

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

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**IEEE Transformers Committee
of the
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Foreword

(This Foreword is not a part of IEEE Std 637-1985, IEEE Guide for the Reclamation of Insulating Oil and Criteria for Its Use.)

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

1. Introduction

The purpose of this guide is to further oil conservation by providing detailed procedures for reclaiming used mineral insulating oils by chemical and mechanical means, making them suitable for reuse as insulating fluids. The guide describes the essential properties required for reuse in each class of equipment and the recommended test methods. The purpose of ANSI/IEEE C57.106-1977 [24]¹ is to aid the operator of the electric power equipment to evaluate the serviceability of new, unused transformer oil contained in new equipment, or as received from the refiner for filling new equipment. The recommendations and tests in ANSI/IEEE C57.106-1977 [24] are intended also to provide the operator with good estimates of the continued reliability of the oil in service in equipment and guidance for the reconditioning of oil by mechanical means. These estimates in turn suggest minimum property limits for restoring used oils to as near their original condition as possible utilizing current techniques.

The greatest benefit derived from widespread reclamation may be in the substitution of suitably reclaimed oil for large quantities of new oil which are normally required in service for maintenance or makeup oil. This will free a considerable volume of new oil for use in new apparatus. In this respect, it is proper to state that even though the functional oil tests in use today measure certain key oil properties considered critical to their application, there is evidence that service aged and reclaimed oils do not contain all of the desirable natural components and may contain materials not found in new oil. It is not the intention of this guide to suggest that reclaimed oils are equivalent to new oils; rather this guide seeks to expand the use of reclaimed oils to occupy the considerable volume for which they are entirely suitable.

2. 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 oils are considered suitable. This guide does not cover the use of oil in new apparatus under warranty.

¹The numbers in brackets correspond to those of the references listed in Section 4. of this guide.

3. Definitions

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 ANSI/ASTM D2864-84 [21]).

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 so that any gases produced will consist predominantly of noncombustible hydrogen chloride with lesser amounts of combustible gases.

The following trade names are some of the titles which have been used to identify askarels containing polychlorinated biphenyls (PCBs).

Aroclor	Elemex
Chlorextol	Hyvol
Chlorphen	Inerteen
Diaclor	Noflamol
Dykanol	Pyranol

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

oxidation inhibitor: Any substance added to an insulating fluid to improve its resistance to deleterious attack in an oxidizing environment. For example, 2, 6-ditertiary-butyl para-cresol or 2, 6-ditertiary-butyl phenol, or both, are sometimes added to petroleum insulating oil to improve its oxidation stability.

PCB: *See: askarel*

reclamation: The restoration to usefulness 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.

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.

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 generic term for a family of relatively inert liquid organosiloxane polymers used as electrical insulation.

4. References

When the following American National Standards referred to in this guide are superseded by a revision approved by the American National Standards Institute, Inc, the latest revision shall apply.

- [1] ANSI/ASTM D88-56 (R1973), Standard Test Method for Saybolt Viscosity.^{2,3}
- [2] ANSI/ASTM D92-78, Standard Test Method for Flash and Fire Points by Cleveland Open Cup.
- [3] ANSI/ASTM D97-66 (R1978), Standard Test Method for Pour Point of Petroleum Oils.
- [4] ANSI/ASTM D445-83, Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (And the Calculation of Dynamic Viscosity).
- [5] ANSI/ASTM D831-63 (R1978), Standard Test Method for Gas Content of Cable and Capacitor Oils.
- [6] ANSI/ASTM D877-80, Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes.
- [7] ANSI/ASTM D892-74 (R1979), Standard Test Method for Foaming Characteristics of Lubricating Oils.
- [8] ANSI/ASTM D971-82, Standard Test Method for Interfacial Tension of Oil Against Water by the Ring Method.
- [9] ANSI/ASTM D974-80, Standard Test Method for Neutralization Number by Color-Indicator Titration.
- [10] ANSI/ASTM D1298-80, Standard Test Method for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method.
- [11] ANSI/ASTM D1473-80, Standard Test Method for 2, 6-Ditertiary-Butyl Para-Cresol in Electrical Insulating Oils.
- [12] ANSI/ASTM D1500-82, Standard Test Method for ASTM Color of Petroleum Products (ASTM Color Scale).
- [13] ANSI/ASTM D1524-69 (R1979), Standard Method for Visual Examination of Used Electrical Insulating Oils of Petroleum Origin in the Field.
- [14] ANSI/ASTM D1533-79, Standard Specification for Synthetic Rubber Insulation for Wire and Cable, 90 °C Operation.
- [15] ANSI/ASTM D1534-78, Standard Test Method for Approximate Acidity of Used Electrical Insulating Liquids by Color Indicator Titration.
- [16] ANSI/ASTM D1816-79, Standard Test Method for Dielectric Breakdown of Insulating Oils of Petroleum Origin Using VDE Electrodes.
- [17] ANSI/ASTM D1827-64 (R1979), Standard Test Method for Gas Content (Nonacidic) of Insulating Liquids by Displacement with Carbon Dioxide.
- [18] ANSI/ASTM D2161-82, Standard Method for Conversion of Kinematic Viscosity to Saybolt Universal Viscosity or to Saybolt Furol Viscosity.

²ANSI publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

³ASTM publications are available from the American Society for Testing and Materials, 1916 Race St, Philadelphia, PA 19103.

- [19] ANSI/ASTM D2285-68 (R1978), Standard Test Method for Interfacial Tension of Electrical Insulating Oils of Petroleum Origin Against Water by the Drop-Weight Method.
- [20] ANSI/ASTM D2668-77, Standard Test Method for 2, 6-Ditertiary-Butyl Para-Cresol and 2, 6-Ditertiary-Butyl Phenol in Electrical Insulating Oil by Infrared Adsorption.
- [21] ANSI/ASTM D2864-84, Standard Definitions of Terms Relating to Electrical Insulating Liquids and Gases.
- [22] ANSI/ASTM D2945-71 (R1980), Standard Test Method for Gas Content of Insulating Oils.
- [23] ANSI/ASTM D3612-79, Standard Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography.
- [24] ANSI/IEEE C57.106-1977 IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment.⁴
- [25] ASTM D924-82, Standard Test Method for Power Factor and Dielectric Constant of Electrical Insulating Liquids.
- [26] ASTM D1817-81, Standard Method of Testing Rubber Chemicals—Density.
- [27] ASTM D2112-81, Standard Testing Method for Oxidation Stability of Inhibited Mineral Insulating Oil by Rotating Bomb.
- [28] ASTM D2440-83, Standard Testing Method for Oxidation Stability of Mineral Insulating Oil.
- [29] ASTM D3487-82, Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus.
- [30] ASTM D4059-83, Standard Method for Analysis of Polychlorinated Biphenyls in Mineral Insulating Oils by Gas Chromatography.
- [31] 40 CFR, Part 761, Environmental Protection Agency.⁵

5. Classification of Service-Aged Oils and Criteria for Reuse

5.1 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. It is therefore impossible to indicate the significance of specific tests and recommended test limits for all possible existing applications of insulating oil in service. 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. Oils in service may be placed in the following classifications based upon the evaluation of the following significant characteristics:

- 1) *Group I.* Oils that are in satisfactory condition for continued use
- 2) *Group II.* Oils that required only reconditioning for further service
- 3) *Group III.* Oil in poor condition. Such oil should be reclaimed or disposed of depending upon economic considerations
- 4) *Group IV.* Oils in such poor condition that it is technically advisable to dispose of them

⁴IEEE publications are available from IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854.

⁵CFR publications are available from Superintendent of Documents, US Government Printing Office, Washington, DC 20402.

5.2 Suggested Limits for Classes of Service-Aged Oils

Suggested test limits by voltage class for oils in power transformers to remain in continued service [5.1(1), Group I] are given in Table 1. 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 shall 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 II) or reclamation (Group III). Suggested limits for oils in these groups are contained in Table 2. Oils that do not meet the suggested limits for Group III should be discarded unless the reclamation process in use can restore the oils to the limits given in Tables 3 and 4.

Table 1— Suggested Limits for In-Service Oils Group I by Voltage Class

Property	Limit			ASTM Test Method
Voltage Class	69 kV and Below	Above 69V Through 288 kv	345 kV and Above	
Dielectric breakdown voltage, 60 Hz, 0.100 gap 1 min, kV, min	26	26	26	D877 [6]
Dielectric breakdown voltage, 0.040 gap, kV, min	23	26	26	D1816 [16]
Dielectric breakdown voltage, 0.080 gap, kV, min	34	45	45	D1816 [16]
Neutralization number max, mg KOH/g	0.2	0.2	0.1	D974 [9]
Interfacial tension, min, mN/m	24	26	30	D971 [8]
Water max, ppm *	35	25	20	D1533 [14]
Gas content when specified, max %	†	†	†	D831 [5] D1847 [26] or D2945 [22]

*Does not pertain to free breathing transformer or compartment.

†Some transformers are equipped with diaphragms to prevent the introduction of air. The dissolved gas content in these transformers should be maintained in accordance with the manufacturer's recommended limit.

Table 2— Suggested Limits for Oil to Be Reconditioned or Reclaimed

Property	Group II	Group III	ASTM Test Method
Neutralization number max, mg KOH/g	0.2	0.5	D974 [9]
Interfacial tension, min, mN/m	24	16	D971 [8]

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 the Environmental Protection Agency (EPA) and local regulations.

Table 3— Suggested Property Requirements of Reclaimed Oil for Transformers

Property	Limit	ASTM Test Methods
Physical		
Flash point, min, °C	140*	D92 [2]
Pour point, min, °C	−40†	D97 [3]
Specific gravity, 15 /15 °C, max	0.91	D1298 [10]
Viscosity, max, cSt at 40 °C (mm ² /s)	12.0	D88 [1] or D445 [4]
Color max	1.5	D1500 [12]
Visual examination	Clear	D1524 [13]
Interfacial tension, min, mN/m	35	D971 [8]
Electrical		
Dielectric breakdown voltage, 60 Hz, kV, min	30	D877 [6]
Power factor at 60 Hz, 100 °C, max, %	1	D924 [25]
Chemical		
Neutralization number, max, mg KOH/g	0.05	D974 [9]
Oxidation inhibitor, max %, by wgt	0.3	D2668 [20]
Oxidation stability, min, minutes	150	D2112 [27]
Oxidation stability 164 h % sludge, max	0.25	D2440 [28]
Total acid no, max, mg KOH/8	0.50	
Water max, ppm	35	D1533 [14]

*145 °C flash point may be desired for 65 °C rise transformers.

†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.

Table 4— Suggested Test Limits for Reclaimed Oil in Transformers and Reactors After Filling but Before Energizing

Property	Limit			ASTM Test Methods
Voltage Class	69 kV and Below	Above 69 kV Through 288 kV	345 kV and Above	
Dielectric breakdown voltage, 60 Hz, kV, min	30	35	35	D877 [6]
Dielectric breakdown voltage, 60 Hz, kV, min 0.040 gap	26	26	26	D1816 [16]
Desirable, kV	30	30	30	D1816 [16]
Neutralization number max, mg KOH/g	0.05	0.05	0.05	D974 [9]
Interfacial tension, min, mN/m	35	35	35	D971 [8]
Water max, ppm	35	20	15 (10 desirable)	D1533 [14]
Gas content when specified, max %	*	*	*	D831 [5] D1817 [26] or D2945 [22]
Color, max	1.5	1.5	1.5	D1500 [12]
Condition-visual	Clear	Clear	Clear	D1524 [13]

*Some transformers are equipped with diaphragms to prevent the introduction of air. The dissolved gas content in these transformers should be maintained in accordance with the manufacturer's recommended limits.

5.3 Economic Factors

The cost of reconditioning or reclaiming oils by various users will vary significantly and is dependent upon the type of system, field inspection operations, and laboratory and shop facilities. In determining whether or not reconditioning or reclaiming of insulating oil, or both, are economically justifiable, a number of factors shall be considered. Some of these factors are as follows:

- 1) Cost of materials
- 2) Disposition of service-aged or contaminated materials, or both
- 3) Total cost of process versus quality of end product
- 4) Equipment maintenance and amortization
- 5) Cost of collection and storage of oil
- 6) Labor and transportation costs
- 7) Laboratory costs
- 8) Cost and availability of new oil versus cost of reprocessed oil
- 9) Loss of oil during reprocessing
- 10) Cost and availability of oxidation inhibitors and cost of blending process
- 11) Value of service-aged oil when used for some other purpose

The economic justification of whether reconditioning or reclamation work, or both, are performed by company personnel or contractors shall be resolved on the basis of the factors applicable in each particular case.

5.4 Sources of Oil to Be Reclaimed

Service-aged insulating oils generally contain contaminants as the result of their decomposition, or derived from the construction materials of 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. It is therefore recommended that reclaimed oil not be used in new equipment under warranty unless agreed to by the manufacturer and the user.

Suggested sources of oil for reclamation include transformers, reactors, voltage regulators, circuit breakers, and reclosers. Oil from cables, capacitors, generators, or devices filled with non-mineral oil are not recommended for reclaiming. 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.

5.5 Precautions

Care shall be taken in the selection of oil for reclaiming so that it is not contaminated with any of the following substances:

5.5.1 Askarel

Oil containing askarel with PCBs shall be handled in accordance with Federal Regulation 40 CFR, Part 761 [31] and local regulations where applicable.

5.5.2 Silicone Fluids

Oil containing traces of silicone fluids can foam excessively and therefore should not be reclaimed.

5.5.3 Other Fluids

Fluids with original properties not conforming to ASTM D3487-82 [29] should not be pooled.

5.5.4 Suspended Carbon

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

5.6 Criteria for Reuse of Reclaimed Oil

5.6.1 Makeup or Replacement Oil for Transformers and Reactors Which Are Out of Warranty

Oil 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 neutralization 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, 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 arced products, oil from oil circuit breakers, 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. In concentrations up to 0.3% by weight, to extend the life of the oil, 2, 6-ditertiary-butyl para-cresol and 2, 6-ditertiary-butyl phenol have been used.

Suggested requirements for reclaimed oil for use in transformers and reactors are given in Table 3.

Table 5— Suggested Test Limits for Reclaimed Oil in Circuit Breakers, Reclosers, and Load Tap Changing Compartments After Filling, but Before Energizing

Property	Limit	ASTM Test Methods
Physical		
Flash point, min, °C	140	D92 [2]
Pour point, min, °C	−40*	D97 [3]
Viscosity, max, cSt at 40 °C (mm ² /s)	12.0	D88 [1] or D445 [4]
Color max	2.0	D1500 [12]
Interfacial tension at 25 °C, min, mN/m	25	D971 [8]
Electrical		
Dielectric breakdown voltage 60 Hz, kV, min	30	D877 [6]
	26	D1816 [16]
Chemical		
Neutralization number max, mg KOH/g	0.15	D974 [9]

* 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.

Properly reclaimed oil meeting the minimum requirements of Table 3 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. Suggested limits for oil after filling but before energizing, at various voltage classes, are given in Table 4.

5.6.2 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 5. 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 judgement shall be exercised. The resultant effects of oil mixing and the addition of inhibitors upon thermal properties shall 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.

6. Types of Reconditioning and Reclamation Processes

Reclamation involves the use of methods and processes which result in a beneficial change in the oil composition. Table 6 shows the various oil-purification practices and lists the types of contaminants removed by the various processes. A description of the method and material used is as follows:

Table 6— Oil-Purification Practices

Oil-Purification Practices	Types of Contamination Removed						Page No
	Solid	Free Water	Soluble Water	Air and Gas	Acids, Sludge, etc	Other	
(1) Vacuum dehydrator	No	Yes	Yes	Yes	Most	No	12
(2) Mechanical filter (blotter or filter press)	Yes	Partial	Partial	No	No	No	12
(3) Centrifuge	Yes	Yes	No	No	No	No	14
(4) Coalescing filter	Yes	Yes	No	No	No	No	14
(5) Precipitation settling	Yes	Yes	No	No	No	No	14
(6) Contact process	Yes	Yes	Yes	No	Yes	Yes	18
(7) Percolation by gravity	Yes	Yes	Partial	No	Yes	Yes	19
(8) Percolation by pressure	Yes	Yes	Partial	No	Yes	Yes	20
(9) Thermo-siphon bypass	No	No	Partial	No	Partial	Partial	23
(10) Activated carbon sodium silicate process	Yes	No	No	No	Yes	Yes	23
(11) Trisodium phosphate process	Yes	No	No	No	Yes	Yes	25

6.1 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 general 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 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.