IEEE STANDARDS ASSOCIATION

IEEE Guide for the Reclamation of Mineral Insulating Oil and Criteria for Its Use

IEEE Power and Energy Society

Sponsored by the
Transformers Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std C57.637™-2015
(Revision of
IEEE Std 637-1985)

IEEE Std C57.637™-2015
(Revision of
IEEE Std 637-1985)

IEEE Guide for the Reclamation of Mineral Insulating Oil and Criteria for Its Use

Sponsor

Transformers Committee
of the
IEEE Power and Energy Society

Approved 26 October 2015

IEEE-SA Standards Board

Abstract: Covered in this guide are: mineral insulating oil commonly defined as transformer oil; definitions and descriptions of reclaiming procedures; the test methods used to evaluate the progress and end point of the reclamation process; and recommended criteria for the suitable use of reclaimed oils. The use of oil in new apparatus under warranty is not covered in this guide.

Keywords: IEEE C57.637, mineral insulating oil, petroleum mineral oil dielectric fluid, reclamation, reconditioning, transformer mineral oil dielectric fluid

---

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

PDF: ISBN 978-1-5044-0062-6 STD20490
Print: ISBN 978-1-5044-0063-3 STDPD20490

Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page, appear in all standards and may be found under the heading “Important Notice” or “Important Notices and Disclaimers Concerning IEEE Standards Documents.”

Notice and Disclaimer of Liability Concerning the Use of IEEE Standards Documents

IEEE Standards documents (standards, recommended practices, and guides), both full-use and trial-use, are developed within IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (“IEEE-SA”) Standards Board. IEEE (“the Institute”) develops its standards through a consensus development process, approved by the American National Standards Institute (“ANSI”), which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

IEEE does not warrant or represent the accuracy or content of the material contained in its standards, and expressly disclaims all warranties (express, implied and statutory) not included in this or any other document relating to the standard, including, but not limited to, the warranties of: merchantability; fitness for a particular purpose; non-infringement; and quality, accuracy, effectiveness, currency, or completeness of material. In addition, IEEE disclaims any and all conditions relating to: results; and workmanlike effort. IEEE standards documents are supplied “AS IS” and “WITH ALL FAULTS.”

Use of an IEEE standard is wholly voluntary. The existence of an IEEE standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document, should rely upon his or her own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

Translations

The IEEE consensus development process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English version published by IEEE should be considered the approved IEEE standard.

Official statements

A statement, written or oral, that is not processed in accordance with the IEEE-SA Standards Board Operations Manual shall not be considered or inferred to be the official position of IEEE or any of its committees and shall not be considered to be, or be relied upon as, a formal position of IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position of IEEE.

Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE. However, IEEE does not provide consulting information or advice pertaining to IEEE Standards documents. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to comments or questions except in those cases where the matter has previously been addressed. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in revisions to an IEEE standard is welcome to join the relevant IEEE working group.

Comments on standards should be submitted to the following address:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
Piscataway, NJ 08854 USA

Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not imply compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Copyrights

IEEE draft and approved standards are copyrighted by IEEE under U.S. and international copyright laws. They are made available by IEEE and are adopted for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making these documents available for use and adoption by public authorities and private users, IEEE does not waive any rights in copyright to the documents.

Photocopies

Subject to payment of the appropriate fee, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Updating of IEEE Standards documents

Users of IEEE Standards documents should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect.

Every IEEE standard is subjected to review at least every ten years. When a document is more than ten years old and has not undergone a revision process, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE standard.

In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit the IEEE-SA Website at http://ieeexplore.ieee.org/xpl/standards.jsp or contact IEEE at the address listed previously. For more information about the IEEE-SA or IEEE's standards development process, visit the IEEE-SA Website at http://standards.ieee.org.

Errata

Errata, if any, for all IEEE standards can be accessed on the IEEE-SA Website at the following URL: http://standards.ieee.org/findstds/errata/index.html. Users are encouraged to check this URL for errata periodically.

Patents

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE-SA Website at http://standards.ieee.org/about/sasb/patcom/patents.html. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

Participants

At the time this IEEE guide was completed, the IEEE Guide for the Reclamation of Mineral Insulating Oil and Criteria for Its Use Working Group had the following membership:

James A. Thompson, *Chair*
David Sundin *Vice Chair*

Derek Baronowski
Claude Beuchemin
Paul Boman
Juan Castenellos
Donald Cherry
C. Clair Claiborne
James Graham
Mark McNally
Susan McNelly
Alan Peterson
Bob Rasor
Ed Tenyenhuis
Ryan Thompson
Vasanth Vailoor

The following members of the individual balloting committee voted on this guide. Balloters may have voted for approval, disapproval, or abstention.

Javier Arteaga
Roberto Asano
Peter Balma
Thomas Barnes
W. J. (Bill) Bergman
Wallace Binder
Thomas Bishop
Thomas Blackburn
William Boettger
Paul Boman
Chris Brooks
Paul Buchanan
Paul Cardinal
Juan Castellanos
Donald Cherry
C. Clair Claiborne
Craig Colopy
Willaim Darovny
Alan Darwin
Dieter Dohnal
Gary Donner
Charles Drexler
Fred Elliott
Jorge Fernandez Daher
Joseph Foldi
George Frimpong
Doaa Galal
Frank Gerleve
Edwin Goodwin
James Graham
Randall Groves
Bal Gupta
Ajit Gwal
Roger Hayes
Jeffrey Helzer
Philip Hopkinson
John John
Laszlo Kadar
John Kay
Gael Kennedy
Sheldon Kennedy
James Kinney
Neil Kranich
Jim Kulchisky
Saumen Kundu
John Lackey
Chung-Yiu Lam
Thomas La Rose
Thomas Lundquist
J. Dennis Marlow
Mark McNally
Susan McNelly
Daleep Mohla
Daniel Mulkey
Jerry Murphy
Ryan Musgrove
Arthur Neubauer
Joe Nims
Lorraine Padden
Bansi Patel
Christopher Petrola
Alvaro Portillo
Tom Prevost
Timothy Charles Raymond
Jean-Christophe Riboud
John Roach
Michael Roberts
Oleg Roizman
John Rossetti
Thomas Rozek
Bartien Sayogo
Ewald Schweiger
Charles Simmons
Jerry Smith
Brian Sparling
David Stankes
David Sundin
Ed Tenyenhuis
David Tepen
James A. Thompson
John Vergis
Jane Verner
David Wallace
David Wallach
Kipp Yule
James Ziebarth

When the IEEE-SA Standards Board approved this guide on 26 October 2015, it had the following membership:

Contents

1. Overview 1
   1.1 Scope 1
   1.2 Purpose 1

2. Normative references........ 1

3. Definitions 3

4. Classification of service-aged oils and criteria for reuse 5
   4.1 General classification of service-aged oils 5
   4.2 Suggested limits for classes of service-aged oils 5
   4.3 Economic factors 6
   4.4 Sources of oil to be reclaimed........ 7
   4.5 Precautions 7
   4.6 Worker protection measures 8
   4.7 Criteria for reuse of reclaimed oil........ 8

5. Types of reconditioning and reclamation processes 10
   5.1 Overview 10
   5.2 Gases and water—vacuum dehydration........11
   5.3 Water and solids 11
   5.4 Adsorption of soluble contaminants 12
   5.5 Types of pressure percolation........16
   5.6 Regenerative fuller's earth system........18
   5.7 Modern oil processing systems........19
   5.8 Locations 21
   5.9 Choice of methods 21

6. Oil tests and their significance........22

Annex A (informative) Trade names of askarel (PCB) products........26

Annex B (informative) Bibliography........28

IEEE Guide for the Reclamation of Mineral Insulating Oil and Criteria for Its Use

IMPORTANT NOTICE: IEEE Standards documents are not intended to ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks. Implementers of IEEE Standards documents are responsible for determining and complying with all appropriate safety, security, environmental, health, and interference protection practices and all applicable laws and regulations.

This IEEE document is made available for use subject to important notices and legal disclaimers. These notices and disclaimers appear in all publications containing this document and may be found under the heading "Important Notice" or "Important Notices and Disclaimers Concerning IEEE Documents." They can also be obtained on request from IEEE or viewed at http://standards.ieee.org/IPR/disclaimers.html.

1. Overview

1.1 Scope

The scope of this guide covers mineral insulating oil commonly defined as transformer oil; definition and description of reclaiming procedures; the test methods used to evaluate the progress and end point of the reclamation process, and what criteria recommended for the use of reclaimed mineral oils are considered suitable. This guide does not cover the use of mineral oil in new apparatus under warranty.

1.2 Purpose

The purpose of this guide is to provide detailed procedures for reclaiming used mineral insulating oils by chemical and mechanical means, making them suitable for reuse as insulating fluids, and to describe the essential properties suggested for reuse in each class of equipment and the recommended test methods.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ASTM D88, Standard Test Method for Saybolt Viscosity.[1]

ASTM D92, Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester.

ASTM D97, Standard Test Method for Pour Point of Petroleum Products.

ASTM D445, Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity).

ASTM D831, Standard Test Method for Gas Content of Cable and Capacitor Oils.

ASTM D877, Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes.

ASTM D892, Standard Test Method for Foaming Characteristics of Lubricating Oils.

ASTM D924, Standard Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids.

ASTM D971, Standard Test Method for Interfacial Tension of Oil Against Water by the Ring Method.

ASTM D974, Standard Test Method for Acid and Base Number by Color-Indicator Titration.

ASTM D1275B, Standard Test Method for Corrosive Sulfur in Electrical Insulating Oils.

ASTM D1298, Standard Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method.

ASTM D1500, Standard Test Method for ASTM Color of Petroleum Products (ASTM Color Scale).

ASTM D1524, Standard Test Method for Visual Examination of Used Electrical Insulating Oils of Petroleum Origin in the Field.

ASTM D1533, Standard Test Method for Water in Insulating Liquids by Coulometric Karl Fischer Titration.

ASTM D1534, Standard Test Method for Approximate Acidity in Electrical Insulating Liquids by Color-Indicator Titration.

ASTM D1816, Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using VDE Electrodes.

ASTM D2112, Standard Test Method for Oxidation Stability of Inhibited Mineral Insulating Oil by Pressure Vessel.

ASTM D2161, Standard Method for Conversion of Kinematic Viscosity to Saybolt Universal Viscosity or to Saybolt Furol Viscosity.

ASTM D2440, Standard Test Method for Oxidation Stability of Mineral Insulating Oil.

---

[1] ASTM publications are available from the American Society for Testing and Materials (http://www.astm.org/).

ASTM D2668, Standard Test Method for 2,6-di-tert-Butyl-p-Cresol and 2,6-di-tert-Butyl Phenol in Electrical Insulating Oil by Infrared Absorption.

ASTM D2864, Standard Terminology Relating to Electrical Insulating Liquids and Gases.

ASTM D2945, Standard Test Method for Gas Content of Insulating Oils.

ASTM D3487, Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus.

ASTM D3612, Standard Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography.

ASTM D4059, Standard Test Method for Analysis of Polychlorinated Biphenyls in Insulating Liquids by Gas Chromatography.

ASTM D4768, Standard Test Method for Analysis of 2,6-Ditertiary-Butyl Para-Cresol and 2,6–Ditertiary-Butyl Phenol in Insulating Liquids by Gas Chromatography.

ASTM D5222, Standard Specification for High Fire-Point Mineral Electric Insulating Oils.

ASTM D6786, Standard Test Method for Particle Count in Mineral Insulating Oil Using Automatic Optical Particle Counters.

ASTM D6871, Standard Specification for Natural (Vegetable Oil) Ester Fluids Used in Electrical Apparatus.

IEEE Std C57.104™, IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers.[2, 3]

IEEE Std C57.106™, IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment.

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[4]

The definitions contained in this guide pertain to terms that are used in conjunction with electrical insulating fluids and are consistent with general usage (see ASTM D2864).

additive: A chemical compound or compounds added to an insulating fluid for the purpose of imparting new properties or altering those properties which the fluid already has.

antioxidant: *See:***oxidation inhibitor**

askarel: A generic term for a group of synthetic, fire-resistant, chlorinated, aromatic hydrocarbons used as electrical insulating liquids. They have a property under arcing conditions such that any gases produced will consist predominantly of noncombustible hydrogen chloride with lesser amounts of combustible gases. There have been many trade names used for askarel fluids, from different manufacturers. See Annex A.

---

[2] The IEEE standards or products referred to in this clause are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

[3] IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

[4] *IEEE Standards Dictionary Online* subscription is available at: http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

Most countries have prohibited their manufacture and restricted their use by the early 1980s because of bioaccumulation and health concerns.

high molecular weight hydrocarbon (HMWH): A specially refined paraffinic hydrocarbon-based less-flammable insulating liquid and coolant for use in fire-resistant indoor and outdoor transformers, which generally conforms to ASTM D5222 when new. Because of their chemical similarity to conventional mineral insulating oil, HMWH fluids can be handled, processed, and reclaimed using the same techniques described in this guide. Refer to the instructions offered by the HMWH manufacturer for specific recommendations.

inhibitor: Any substance that when added to an electrical insulating fluid retards or prevents undesirable reactions. See oxidation inhibitor.

natural ester insulating fluid: A specially refined and formulated seed-oil (vegetable oil) based dielectric fluid for insulating and cooling electrical equipment for indoor and outdoor installations, which generally conforms to ASTM D6871 when new.

oxidation inhibitor: Any substance added to an insulating fluid to improve its resistance to oxidation. Inhibitors, such as 2,6-ditertiary-butyl para-cresol (DBPC) or 2,6-ditertiary-butyl phenol (DPC), are sometimes added to mineral insulating oil to improve their stability. This may include any substance added to an insulating fluid to improve its resistance to deleterious attack in an oxidizing environment.

polychlorinated biphenyl PCB: A group of chemical compounds characterized by two phenyl (6 carbon) rings with two or more chlorine atoms. When mixed with solvents, PCB fluids were generically called **askarel** fluids. PCB fluids were widely used as nonflammable dielectric fluids from the 1930s through the 1970s. Most countries had forbidden their manufacture and use by the early 1980s because of bioaccumulation and health concerns. *See:* **askarel**.

reclamation: The restoration of oil to a useful state by the removal of contaminants and products of degradation such as polar, acidic, or colloidal materials from used electrical insulating liquids by chemical or adsorbent means.

NOTE—The methods listed under reconditioning are usually performed in conjunction with reclaiming. Reclaiming typically includes treatment with clay or other adsorbents.[5]

re-refining: The use of primary refining processes on used electrical insulating liquids to produce liquids that are suitable for further use as electrical insulating liquids. This is a much more intensive technique than reclamation. As such, re-refining is outside the scope of this guide.

NOTE—Techniques may include a combination of distillation and acid, caustic solvent, clay or hydrogen treating, and other physical and chemical means.

reconditioning: The removal of insoluble contaminants, moisture, and dissolved gases from used electrical insulating liquids by mechanical means.

NOTE—The typical means employed are settling, filtering, centrifuging, and vacuum drying or degassing.

silicone oil: A specially formulated polydimethyl siloxane less-flammable insulating fluid and coolant for use in fire-resistant indoor and outdoor transformers.

synthetic ester insulating fluid: A specially formulated polyol ester based less-flammable insulating fluid and coolant for use in fire-resistant indoor and outdoor transformers.

---

[5] Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

4. Classification of service-aged oils and criteria for reuse

4.1 General classification of service-aged oils

The functional limits of oil properties in different apparatus vary with the type and design so that the acceptable limits for oils that can remain in service are dependent upon the requirements of the specific apparatus. Suggested limits for oil remaining in service at various voltage classes are given in IEEE Std C57.106™. It is therefore impossible to indicate the significance of specific tests and recommended test limits for all possible existing applications of in-service insulating oil. It should also be recognized that no one test can be used as the sole criterion of the condition of oil in service. It is possible, however, to summarize the value and importance of current tests and to suggest methods of treatment for the oil being examined, such methods being based on current industry experience.

4.2 Suggested limits for classes of service-aged oils

The suggested limits for mineral oil after equipment filling but before energizing, at various voltage classes, are given in IEEE Std C57.106. It is not intended that oil be removed from service when a single property limit is exceeded or that the oil be left in service until all property values are outside the stated limits. *Each case should be examined individually and manufacturer's advice may be considered.*

Oils that do not meet the suggested limits for continued service in their respective voltage classes may be considered for reuse in similar apparatus operating at a lower voltage class if they meet the limits for that class, or they may be suitable for reconditioning (Group I) or reclamation (Group II). Suggested limits for oils in these groups are contained in Table 1. Oils that do not meet the suggested limits for Group II should be discarded unless the reclamation process in use can restore the oils to the limits given in Table 2. Table 2 provides suggested requirements for reclaimed mineral oil for use in transformers prior to filling the equipment. Properly reclaimed oil meeting the minimum requirements of Table 2 may contain excessive quantities of water and dissolved gases for use in some transformers and should, therefore, be subjected to additional processing during filling, such as vacuum dehydration if required, to comply with the apparatus manufacturer's specification limits for water.

Table 1—Suggested limits for oil to be reconditioned or reclaimed

ASTM test property	**Group I**	**Group II**	**ASTM test method**
Acid number maximum, mg KOH/g	0.2	0.5	D974
Interfacial tension, minimum, mN/m	24	16	D971

The most appropriate method for disposal of rejected oils will depend upon local conditions and the volume of oil to be discarded. In all cases caution should be exercised to ensure that the disposal method is in compliance with applicable environmental laws or regulations.

NOTE—Information on suggested limits for in-service oils Group I by voltage class may be found in IEEE Std C57.106.

Table 2—Suggested property requirements of reclaimed oil for transformers[a, b]

ASTM test property	Limit	ASTM test method
Physical		
Flash point, minimum, °C	140[c]	D92
Pour point, minimum, °C	–40[d]	D97
Specific gravity, 15/15 °C, maximum	0.91	D1298
Viscosity, maximum, cSt at 40 °C (mm²/s)	12.0	D88 or D445
Color, maximum	1.5	D1500
Visual examination	Clear	D1524
Interfacial tension, minimum, mN/m	35	D971
Electrical		
Dielectric breakdown voltage, 60 Hz, kV, minimum	30	D877
Power factor at 60 Hz, 100 °C, maximum, %	1	D924
Chemical		
Acid number, maximum, mg KOH/g	0.05	D974
Oxidation inhibitor, maximum %, by weight	0.3	D2668
Oxidation stability, minimum, minutes	150	D2112
Oxidation Stability 164h		D2440
% sludge, maximum	0.25	
Total acid no, maximum, mg KOH/g	0.50	
Water, maximum, ppm	35	D1533

[a] Before processing, the test ASTM D1275B should be performed for the presence of corrosive sulfur, especially for transformers built, or refilled, after 1990. If the oil contains corrosive sulfur according to method ASTM 1275B, it is possible that some damage has occurred in paper-insulated components of the transformer. Consult the transformer manufacturer before proceeding.

[b] The mineral insulating oil should be tested for PCB in accordance with ASTM D4059.

[c] 145 °C flash point may be desired for 65 °C rise transformers.

[d] In certain regions it is common practice to specify a lower or higher pour point, depending upon climatic conditions.

NOTE—Information on suggested test limits for oil in transformers and reactors after filling but before energizing may be found in IEEE Std C57.106.

4.3 Economic factors

The economic factors associated with the reconditioning or reclaiming of used mineral insulating oils will vary significantly and depends on the type of processes used as indicated in this guide. The following factors, but not limited to, should be considered in determining if reconditioning and/or reclaiming used mineral insulating oil may be economically justifiable:

a) Cost and availability of materials

b) Cost of collection and storage of oil

c) Cost and availability of new oil versus cost of reprocessing the insulating oil
d) Total cost of process versus quality of end product
e) Factoring the life extension of the cellulose due to reduced acids in the cellulose
f) Cost associated with compliance with applicable environmental laws or regulations
g) Disposition of service-aged or contaminated materials, or both
h) Equipment maintenance and amortization
i) Labor and transportation costs
j) Laboratory cost
k) Loss of oil during processing
l) Value of service-aged oil when used for other purposes

4.4 Sources of oil to be reclaimed

Suggested sources of oil for reclamation include transformers, reactors, voltage regulators, circuit breakers, and reclosers. Insulating fluid from cables, capacitors, generators, or devices filled with non-mineral insulating oil are not included in the scope of this guide. It is common practice to collect and store reclaimable oil from a variety of sources until a sufficient quantity is accumulated to reclaim as a batch. The nature of contaminants remaining in such pooled oil after reclamation is much more unpredictable than those from a single source, so the reuse of this pooled oil should be restricted to apparatus with less stringent oil requirements.

CAUTION

Service-aged insulating oils generally contain contaminants as the result of their decomposition, or derived from the construction materials from within the apparatus. The reclamation process may not adequately remove these contaminants and may also remove some of the desirable natural components found in new oil. Furthermore, any adverse effects due to the contaminants may not be demonstrated by standard laboratory tests. Therefore, reclaimed oil should not be used in new equipment under warranty. New equipment should be filled with new oil conforming to IEEE Std C57.106 and ASTM D3487.

4.5 Precautions

4.5.1 Introduction

Care should be taken in the selection of oil for reclaiming so that it is not contaminated with any of the substances listed in this section.

4.5.2 Askarel (PCBs)

Oil containing askarel, or polychlorinated biphenyls (PCBs) should be handled in accordance with applicable laws or regulations. See Annex A for a list of askeral (PCBs) tradenames.

4.5.3 Silicone fluids

Oil containing traces of silicone fluids can foam excessively and therefore should not be reclaimed. (See Clause 6 and ASTM D892.

4.5.4 Other fluids

Fluids with original properties not conforming to ASTM D3487 should not be pooled.

4.5.5 Suspended carbon

Oil containing significant amounts of suspended carbon should generally be processed separately.

4.5.6 Corrosive sulfur

Oil should be tested for corrosive sulfur prior to processing. See Table 2 and ASTM D1275B.

4.6 Worker protection measures

a) Naphthenic-based mineral insulating oils may contain polyaromatic hydrocarbons (PAHs), including benzene at greater than 0.1 percent. For PAHs OSHA has set permissible exposure limits (PELs) based on 8-hour, time-weighted average exposure. See OSHA Standard 1910.1000 Table Z-1. For analytic methods see NIOSH Method 5026, NIOSH Manual of Analytical Methods (NMAM).

b) Heated mineral insulating oils may contain oil mist. For mineral oil mists OSHA has set permissible exposure limits (PELs) based on 8-hour, time-weighted average exposure. See OSHA Standard 1910.1000 Table Z-1. For analytic methods see NIOSH Method 5515 and NIOSH method 5506, NIOSH Manual of Analytical Methods (NMAM).

c) For instance in the United States, information on personal protective measures from these compounds may be found in OSHA's primary personal protective equipment standards located in Title 29 of the Code of Federal Regulations (CFR), part 1910 subpart I.

4.7 Criteria for reuse of reclaimed oil

4.7.1 Makeup or replacement oil for transformers and reactors which are out of warranty

Oils in transformers and reactors are usually subjected to elevated operating temperatures and deteriorate primarily by oxidation. This can result in the lowering of dielectric properties and interfacial tension, an increase in acid number, and the formation of sludge. The rate of deterioration varies in different apparatus depending upon factors such as temperature, the availability of oxygen, and variations in materials of construction.

Oil from transformers and reactors, unlike oil from oil circuit breakers or load tap changers, generally does not contain carbon or other products resulting from the arcing process. Therefore, oil to be reclaimed for use in transformers or reactors should, for the most part, only be from the apparatus to be filled or from similar apparatus. Oil from transformers or reactors containing significant quantities of arcing products, oil from oil circuit breakers and load tap changers, and pooled oils should generally not be reclaimed for use in transformers and reactors.

The rate of oil oxidation in transformers and reactors varies, so it is usually desirable to add an oxidation inhibitor to reclaimed oil. 2,6-ditertiary-butyl para-cresol and 2,6-ditertiary-butyl phenol have been used in concentrations up to 0.3% by weight to extend the life of the oil.

Suggested requirements for reclaimed oil for use in transformers and reactors are given in Table 2. Properly reclaimed oil meeting the minimum requirements of Table 2 may contain excessive quantities of water and dissolved gases for use in some transformers and reactors and should, therefore, be subjected to additional processing during filling, such as vacuum dehydration if required, to comply with the apparatus manufacturer's specification limits for water.

NOTE—Information on suggested test limits for reclaimed oil in transformers and reactors after filling but before energizing may be found in IEEE Std C57.106.

4.7.2 Makeup or replacement oil for oil circuit breakers

The requirements of insulating oil for use in oil circuit breakers are different from those for insulating oil in transformers. See Table 3. Modern oil circuit breakers require low viscosity, low pour-point oil since a large percentage of them are used outdoors and, in many cases, at low temperatures. All circuit breakers are free breathers (open to the atmosphere through a breathing device) which allows the admittance of humid air. In the case of older circuit breakers where use of high-viscosity oil is deemed necessary, caution and judgment should be exercised. The resultant effects of oil mixing and the addition of inhibitors upon thermal and viscous properties should be considered.

Although it has been customary to recondition or reclaim circuit-breaker oil in much the same manner as oil from transformers, the problem is somewhat different. Whereas oxidation and sludging are usually the principal problem in transformer oil, such is not the case with circuit-breaker oil because circuit breakers normally operate at, or near, ambient temperatures instead of at elevated temperatures. In a circuit breaker, the chief function of the insulating oil is to quench the arc. In so doing, thermal cracking occurs and minute particles of carbon form. These particles, coupled with moisture, can lower the dielectric breakdown voltage of the oil.

Table 3—Suggested test limits for reclaimed oil in circuit breakers, reclosers, and load tap changing compartments after filling, but before energizing

Property	Limit	ASTM test method
Physical		
Flash point, minimum, °C	140	D92
Pour point, minimum, °C	–40[a]	D97
Viscosity, maximum, cSt at 40 °C (mm^2/s)	12.0	D88 or D445
Color maximum	2.0	D1500
Interfacial tension at 25 °C, minimum, mN/m	25	D971
Electrical		
Dielectric breakdown voltage 60 Hz,	30	D877
kV, minimum 1 mm (0.039 in) gap	35	D1816
Chemical		
Acid number maximum, mg KOH/g	0.15	D974

[a] In certain sections of the United States and Canada, it is common practice to specify a lower or higher pour point, depending upon climatic conditions.

5. Types of reconditioning and reclamation processes

5.1 Overview

Reclamation involves the use of methods and processes which result in a beneficial change in the oil composition. Table 4 shows the various oil-purification practices and lists the types of contaminants removed by the various processes. In terms of mineral oil reclamation, Table 1 provides suggested guidelines that include the tests for interfacial tension and acid number which are the measures of the contaminants relating to acids and sludge. A description of the method and material used follows.

Table 4—Oil-purification practices

Oil-purification practices	Types of contamination removed					
	Solids	Free water	Soluble water	Air and gas	Volatile acids	Other
(1) Vacuum dehydrator	No	Yes	Yes	Yes	Most	No
(2) Mechanical filter (blotter or filter press)	Yes	Partial	Partial	No	No	No
(3) Centrifuge	Yes	Yes	No	No	No	No
(4) Coalescing filter	Yes	Yes	No	No	No	No
(5) Precipitation settling	Yes	Yes	No	No	No	No
(6) Contact process	Yes	Yes	Yes	No	Yes	Yes
(7) Percolation by gravity	Yes	Yes	Partial	No	Yes	Yes
(8) Percolation by pressure	Yes	Yes	Partial	No	Yes	Yes
(9) Activated carbon sodium silicate process	Yes	No	No	No	Yes	Yes
(10) Trisodium phosphate process	Yes	No	No	No	Yes	Yes

5.2 Gases and water—vacuum dehydration

The vacuum dehydrator is an efficient means of reducing the gas and water content of an insulating oil to a very low value. There are several types of vacuum dehydrators in use today. The guiding principle of each is the same; that is, the oil is exposed to a high vacuum and heat for a short interval of time. In one method the exposure of the oil is accomplished by spraying the oil through a nozzle into a vacuum chamber. In another type of vacuum dehydrator the oil is allowed to flow over a series of baffles inside a vacuum chamber thus forming thin films so that a large surface is exposed to the vacuum. If the oil contains solid matter, it is advisable to pass it through some kind of filter before processing it in the vacuum dehydrator, since solid contaminants may plug the nozzle of one type of dehydrator or even pass through either type without being removed from the oil.

The operation of vacuum dehydrators is continuous. In addition to removing water, vacuum dehydrators will degas the oil and remove the more volatile acids. The other acids, however, will be relatively unaffected so the overall acidity of an oil will not be much improved by the vacuum dehydration method. In either type of dehydrator some means of automatically recirculating a very wet oil should be provided as a safety device to prevent an excessive water content in the outgoing oil.

5.3 Water and solids

5.3.1 Blotter or filter press

The blotter press and similar filter-press devices are based upon the principle of forcing oil under pressure through a series of porous materials, usually paper. Filters of this type are capable of removing carbon, water, and sludge when they are in suspension, but cannot remove them effectively when carbon or sludge is in colloidal form. These devices will not remove air and they tend to aerate the oil.

The water-removing ability of the filter is dependent upon the dryness of the filter medium, and, consequently, suitable ovens should be provided to dry it before use. When filtering oil containing water, the filter medium rapidly comes into equilibrium with the water content of the oil and from that time on the filtered oil may contain water up to equilibrium at the temperature and relative humidity at which the filtering is done. Since the amount of dissolved water at saturation increases markedly with increasing temperature, filtering at low temperature is more effective in removing water. There is no satisfactory method of directly determining when the filter medium is too wet for further use, other than measuring the water content of the outgoing oil. Chief reliance has been placed upon inspection of the medium, an increase in input pressure, or a lowering in the dielectric strength of the filtered oil. Means are available that permit a continuous indication of the water content of the outgoing oil. When the oil being processed contains much contamination, it is necessary to change the filter medium at frequent intervals. Bag filters can be used to remove gross contamination down to 1 micron. The bag type filters have a very large particulate-holding capacity.

5.3.2 Centrifuge

Centrifuges are a mechanical means for separating free and suspended contaminants such as carbon, water, sludge, and oil. In general, the centrifuge can handle a much greater concentration of contamination than most other means. It is not usually used for bulk cleaning of contaminated oil. The centrifuge cannot remove dissolved water or finely divided carbon, thus the oil leaving the centrifuge may be saturated with water at the temperature and relative humidity of operation. The centrifuge is not designed to treat the oil chemically.

In oil-reclamation processes, the centrifuge or filter separator can be used in conjunction with other reclamation equipment.

5.3.3 Coalescing filter

A coalescing filter functions somewhat similarly to a centrifuge, but with no moving parts. Coalescing filters are made of fiberglass and are contained in circular tanks. The fiberglass traps small water droplets and increases differential pressure across the filter medium, thus forcing the droplets of water together and extruding water in the form of large water drops at the outer surface of the fiberglass element. The water drops are retained within a water-repellent separator screen and collect by gravity at the bottom of the filter while dry oil passes through the separator screen. They are suitable for unattended and automatic operation. They are usually used as a prefilter for vacuum treatment or clay treatment of oils to remove free water.

5.3.4 Precipitation or settling

Precipitation is a very useful and the least expensive way to rid oil of some free water, sludge, and solid contamination heavier than the oil. Even very dirty oil can be reclaimed to a degree after a period of rest. Water is drained periodically from the bottom, while oil is decanted from the top layer. The effectiveness of removing the moisture from the oil is temperature dependent. The warmer the oil, the more moisture will remain in suspension.

5.4 Adsorption of soluble contaminants

Adsorption is a process in which one substance attracts and holds the other substance tenaciously to its surface area. Most of the contaminants in oil, including water, are polar in nature and are therefore easily adsorbed.

Several types of materials are readily available as adsorbents, such as fuller's earth, attapulgite, activated alumina, and molecular sieves.

5.4.1 Materials

5.4.1.1 Fuller's earth

The term *fuller's earth* as used today refers to a class of naturally occurring adsorbent clays, rather than to a specific mineralogical specie. The main constituent in this class is attapulgite clay, mined principally in south Georgia and north Florida. Specifically, attapulgite clay has been found most satisfactory for purifying transformer oils because it has the ability to neutralize acids, adsorb polar compounds, and decolorize to a clear oil.

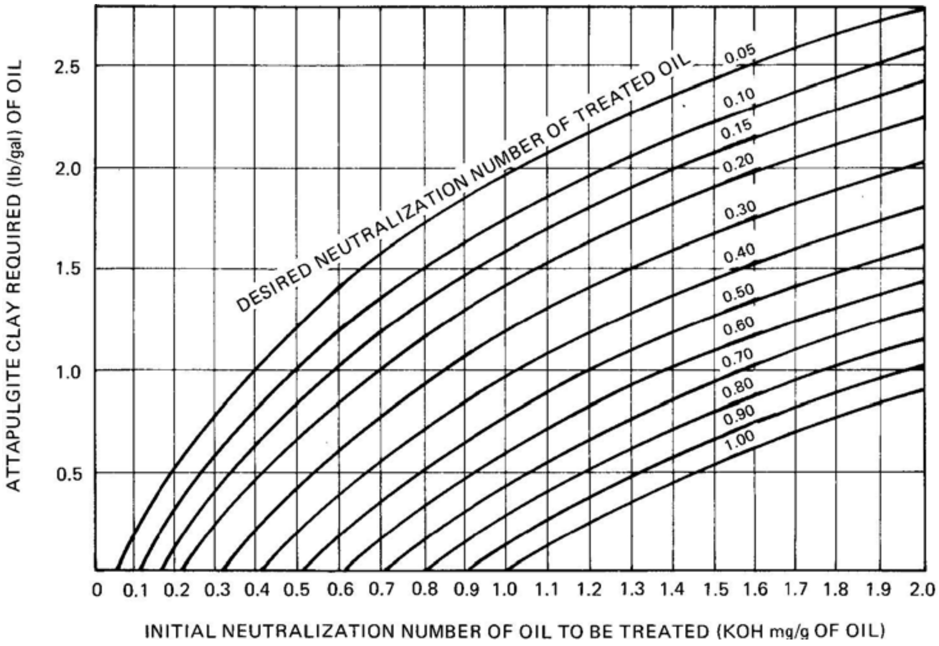
What makes attapulgite unique is its crystalline structure. As mined, the clay is a hydrated magnesium aluminum silicate. During processing, the clay is crushed, heat activated, ground, screened, and bagged. The temperature of the heat activation or drying stage determines the degree of internal porosity. This porosity contributes to the clay's high surface area and hence adsorption capacity. High temperature activation produces a low volatile matter (LVM) clay. This is the most active material that strongly adsorbs water, has high acid adsorption, but less than optimum decolorizing efficiency. Lower temperature activation produces a regular volatile matter (RVM) clay characterized by lower water-adsorbing capacity, but greater de-colorization efficiency, than LVM while acid neutralization is about the same.

It has been found that extruding an attapulgite clay will further enhance its adsorbing powers over a non-extruded clay. An extruded clay is designated AA. For transformer-oil reclamation, only two available designations are generally applicable—AARVM for maximum decoloring in a moisture-free system, or AALVM for good acid removal from an oil containing high moisture.

Choice of clay particle size or mesh size is a function of the type of reclamation equipment in use. *Percolation* towers use granular clays while *contact* systems use powdered clays. Usually a 30/60 mesh AALVM clay is employed for bulk treating transformer oil in clay towers equipped with a prefilter to remove water. However, depending on production flow rates, oil viscosity, and allowable contact time, a smaller mesh size (50/80) is also used because of its higher external surface area. Thus 50/80 RVM and 50/80 LVM are available for bulk oil purifiers.

In contact treating of oil, 100 and higher RVM or 100 and higher LVM are alternate choices, again depending on flow rates, viscosity of oil, etc.

Activated attapulgite clay can neutralize sizeable quantities of acid as shown in Figure 1. The amount of acid removed, correlated as the acid number, depends on many factors since adsorption is a dynamic equilibrium process. Temperature, flow rates, viscosity of oil, residence time, and initial level of acid all affect the rate and capacity of adsorption. Hence, Figure 1 should be used as a guideline for typical expected values only.



EXAMPLE: Assume that a spent oil has an acid (neutralization) number of (0.2 mg/KOH)/g of oil. To reduce the acid (neutralization) number to 0.05, approximately 0.29 kg (0.64 lb) of attapulgite clay will be required for each gallon of oil treated.

Figure 1—Adsorption by attapulgite clay[6]

5.4.1.2 Alumina or bauxite

Activated bauxite consists principally of hydrated aluminum oxide and is activated by thermal treatment alone. It is then a hard, durable, thermally resistant adsorbent and can be regenerated and reused longer than clays.

The activated bauxite is available in bulk in various mesh sizes and is used for percolation filtering of oils.

5.4.1.3 Molecular sieves

Molecular sieves are a group of unique crystalline adsorbents capable of separating substances based on their molecular size. These adsorbents are uniformly porous and have a strong affinity for water. Molecular sieves belong to a class of materials known as zeolites. The zeolites are aluminosilicates with the unusual characteristic of being able to undergo dehydration with essentially no change in crystal structure. The type 4A is used with transformer oil and has an unusual affinity for polar compounds, particularly water.

The molecular sieve 4A is available in bulk quantities and can be regenerated. It is significantly more expensive than the other adsorbent materials.

---

[6] Reprinted with permission of BASF Corporation, Florham Park, New Jersey, 07924

5.4.2 Contact process

The contact process for reclaiming oil makes use of 200-mesh (77 mesh/cm) clay and relatively high operating temperatures. This process makes the most efficient use of the clay and produces a uniform product. The degree of reclaiming depends on the amount of clay used and the condition of the oil.

In a typical commercial apparatus, oil to be reclaimed is introduced into a heated mixing chamber as a measured amount of clay is fed in through a hopper. The mixture is stirred as heat is applied, and the process continues until the desired temperature is reached. The time involved in this operation is approximately half an hour. The oil is then dropped into a tank before it is pumped through a filter especially built to accommodate the clay. Much of the oil ordinarily retained in the earth is extracted by the application of compressed air to the filter.

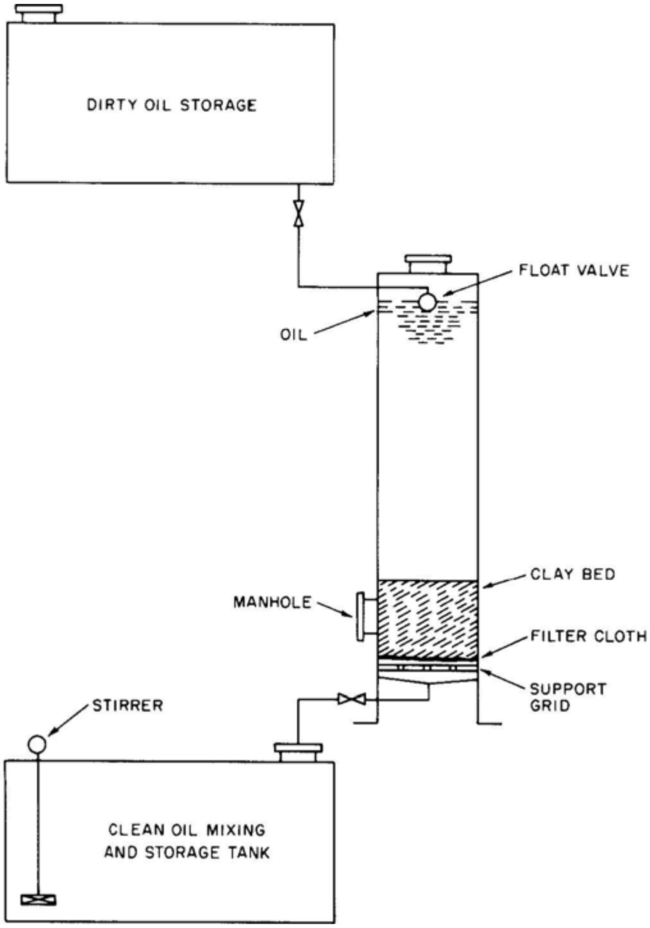


Figure 2—Schematic diagram of gravity-percolation refining apparatus

This type of apparatus should not be used to process oil containing di-butyl para-cresol (DBPC), as this material, when catalyzed by clay, will begin to decompose at 100 °C.

5.4.3 Percolation by gravity

Gravity percolation makes use of gravity—as the hydrostatic head of a column of oil—to force the oil through a column of adsorbent, such as clay. A typical gravity system, shown schematically in Figure 2 consists of three tanks on different levels. The upper tank is used as a dirty-oil reservoir, the middle tank as the filter containing the clay, and the lower tank as a blending tank for the filtered oil. The middle tank is equipped with a strainer-type bottom covered by a filter cloth supporting a 1.8 m (6 ft) high bed of clay. A float valve controls the flow of oil from the dirty-oil storage tank so that a constant head of approximately 4.6 m (15 ft) to the filter plate is provided. Once the process is started it continues in operation with very little attention other than periodic sampling.

The output of gravity percolation is a graded one starting with over-treated oil and ending with oil in approximately the same condition as before treatment. To obtain a uniform product, blending is necessary. By this method, the oil can be treated to any desired degree. The rate of flow is slow, being about 407 L/h-m^2 (10 gal/h-ft^2) filter bed area for an installation such as the one described above. The slow flow rate results in long contact time with the filter medium which permits efficient use of the adsorbent.

5.4.4 Percolation by pressure

Pressure percolation is similar to gravity percolation in general principle except that the oil is forced through the adsorbent by a pump. Pressure percolators are commercially available and all have a chamber to hold a container such as a bag or cartridge filled with the adsorbent. The chamber is designed so that oil is admitted around the outside of the adsorbent pack and should pass through the adsorbent before leaving the chamber.

These machines are capable of processing large volumes of oil in a relatively short time. Since the amount of adsorbent is relatively small with respect to the amount of oil, frequent changes of the adsorbent are required.

An advantage of such machines is that they may be brought to the job site and used directly on apparatus whose oil is to be reclaimed.

5.5 Types of pressure percolation

In these examples clay is indicated as the adsorbent. Other materials may be used.

5.5.1 Bulk filters

Large pressure tanks have a fine mesh screen across the bottom and are filled with granular clay through an open-top cover. In operation, the hot oil flows through layers of clay slowly by gravity or by pressure from an inlet oil pump. The process thus may make use of gravity or pressure percolation. See Figure 3.

The clay may be placed in large baskets for easy removal with a lifting device, or shoveled out through a side opening, or, in some instances, the entire pressure tank can be tilted for dumping the spent cake.

The cost of operation of bulk filters is lower than that of cartridge types.

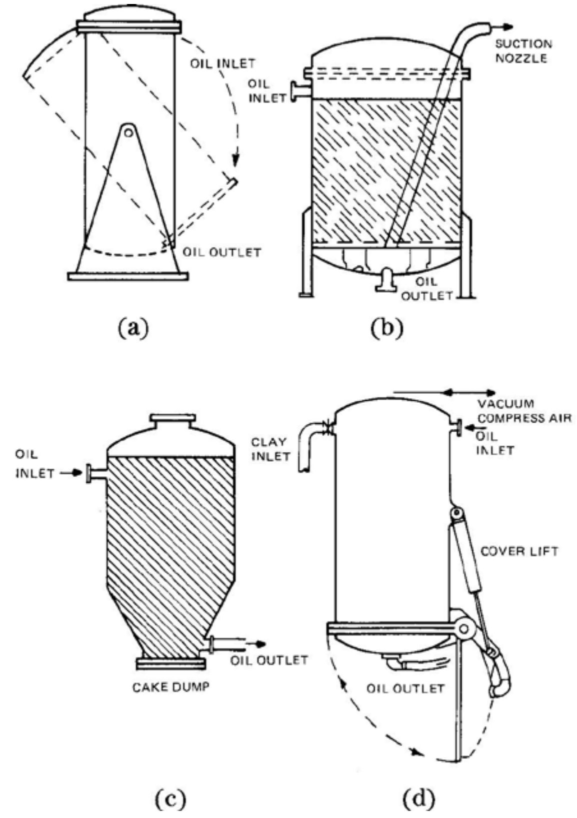


Figure 3—Bulk clay filters

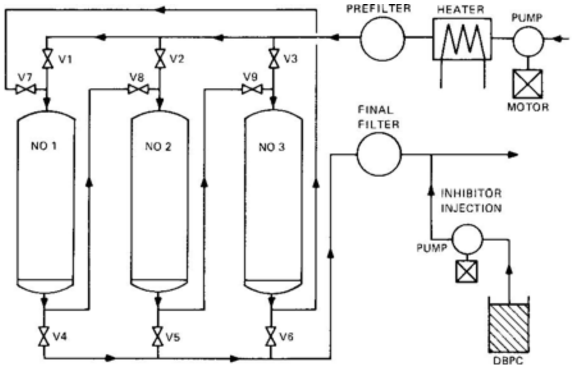


Figure 4—Three-clay tower system

5.5.2 Deep bed filtration

Today's trend is toward slender columns packed with loose clay by means of vacuum or conveyors with spent cake discharged through a bottom opening cover.

This design ensures long contact time of oil flowing from top to bottom, minimizes channeling, and provides the greatest improvement of oil conditions in a single pass. Two or three such columns or *towers,* piped in series, provide for a better utilization of clay (Figure 4). Only the first tower in series is replaced with new clay and switched into the final tower position. In this manner, an almost continuous run with a consistent quality of effluent can be obtained.

Each tower contains from 227 kg (500 lb) to 1361 kg (3000 lb) of clay. Even in mobile operation, the tanks contain 91 kg (200 lb)—454 kg (1000 lb) each.

5.5.3 Throw-away and repackable cartridges

Granular types of clay are packaged in throw-away canisters, holding 4.5 kg (10 lb)—13.6 (30 lb) of material, which are placed inside pressure-filter tanks. Protective antimigration filter cloth wrap is either inside the element or wrapped around the center tube. See Figure 5.

Throw-away cartridges and canisters are relatively expensive and can be justified only in emergencies or when a marginal condition of the oil requires removal of a trace contaminant. The limited amount of clay cannot be effective on very contaminated oil.

Repackable cartridges or canisters are less costly and are usually of a larger size, holding as much as 22.7 kg (50 lb) or more of clay each. After use, the canisters are removed and the clay replaced with new, dry material. In most cases this is more economical than the throw-away cartridges.

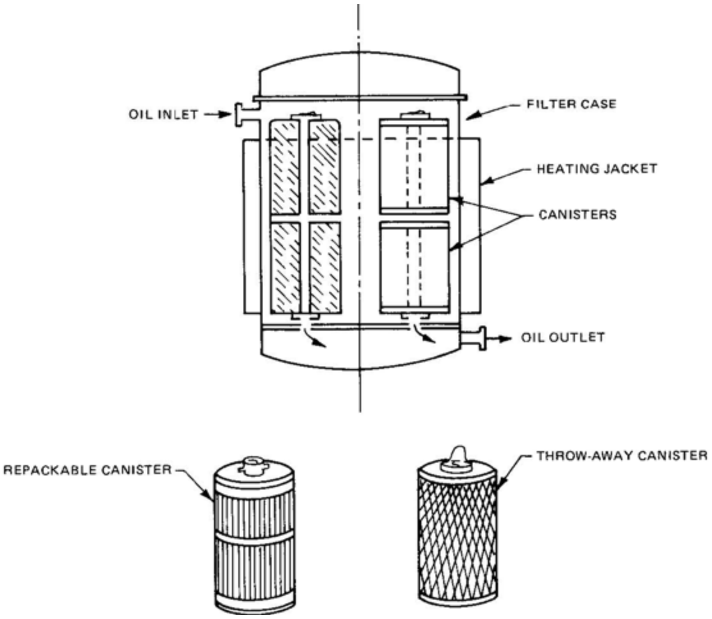


Figure 5—Fuller's earth cartridge filters

5.6 Regenerative fuller's earth system

Fuller's earth systems have been produced that can "clean" or "regenerate" spent fuller's earth that has been used to reclaim oxidized transformer oil and has become saturated to the point it will no longer absorb contaminants. These systems use a blend of fuller's earth and activated alumina. Regenerative clay systems remove more inhibitor than lower process temperatures systems. Furans are also stripped in most types of clay filtering equipment as the furanic compounds are polar.

These “regenerative” systems use high heat to vaporize as much of the oil as possible that is trapped within the fuller’s earth. Reportedly the towers can be regenerated up to 300 times before the pores of the fuller’s earth are so plugged with residue that the earth must be dumped and the towers reloaded. With each “regeneration” of the fuller’s earth, there is increasing residue left in the earth so the intervals between regeneration decrease and the regeneration period increases. The hot exhaust gasses produced during regeneration are usually quite odorous and a catalytic converter is used to reduce the odor levels. Current concerns with this exhaust gas and possible carcinogens being formed are being investigated. Care must be taken to make sure any oil processed by regenerative systems is free of PCBs.

5.7 Modern oil processing systems

5.7.1 Normal systems

A flow diagram (Figure 6) shows a modern, multipurpose system. In most cases the equipment is installed on a trailer unit so that it can be moved to the transformer site for reclamation, or to new transformer locations for installation. Also, oil reclamation and upgrading systems may be used as stationary systems.

5.7.2 On-line energized systems

The practice of reclamation of transformer oil or desludging of a severely aged transformer is not as common a practice as it was during the 1970s. Desludging or reclaiming oil in on-line energized systems requires specialized equipment and very highly trained operators. Energized processes are seldom done over 138 kV. The only exception would be the application of an on-line dryer. On-line systems used today focus on removing moisture and gasses from on-line energized transformers by processing the oil in a device external to the transformer.

The practice of reclamation of transformer oil with the equipment energized requires utilizing proper equipment and well-trained personnel or experts in the field. These systems are in common practice today and are typically of two types. One system uses absorptive media such as specially prepared filter elements or a regenerative desiccant. The other system uses vacuum dehydration and degasification to remove moisture and reduce gas levels. Either type of system must have safeguards to make sure the oil level within the energized transformer does not change and that no bubbles are injected or created in the transformer.

The absorptive media–type system usually has monitoring devices to indicate when the media must be changed. The vacuum dehydrator/degassifier exhausts the removed moisture to atmosphere and does not require absorptive media. The ratio of gasses continues and can be used for diagnosis. The on-line system simply maintains the gas levels at a point where the transformer can usually remain on line. Absorptive media or regenerative desiccant systems have no effect on gas. Absorptive media systems usually have a lower initial cost, but can have higher operating costs due to replacing the absorptive media.

Vacuum dehydrator/degassifier systems have a higher initial cost, but lower operating costs as they do not use absorptive media. Although this is a practice that is successfully being used, some equipment manufacturers and operators recommend against reclamation of oil in energized equipment due to the difficulty in controlling risks. There are system conditions which can impact the reliability and safety of energized reclamation, including potential problems resulting from lightning or switching surges occurring during reclamation.

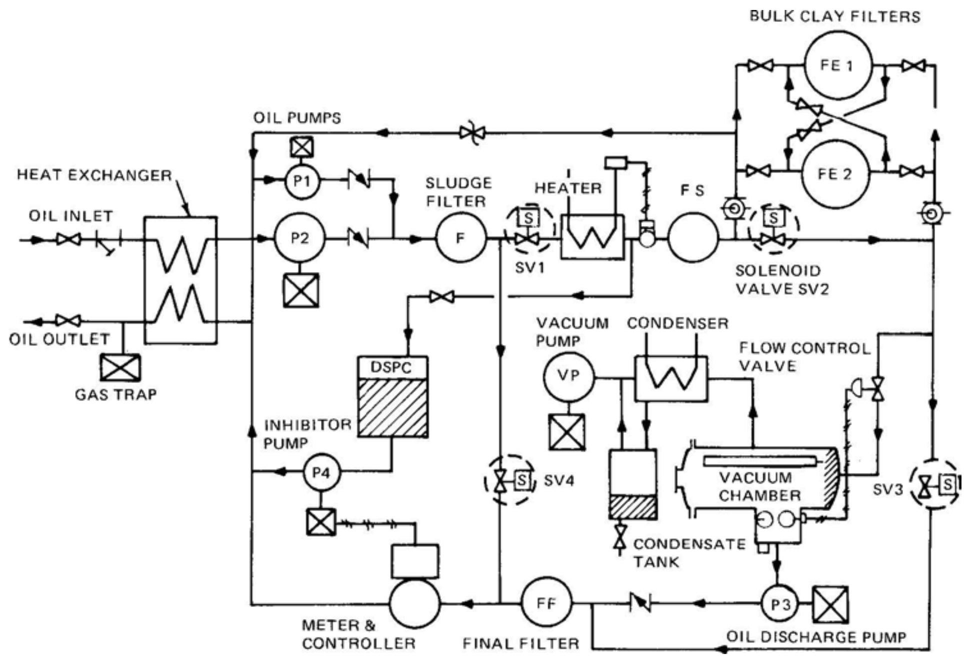


Figure 6—Typical flow diagram for modern, oil-reclamation system

A typical modern reclamation system for such application includes as a minimum: a combination of an oil and electric heater, or both, deep-bed adsorbent towers, vacuum dehydration, and a final filter with a nominal pore size of one-half micron.

Proper safety precautions are required to protect operating personnel. This includes specially designed commercial equipment to safeguard against certain possible hazards. There is a risk of damage or failure of the apparatus to be serviced. One risk centers on the possible bubble formation in the system. A properly designed system uses double protection against this possibility through proper use of a gas trap and vacuum degassification.

A second possibility concerns stirred-up contamination in the transformer due to movement of particulate matter and chemical contaminants which will reduce the dielectric strength. This concern is minimized in a properly designed system.

As a precaution, a proper evaluation of various transformer applications reveals that *not* every unit should be a candidate for energized reclamation. Costs for reclaiming are weighted high in the disposal of the spent clay. Oil and oil clay must be disposed of after they can no longer remove adequate contaminants to improve the oil. These costs are compounded for mobile systems by the need to drum up the spent clay and provide legal disposal.

Specific criteria dictate whether a given transformer should not undergo oil treatment while energized. The following criteria would recommend against reclamation of the oil in these transformers while they are energized:

a) When dissolved gas-in-oil analysis reveals certain combustible concentrations, then repair and degassification would first be required. See IEEE Std C57.104™.

b) Oil tests reveal cloudy oil or sediment containing iron oxide, bits of insulation, or sludge. Insulation tests should determine the effect of these items on the integrity of the insulation system.

c) When free water or high-moisture content has been found in the unit, insulation tests would come first.

d) Transformers (>35 years old) when coupled with general poor condition of the units.
e) Transformers rated 345 kV and higher.
f) Transformers with forced-oil cooling introduce a greater risk when processed with the forced cooling system energized.

5.8 Locations

5.8.1 Centralized reclamation site for pooled oil

This method is used by utilities and large industries where large amounts of oil can be received after it is collected. It consists of a tower filled with an adsorbent material such as fuller's earth, storage tanks for the pooled oil and the reclaimed oil, and the necessary pumps and plumbing required to circulate the used oil through the system. This type of reclamation can be done by either gravity or pressure percolation. This equipment is usually custom built for the particular job.

5.8.2 Mobile reclamation of pooled oil

The method is similar to 5.8.1 except that the treating unit is mobile and can be transferred from one source of pooled oil to another. This system normally employs a pressure percolation method. Equipment for this method is commercially available.

5.8.3 Reclamation of oil in transformers and associated devices using mobile equipment

In this method, oil is withdrawn from the bottom of the unit, heated, and pumped through an adsorbent bed such as fuller's earth, filtered, degassed, and dehydrated before it is returned to the top of the unit. The process is continuous and is concluded when the oil meets prescribed test values. The processing equipment is commercially available.

NOTE—Vacuum oil purifiers are most commonly used for these applications.

5.9 Choice of methods

Vacuum oil purifiers are frequently used. However the choice of reclamation methods that will prove the most practical and economical for a given system depends upon the geographical characteristics of the power system, the existing facilities available for application to such work, and the facts concerning the various types of refining equipment and methods previously described.

For example, on a compact system with large quantities of deteriorated oil, or on a system where oil reconditioning has been done in the past at a central location, the gravity-percolation method of reclaiming has many advantages in requiring a minimum amount of new equipment, attention, and labor. On a system where the oils requiring attention are widely scattered in location, service outages are difficult to obtain, and spare equipment is at a premium, some type of portable pressure percolator may be indicated for reclaiming in the field by recirculating the oil in the equipment.

Irrespective of the type of clay treatment used, additional processes should also be incorporated with the treatment.

a) The oil should be put through some device for removing free water before it contacts the clay to prevent water from wetting the clay. Water will cause at least partial and possible complete blocking of the clay, thus making it necessary to discard that batch of clay.

b) The oil coming out of the clay treater should be put through a completely automatic dehydrator equipped with positive means and safeguards for preventing water from being present in the finished product. This is particularly important when recirculating the oil in a transformer.

c) The oil should be passed through a one-half micron particle final filter prior to returning to the transformer, to filter out any remaining clay, lint, fine-ground iron, or other contaminants passed through the process equipment. These particle contaminants reduce the dielectric strength of the oil and therefore the dielectric integrity of the equipment.

d) Processing hot oil through fuller's earth above 70 °C can reduce the oxidation stability of the oil. Increasing the temperature above this value will additionally reduce the concentration of any oxidation inhibitor. Therefore, it is desirable to add an oxidation inhibitor to reclaimed oil in concentrations up to 0.3% by weight.

6. Oil tests and their significance

There are many established ASTM tests of practical significance which have been applied to insulating oil, such as dielectric breakdown voltages, power factor, and interfacial tension. See ASTM D877, ASTM D1816, ASTM D924, and ASTM D971.

Additional tests to detect the presence of deleterious products of oxidation or contamination (especially traces of PCBs) in service-aged oils also seem appropriate.

Table 5—ASTM test methods

Test	ASTM method
(1) Color	D1500
(2) Visual appearance	D1524
(3) Flash point	D92
(4) Interfacial tension	D971
(5) Pour point	D97
(6) Specific gravity	D1298
(7) Viscosity	D445, D2161
(8) Gas content	D2945, D3612
(9) Oxidation inhibitor content	D4768,D2668
(10) Water content	D1533
(11) Acid number	D974, D1534
(12) Oxidation stability	D2112, D2440
(13) PCBs in oil by gas chromatography	D4059
(14) Dielectric breakdown voltage	D877, D1816
(15) Power factor	D924
(16) Foaming characteristics of (lubricating) oils	D892
(17) Gas content of cable and capacitor oils	D831
(18) Corrosive sulfur	D1275B

In Table 5 the list of tests and their significance is recommended for classification purposes and to determine the suitability for use of reclaimed oils. Tests should be made using the latest revisions of accepted standards or tentative standards approved by ASTM. These tests and their significance are as follows:

1) *Color—D1500*. A low color number is an essential requirement for inspection of assembled apparatus in the tank. An increase in the color number during service is an indication of deterioration of the mineral insulating oil.

2) *Visual appearance—D1524*. The color and condition of a service-aged oil may be estimated during a field inspection by this method, thus assisting in the decision whether or not the oil is suitable for continued service or should be reprocessed in some manner. Unusual changes in color or contamination with particulate matter may be detected.

3) *Flash point—D92*. The flash point of oil is the temperature to which the material should be heated to give off sufficient vapor to form a flammable mixture with air under the conditions of the test. A low flash point indicates the presence of hazardous, volatile combustible contaminants in the insulating oil. The safe operation of the apparatus requires an adequately high flash point.

4) *Interfacial tension—D971*. The interfacial tension between an electrical insulating oil and water is a measure of the molecular attractive force between their unlike molecules at the interface. It is expressed in milli-Newtons per meter. This test provides a means of detecting soluble polar contaminants and products of deterioration. Soluble-contamination or oil-deterioration products generally decrease the interfacial tension value.

5) *Pour point—ASTM D97*. The temperature at which insulating oil will just flow under the prescribed conditions is known as the pour point. The viscosity characteristics of the oil can affect this value. Presently, the pour point has little significance as far as contamination or deterioration is concerned, but may be useful for type identification and for determining the type of equipment in which it can be used.

   If, in the future, oils containing pour depressant additives are used, a significant increase in pour point during use could indicate a deterioration of the additive itself.

6) *Specific gravity—D1298*. The specific gravity (relative density) of an insulating oil is the ratio of the weights of equal volumes of oil and water at 15 °C or 60 °F. The specific gravity of a mineral insulating oil influences the heat transfer rates and may be pertinent in determining suitability for use in specific applications. In certain cold climates, ice may form in de-energized transformers exposed to temperatures below 0 °C, and the maximum specific gravity of the oil used in such equipment should be a set value that will ensure that ice will not float in the oil at any temperature the oil might attain. It can also be used as a quick check for gross contamination with other fluids, that is, silicones or PCBs.

7) *Viscosity—D445 and D2161*. The viscosity of an oil is its resistance to uniformly continuous flow without turbulence, inertia, or other forces. Viscosity influences the heat transfer and, consequently, the temperature rise of apparatus. The higher the viscosity, the lower the heat transfer rate will be. At low temperature, the resulting higher viscosity influences the speed of moving parts, such as those in power circuit breakers, switchgear, load tap changer mechanisms, pumps, and regulators. Viscosity controls mineral insulating-oil processing conditions, such as dehydration, degassification and filtration, and oil-impregnation rates. High viscosity may adversely affect the starting up of apparatus in cold climates; for example, spare transformers and replacements. Viscosity is not usually affected by contamination or deterioration unless there has been extreme cracking or oxidation of the oil.

8) *Gas content—D2945 and D3612*. The gas content of an insulating oil may be defined as the volume of gas per 100 volumes of oil. In evaluating service-aged oil, this test normally has little significance in determining the quality or serviceability of the oil. It will have significance to the operator of apparatus where low gas content is required.

   a) *Method D2945*. This method determines the total dissolved gas content of low and medium viscosity, 100 SUs at 100 °F or lower (20 cSt at 40 °C), electrical insulating fluids using a vacuum degassing operation. No determination of the composition of the gas is made.

   b) *Method D3612*. This method determines the total dissolved gas content and composition of dissolved gases in the electrical insulating oils having a viscosity of 100 SUs at 100 °F (20 cSt at 40 °C) or lower. The dissolved gases are separated from the oil by a vacuum degassing operation and are then analyzed by gas chromatography. This test is usually used for diagnostic tests on operating equipment.

9) *Oxidation inhibitor content—D4768 and D2668*. Oxidation inhibitors are added to mineral insulating oil to retard the formation of oil sludge and acidity under oxidative conditions. They are used particularly in systems partially or freely exposed to air during service life. Inhibitor effectiveness is a function of base oil type, freedom from contamination, and concentration. Consequently, methods are provided to assay concentration of inhibitor in insulating oil. Certain un-aged oils may contain naturally occurring substances which have not been added to the oil, yet will yield a positive test within the limits of detectability. Depending upon the sensitivity of the apparatus used for method D2668, similar false indications may also be obtained. Two inhibitors in use are: 2,6-ditertiary-butyl para-cresol and 2,6-ditertiary-butyl phenol. It is anticipated that other oxidation inhibitors will be accepted.

10) *Water content (Karl Fischer method)—D1533*. A low water content of mineral insulating oil is necessary to achieve adequate electrical strength and low dielectric loss characteristics, to maximize the insulation system life, and to minimize metal corrosion.

11) *Acid number—D974*; *and Approximate acidity field test—D1534*. The acid number for service-aged oils is in general a measure of the acidic constituents of the oil. It may be pertinent if compared to the value of the new product, to detect contamination by substances with which the oil has been in contact, to reveal a tendency toward chemical change or deterioration, or to indicate chemical changes in additives. It may be used as a general guide for determining when an oil should be replaced or reclaimed, provided suitable rejection limits have been established and confirmation is received from other tests. The tests for field use are not intended to replace standard laboratory tests, but rather are intended as screening tests to minimize the number of field samples submitted to the laboratory. They permit approximate evaluations of the amount of acid and polar constituents and hence of the degree of deterioration, or contamination, or both, of the oil. However, they are only semi-quantitative and any decision to replace or reclaim an oil should be confirmed by laboratory tests.

12) *Oxidation stability—D2112 and D2440*. The resistance to oxidation of mineral insulating oils may be indicated by a) the percentage of insoluble matter formed in a prescribed length of time, b) the amount of acidity formed in a prescribed length of time, and c) the length of time required for the oil to react with a given volume of oxygen, when a sample of oil is heated and oxidized under prescribed conditions. The development of oil sludge and acidity resulting from oxidation during storage, processing, and long service life should be held to a minimum. This minimizes electrical conduction and metal corrosion, maximizes insulation system life and electrical breakdown strength, and ensures satisfactory heat transfer. These tests are generally applicable to new or reclaimed insulating oils, or both, and D2112 is intended specifically for inhibited oils. Numerical correlation between results from these laboratory tests and years of service or sludge accumulation in transformers has yet to be established.

13) *PCBs in oil by gas chromatography—D4059.* This method quantitatively measures the amount of PCBs present in oils. If PCBs are found to be present, the oil should be handled or disposed of in the manner prescribed by law.

14) *Dielectric breakdown voltage—D877 and D1816*. The dielectric breakdown voltage of an insulating liquid is of importance as a measure of its ability to withstand electric stress without failure. It is the voltage at which breakdown occurs between two electrodes under prescribed test conditions. It serves primarily to indicate the presence of contaminating agents such as water, dirt, or conducting particles in the liquid, one or more of which may be present when low dielectric breakdown is found by testing. However, a high dielectric breakdown voltage does not indicate the absence of all contaminations. Two methods are recognized for measuring the dielectric breakdown voltage of an oil (D877 and D1816). Method D877 frequently used to assess the quality of service-aged oil. Method D1816 is a method for use on oil being processed into apparatus and is finding increased usage for oil contained in apparatus. This method is used for the acceptance testing of new, unprocessed oil as received from a vendor.

15) *Power factor—D924*. Power factor (dissipation factor) is a measure of the dielectric losses in an oil. A high value is an indication of the presence of contaminants or deterioration products such as oxidation products, metal soaps, and charged colloids.

16) *Foaming characteristics of (lubricating) oils—D892.* Very small traces of silicone oils of the types used as insulating oils dissolved in mineral insulating oil can lead to foaming of the oil during vacuum dehydration and filling of equipment. This test, while not designed for insulating oils, may give some measure of the propensity of the oil to foam.

17) *Gas content of cable and capacitor oils—D831.* Gas bubbles can have an adverse effect on the insulating properties of an oil. This method determines the gas content of electrical insulating oils of low and medium viscosities.

18) *Corrosive sulfur—D1275B. Mineral insulating oils may contain substances that cause corrosion under certain conditions.* This method detects the presence of free (elemental) sulfur and corrosive sulfur compounds.

Annex A

(informative)

Trade names of askarel (PCB) products

Trade names of Askarel (PCB) products include:

- Askarel
- ALC
- Apirolio (Italy)
- Aroclor
- Aroclor-B
- Asbestol
- ASK
- Caffaro
- Capacitor 21
- Chlorextol
- Chlorinol
- Chlorphen
- Clophen (Germany)
- Clorinol
- Diaclor
- DK (Italy)
- Dykanol
- EEC-18
- Elemex
- Eucarel
- Fenclor (Italy)
- Hyvol
- Inclorx
- Inerteen
- Kenechlor
- Kennechlor
- Magvar
- MCS-1489
- Montar

- Nepolin
- NoFlamol
- Nonflammable Liquid
- Phenoclor (France)
- Pydraul
- Pyralene (France)
- Pyranol
- Pyrochlor (UK)
- Santotherm
- Santotherm-FR (Japan)
- Santovac 1 and 2
- Solvol
- Sorol (USSR)
- Therminol FR

Taken from U.S. Air Force Technical Letter 96-2, "Elimination of liquid polychlorinated biphenyls (PCBs) prioritization guidance." See also http://www.epa.gov/osw/hazard/tsd/pcbs/pubs/aroclor.htm.

Annex B

(informative)

Bibliography

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

[B1] Code of Federal Regulations Title 40 Part 761 (40CFR761) Polychlorinated biphenyls (PCBs) manufacturing, processing, distribution in commerce, and use prohibitions.

[B2] IEEE Std C57.93™, IEEE Guide for Installation and Maintenance of Liquid-Immersed Power Transformers.[7], [8]

[B3] IEEE Std C57.140™, IEEE Guide for the Evaluation and Reconditioning of Liquid Immersed Power Transformers.

[B4] Oommen, T. V., and E. M. Petrie, "Particle contamination levels in oil-filled large power transformers," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-102, no. 5, pp. 1459–1465, May 1983.

[B5] Oommen, T. V., "Corrosive and non-corrosive sulfur in transformer oils," *Electrical Electronics Insulation Conference and Electrical Manufacturing and Coil Winding Conference,* pp. 309–311, Oct. 1993.

[B6] Oommen, T. V., G. K. Frimpong, and J. M. Walden, "Certain high charging polymeric materials in transformer oil," *Proceedings of the 1998 IEEE 6th International Conference on Conduction and Breakdown in Solid Dielectrics*, 1998, pp. 353–356, June, 1998.

[B7] Oommen, T. V., and S. R. Lindgren, "Bubble evolution from transformer overload," *IEEE/PES Transmission and Distribution Conference and Exposition*, Vol. 1, pp. 137–142, Nov. 2001.

[B8] Rouse, T., "Mineral insulating oil in transformers," *IEEE Electrical Insulation Magazine*, Vol. 14, No. 3, pp. 6–16, May/June 1998.

[B9] Smith, J. R., and P. K. Sen, "Corrosive sulfur in transformer oil," *Industry Applications Society Annual Meeting (IAS)*, pp. 1–4, Oct. 2010.

---

[7] The IEEE standards or products referred to in this clause are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

[8] IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).