric Titration Method

ISO 7537 Petroleum Products—Determination of Acid Number—Semi-micro Colour-indicator Titration Method

ISO 8068 Lubricants, Industrial Oils and Related Products (Class L)—Family T (Turbines)—Specification for Lubricating Oils for Turbines

ISO 9001 Quality Management Systems

ISO 9120 Petroleum Products—Determination of Air-release Properties of Steam Turbine and Other Oils—Impinger Method

ISO 10050 Lubricants, Industrial Oils and Related Products (Class L)—Family T (Turbines)—Specifications of Triaryl Phosphate Ester Turbine Control Fluids (Category ISO-L-TCD)

ISO 11500 Hydraulic Fluid Power—Determination of the Particulate Contamination Level of a Liquid Sample by Automatic Particle Counting Using the Light-extinction Principle

ISO 12185 Crude Petroleum and Petroleum Products—Determination of Density—Oscillating U-tube Method

ISO 14935 Petroleum Products—Determination of Wick Flame Persistence of Fire-resistant Fluids

ISO 15597 Petroleum Products—Determination of Chlorine and Bromine Content—Wavelength X-ray Fluorescence Spectrometry

ISO 20764 Petroleum and Related Products—Preparation of a Test Portion of High-boiling Liquids for the Determination of Water Content—Nitrogen Purge Method

ISO 20823 Petroleum and Related Products—Determination of the Flammability Characteristics of Fluids in Contact with Hot Surfaces—Manifold Ignition Test

2.6 *General Electric Turbine Manufacturing Standards:*[7]

GEK 46357H Steam Turbine-Generator EHC Fluid Specification and Maintenance

2.7 *Siemens Turbine Manufacturing Technical Purchasing Specification:*[8]

TLV 9012 03 Fire-resistant triaryl phosphate ester hydraulic fluids (TXP-free)

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions and terms relating to this specification, refer to Terminology D4175.

4. Significance and Use

4.1 Over the last six decades, increasing demand for greater power supply stability forced the steam-turbine manufacturers to provide a more efficient turbine control system. To accomplish this increased grid stability, faster response to a changing load on the electric grid, and to provide more precise control, a new system, called Electro-Hydraulic Control (EHC), was developed. This EHC system is a complex design consisting of two major systems: electronic control systems and a dedicated high-pressure (typically between 6895 kPa to 13790 kPa (1000 psi to 2000 psi) hydraulic fluid system. In addition, it also has an emergency trip system, valve controllers, and a monitoring system.

[3] Available from British Standards Institution (BSI), 389 Chiswick High Rd., London W4 4AL, U.K., http://www.bsigroup.com or from Deutsches Institut für Normung e.V.(DIN), Am DIN-Platz, Burggrafenstrasse 6, 10787 Berlin, Germany, http://www.din.de.

[4] Available from International Electrotechnical Commission (IEC), 3, rue de Varembé, P.O. Box 131, CH-1211 Geneva 20, Switzerland, http://www.iec.ch.

[5] Available from Energy Institute, 61 New Cavendish St., London, W1G 7AR, U.K., http://www.energyinst.org.

[6] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[7] Available from General Electric, 5 Necco St., Boston, MA 02210, https://www.ge.com

[8] Available from Siemens Energy, 4400 N Alafaya Trail, Orlando, FL 32826, https://www.siemens-energy.com.

4.2 Triaryl phosphate ester hydraulic fluids have been selected by the turbine manufacturers for the EHC systems primarily due to their excellent fire-resistance characteristics.

4.3 This specification defines the minimum requirements of phosphate ester fire-resistant fluids for turbine applications. Users should be aware that system design differences will result in different rates of fluid degradation and, therefore, different levels of performance.

4.4 It is critical for the end user to understand that the initial fill or subsequent addition of the high-quality triaryl phosphate ester fluids to the EHC system will not ensure safe and reliable system performance if the EHC fluid is not adequately prepared and maintained. For more details, see Guide D8323.

4.5 Before the initial fill, it is essential that the user properly cleans and flushes the EHC system prior to adding the fluid. Refer to the Guide D8323 standard for more information on flushing.

5. Composition

5.1 In general, phosphate esters are a class of organophosphorus compounds with the general structure $O{=}P(OR)_3$, where R is alkyl, aryl, or substituted aryl groups. However, in EHC systems and industrial turbine lubrication applications, only triaryl phosphate fluids, where R is a substituted or unsubstituted phenyl group, are used.

5.2 When approved for use in the above applications, the fluid substituents on the aromatic ring are currently either methyl ($-CH_3$) or tertiary butyl ($-C_4H_9$) groups.

5.3 Trixylyl phosphate (TXP) has been designated a Substance of Very High Concern and added to REACH Annex XIV, so its use is prohibited in the EU as of 2023 unless the end user can obtain an exemption from ECHA for their particular use.

6. Safety Precautions

6.1 Fires in operating turbines have usually been caused by fluid or vapors contacting hot surfaces. For example, fluid that may leak, spill and absorb into unprotected thermal insulation can experience an exothermic reaction with resultant potential, rapid temperature increase. The ignition of the absorbed fluid can occur at temperatures below the fluid auto-ignition temperature.

6.2 Phosphate ester fire-resistant fluids are difficult to ignite and show little tendency to propagate a flame but are not non-flammable.

6.3 The fire safety tests are used to measure and describe the properties of fire-resistant fluids under controlled laboratory conditions and should not be considered an exact simulation of the behavior of the fluids under actual fire conditions.

7. Delivery and Storage

7.1 When delivered in originally sealed and properly labeled compatible drums, triaryl phosphate ester fluids should be stored in temperature-controlled warehouses with adequate protection against airborne contaminants (that is, moisture, dust) and in accordance with the local safety requirements.

7.2 The fluid should be transported in a manner that will ensure the container's integrity (that is, drums) and prevent contamination of the fluid prior to delivery to the user site.

7.3 The manufacturer/supplier shall provide the end user with a document (that is, Certificate of Analysis (COA)) confirming agreed upon fluid batch performance.

7.4 The fluid manufacturer shall also provide guidance for the supplier and users on the shelf life of the triaryl phosphate ester fluids stored indoors in original, unopened containers at room temperature.

7.5 Typically, the shelf life of triaryl phosphate ester fluid for EHC systems is at least two (2) years.

7.6 The user may test new triaryl phosphate ester fluids as delivered to ensure that the fluid meets the product technical requirements. Precautions must be taken to avoid fluid contamination during sampling, and the drums must be properly resealed.

8. Sampling

8.1 Sampling shall be in accordance with the applicable clauses of Practice D4057, ISO 3170, or Guide D8112. If drum sampling is required, use a representative "all-levels sample" obtained by weighted tube sampling (Guide D8112).

8.2 Use a clean, dry and contamination free sampling apparatus during the sampling process.

8.3 Care shall be taken to ensure that the fluid is adequately mixed before samples are withdrawn for testing and that the samples are representative of the whole drum.

8.4 The fluid shall meet the specification requirements when it passes from the supplier to the user unless other contractual arrangements have been made.

8.5 When testing a fluid against specification requirements, the laboratory should be accredited against the latest version of ISO 9001 to ensure that the product meets the requirements specified in this standard.

9. Elastomer Compatibility Requirements

9.1 This specification follows descriptions and recommendations on elastomer compatibility provided in ISO 6072.

9.2 The limits on elastomer performance given in ISO 6072 are based on the performance of reference elastomers that, while of similar polymer type, may differ in their chemical composition from their commercial equivalents. It may, therefore, be necessary to separately check (and approve) the use of specific commercial products before use. This process should be agreed upon by the turbine builder, the elastomer and the fluid manufacturers and performed at an independent laboratory under ISO 6072 test conditions.

9.2.1 The elastomer manufacturer should agree to give advanced notice of any change in the elastomer composition to allow time for testing the new elastomer formulation.

9.3 Caution should be given when performing a compatibility test at elevated temperatures (significantly over 100 °C) as this may cause the fluid to degrade and exhibit characteristics that are not typical of in-service use.

9.4 The test conditions for determining Elastomer Compatibility Index are listed in Table 1. Guidelines for acceptable changes of elastomer properties are in Table 2.

10. Functional Property Requirements

10.1 Phosphate ester fluids used in EHC turbine applications shall not contain any viscosity index improver.

10.2 Most of the test methods specified in the tables contain a precision statement. In cases of dispute, the procedure described in ISO 4259 shall be used.

10.3 The turbine fluids shall also be compatible with all material constituents of the lubrication and EHC systems.

10.4 The maximum fluid ISO Cleanliness Codes are provided in Table 3 for lubrication applications and Table 4 for EHC applications. Although fluid, as manufactured, should meet this requirement, contamination can occur during transportation and storage. Therefore, the recommended practice is to filter the fluid when transferring from the original drum into the turbine system.

11. Specification Requirements for Triaryl Phosphate Ester Fluids

11.1 *Application of Triaryl Phosphate Esters for Turbine Bearing Lubrication:*

11.1.1 To improve fire safety, some users modified their turbine systems to allow phosphate ester fluids to be used to lubricate the main turbine bearings. Typically, the lubrication systems are separate from the turbine EHC control systems, and the requirements for new lubricants as delivered are provided in Table 3.

11.1.2 Most of the test methods specified in this table contain a precision statement. In cases of dispute, the procedure described in ISO 4259 shall be used.

11.1.3 The choice of viscosity grade for use in a particular turbine should comply with the turbine manufacturer's recommendations. Usually, ISO 32 or ISO 46 viscosity grades (VG) are used to lubricate main bearings, hydrogen seals and turning gearboxes.

11.2 *Application of Triaryl Phosphate Esters for Turbine EHC Systems:*

11.2.1 Different designs of EHC hydraulic systems exist today and they have different impacts on system reliability and fluid performance. Some differences include different system pressures, flow rates, fluid volumes, and control valves.

11.2.2 One feature of many systems is fine-tolerance servo-valves to control the flow of steam. These operate at relatively high pressures and impose additional stress on the fluid. With fluid degradation, they can, however, suffer from electro-kinetic corrosion.

11.2.3 Electro-kinetic corrosion is usually controlled by maintaining a high fluid resistivity and minimizing the fluid chloride content.

11.2.4 If the EHC systems do not use fine-tolerance servo-valves, the fluid specification does not need resistivity and chloride content requirements.

11.2.5 Requirements for phosphate ester fluids as delivered for use in either type of EHC system are shown in Table 4.

11.2.6 Most test methods specified in the tables contain a precision statement. In cases of dispute, the procedure described in ISO 4259 shall be used.

11.2.7 High air release test values indicate the potential for loss of pump suction leading to a low-pressure trip, sluggish governor controls, accelerated fluid aging/oxidation, and bubble-choked filters.

11.2.8 Excessive foam formation and air entrainment may cause pump cavitation, overflow of reservoirs, inadequate lubrication, and inability to achieve full flow conditions.

TABLE 1 Test Conditions According to ISO 6072 for Determination of Elastomer Compatibility Index[A]

Fluid	Suitable Elastomer	Test Temperature[B] (°C)	Examples of Test Duration (h)[C]	
Aryl phosphate ester	FKM 2 EPDM 1	100 100	168	1000

[A] This material is modified from ISO 6072:2002 Table 11 with permission of the American National Standards Institute (ANSI) on behalf of the International Organization for Standardization (ISO). No part of this material may be copied or reproduced in any form, electronic retrieval system or otherwise or made available on the Internet, a public network, by satellite or otherwise without the prior written consent of the American National Standard Institute, 25 West 43rd 155 Street, New York, NY 10036.
[B] See 9.3 regarding recommended test temperature.
[C] The test duration of 1000 h is recommended for the long-term evaluation of elastomer compatibility as the short-term test may produce conflicting data.