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Monitoring and maintenance guide for mineral insulating oils in electrical equipment

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Committees responsible for this British Standard

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Foreword

This British Standard has been prepared by Technical Committee GEL/10. It is based on IEC 60422 published by the International Electrotechnical Commission (IEC). It supersedes BS 5730:1979, which is withdrawn.

CAUTION (Health and Safety). This British Standard calls for the use of substances and procedures that may be injurious to health if adequate precautions are not taken. It refers only to technical suitability and does not absolve the user from legal obligations relating to health and safety at any stage. In particular, attention is drawn to the following hazards (this list is not exhaustive).

— Prolonged exposure to the insulating oils described in this standard can cause skin sensitization, so it is essential that oils are handled with due regard to personal hygiene.

— The methods described in the standard employ flammable solvents.

CAUTION (Environmental). The insulating oils described in this standard have low biodegradability and can present an environmental hazard if not disposed of correctly. The methods described in this standard can give rise to waste chemicals, contaminated containers and oil contaminated solids which can also present an environmental hazard if not disposed of correctly.

Annex A is normative.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 27 and a back cover.

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Introduction

Monitoring and maintaining oil quality is essential in ensuring the reliable operation of oil-filled electrical equipment. Codes of practice for this purpose have been established by electrical power authorities and power companies in many countries.

A review of current experience reveals a wide variation of procedures and criteria. It is possible, however, to compare the value and significance of standardized oil tests and to recommend uniform criteria for the evaluation of test data.

Much greater difficulties exist in deciding frequency of testing and permissible oil degradation levels which are acceptable for all applications of insulating oil in relation to differences in operating policies, reliability requirements and types of electrical system. For example, large power companies will normally find uneconomical the full application of these recommendations to distribution transformers and tend to accept a higher failure risk. Conversely, the industrial user whose activities depend on the reliability of his power supply, may wish to institute more frequent and stricter controls of oil quality as a means of guarding against power failures.

If a certain amount of oil deterioration is exceeded, there is some erosion of safety margins and the question of the risk of premature failure has to be considered. While the quantification of the risk can be very difficult, a first step involves the identification of potential effects of increased deterioration. The philosophy underlying this guide is to furnish users with as broad a base of understanding of oil quality deterioration as is available, so that they can make informed decisions on inspection and maintenance practices.

The guidelines given in this standard, while technically sound, are mainly intended to serve as a common basis for the preparation of more specific and complete codes of practice by users in the light of local circumstances. Sound engineering judgement will have to be exerted in seeking the best compromise between technical requirements and economic factors.

Reference should also be made to instructions from the equipment manufacturer.

1 Scope

This British Standard gives guidance on the monitoring and maintenance of the quality of the insulating oil in electrical equipment.

This standard is applicable to mineral insulating oils, originally conforming to BS 148, in transformers, switchgear and similar electrical apparatus where oil sampling is reasonably practicable and where the normal operating conditions specified in the equipment specifications apply.

The purpose of this standard is to assist the power equipment operator in evaluating the condition of oil in equipment and in maintaining the oil in a serviceable condition. To this end, the standard gives recommendations on standardized tests and evaluation procedures and outlines methods for reconditioning and reclaiming oil.

NOTE It is recognized that the oil in certain types of equipment may contain dissolved gases and furanic compounds, the analysis of which may be useful in assessing the condition of the insulation system. The methods of analysis are given in BS EN 60567, BS EN 60599 and BS EN 61198. The interpretation of the results with respect to plant condition monitoring is outside the scope of the standard.

2 Normative references

The following normative documents contain provisions which, through reference in this text constitute provisions of this British Standard. For dated references subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the publication referred to applies.

BS 148, *Specification for unused and reclaimed mineral insulating oils for transformers and switchgear.*

BS 171, *Specification for power transformers.*

BS 1752, *Specification for laboratory sintered or fritted filters, including porosity grading.*

BS 2000-15, *Methods of test for petroleum and its products — Petroleum products — Part 15: Determination of pour point.*

BS 2000-196:1997, *Methods of test for petroleum and its products — Petroleum products — Part 196: Determination of colour (ASTM scale).*

BS 5263, *Method of sampling liquid dielectrics.*

BS 5737, *Method for the measurement of relative permittivity, dielectric dissipation factor and d.c. resistivity of insulating liquids.*

BS 5984, *Method for detection and determination of specified anti-oxidant additives in insulating oils.*

BS 6522, *Methods for determination of percentage water saturation of insulating oil.*

BS EN 22719, *Methods of test for petroleum and its products — Petroleum products and lubricants — Determination of flash point — Pensky-Martens closed cup method.*

BS EN 60156, *Insulating liquids — Determination of the breakdown voltage at power frequency — Test method.*

BS EN 60567, *Guide for the sampling of gases and of oil from oil-filled electrical equipment and for the analysis of free and dissolved gases.*

BS EN 60599, *Mineral oil impregnated electrical equipment in service — Guide to the interpretation of dissolved and free gases analysis.*

BS EN 60814, *Insulating liquids — Oil-impregnated paper and pressboard — Determination of water by automatic coulometric Karl Fischer titration.*

BS EN 61125:1993, *Unused hydrocarbon-based insulating liquids — Test methods for the evaluation of oxidation stability.*

BS EN 61198, *Mineral insulating oils — Methods for the determination of 2-furfural and related compounds.*

BS EN 61619, *Insulating liquids — Contamination by polychlorinated biphenyls (PCBs) — Method of determination by capillary column gas chromatography.*

BS EN ISO 3104, *Methods of test for petroleum and its products — Petroleum products — Transparent and opaque liquids — Determination of kinematic viscosity and calculation of dynamic viscosity.*

BS EN ISO 3675, *Crude petroleum and liquid petroleum products — Laboratory determination of density or relative density — Hydrometer method.*

ISO 6295, *Petroleum products — Mineral oils — Determination of interfacial tension of oil against water — Ring method.*

3 Properties and deterioration of oil

The reliable performance of mineral insulating oil in an insulation system depends upon certain basic oil characteristics which can affect the overall performance of the electrical equipment.

In order to accomplish its multiple role of dielectric, heat-transfer agent and arc-quencher, the oil needs to possess certain basic properties, in particular:

- — high dielectric strength to withstand the electric stresses imposed in service;
- — sufficiently low viscosity so that its ability to circulate and transfer heat is not impaired;
- — adequate low-temperature properties down to the lowest temperature expected at the installation site;
- — resistance to oxidation to ensure long life in service.

Mineral oil in service is subject to deterioration due to the conditions of use. In many applications, insulating oil is in contact with air and therefore subject to oxidation. Such reactions are accelerated by elevated temperatures. The presence of metals, organo-metallic compounds or both may act as oxidation promoters.

Change in colour, formation of acidic compounds and, at an advanced stage of oxidation, precipitation properties may be impaired.

In addition to oxidation products, many other undesirable contaminants, including water, solid particles and oil-soluble polar compounds can accumulate in the oil during service and alter its properties.

The presence of such contaminants and any deterioration product of an oil is indicated by a change of one or more properties as described in clause **4**.

Deterioration of main plant equipment materials can also be indicated by changes in oil properties. Such deterioration can interfere with the proper functioning of the electrical equipment and shorten its working life.

4 Oil tests and their significance

4.1 General

A large number of tests can be applied to mineral insulating oils in electrical equipment. The tests listed in Table 1 and discussed in **4.2** to **4.17** are considered to be sufficient to determine whether the oil condition is adequate for continued operation and to suggest the type of corrective action required, where applicable. The tests are not listed in order of priority.

Table 1 — Tests for mineral insulating oils

Property	Subclause	Method
Colour and appearance	**4.2**	BS 2000-196
Odour	**4.2**	—
Breakdown voltage	**4.3**	BS EN 60156
Water content	**4.4**	BS EN 60814
Neutralization value (acidity)	**4.5**	BS 148
Sediment and sludge	**4.6**	Annex A
Dielectric dissipation factor and resistivity	**4.7**	BS 5737
Interfacial tension[a]	**4.8**	ISO 6295
Oxidation stability[a]	**4.14**	BS EN 61125:1993, method C
Dissolved gas content[a]	**4.9**	BS EN 60567
Cellulose degradation products (furanic compounds)[a]	**4.15**	BS EN 61198
Flash-point[a]	**4.10**	BS EN 22719
Compatibility[b]	**4.16**	BS EN 61125:1993, method C
Pour-point[b]	**4.11**	BS 2000-15
Density[b]	**4.12**	BS EN ISO 3675
Viscosity[b]	**4.13**	BS EN ISO 3104
Inhibitor content[c]	**4.14**	BS 5984
Polychlorinated biphenyls (PCBs)	**4.17**	BS EN 61619
NOTE See note to clause 1.		

[a] Only needed under special circumstances, see applicable subclause.

[b] Not essential, but can be used to establish type identification.

[c] Restricted to inhibited oils.

4.2 Colour, appearance and odour

The colour of an insulating oil is determined in transmitted light and is expressed by a numerical value based on comparison with a series of colour standards, as described in BS 2000-196. It is not a critical property, but it may be useful for comparative evaluation. A rapidly increasing or a high colour number may be an indication of oil deterioration or contamination.

Besides colour, the appearance of oil may show cloudiness or sediments which may indicate the presence of free water, insoluble sludge, carbon, fibres, dirt, or other contaminants.

If the oil has an acrid or unusual odour, consideration should be given to carrying out further tests.

4.3 Breakdown voltage

Breakdown voltage is a measure of the ability of an oil to withstand electric stress.

Dry and clean oil exhibits an inherently high breakdown voltage. Free water and solid particles, the latter particularly in combination with high levels of dissolved water, tend to migrate to regions of high electric stress and reduce breakdown voltage dramatically. The measurement of breakdown voltage, therefore, serves primarily to indicate the presence of contaminants such as water or conducting particles. A low breakdown voltage value can indicate that one or more of these are present. However, a high breakdown voltage does not necessarily indicate the absence of all contaminants.

4.4 Water content

Water can originate from the atmosphere or be produced by the deterioration of insulating materials. At comparatively low water content, the water remains in solution and does not alter the appearance of the oil. Therefore dissolved water needs to be detected by chemical methods.

Dissolved water may, in certain circumstances, affect the electrical properties of the oil. The solubility of water in transformer oil increases with temperature and neutralization value (see **4.5** and Figure 1). Above a certain water content (the saturation water content), all the water cannot remain in solution and free water may be seen in the form of cloudiness or water droplets. Free water invariably results in decreased electric strength and resistivity and an increased dielectric dissipation factor.

In a transformer the total mass of water is distributed between the paper and the oil such that the bulk of the water is in the paper. Small changes in temperature significantly modify the dissolved water content of the oil but only slightly modify the water content of the paper.

In the case of transformers, the measured water content should be corrected to 20 °C. This can be done by multiplying the measured water content by the relevant correction factor as shown in Figure 2.

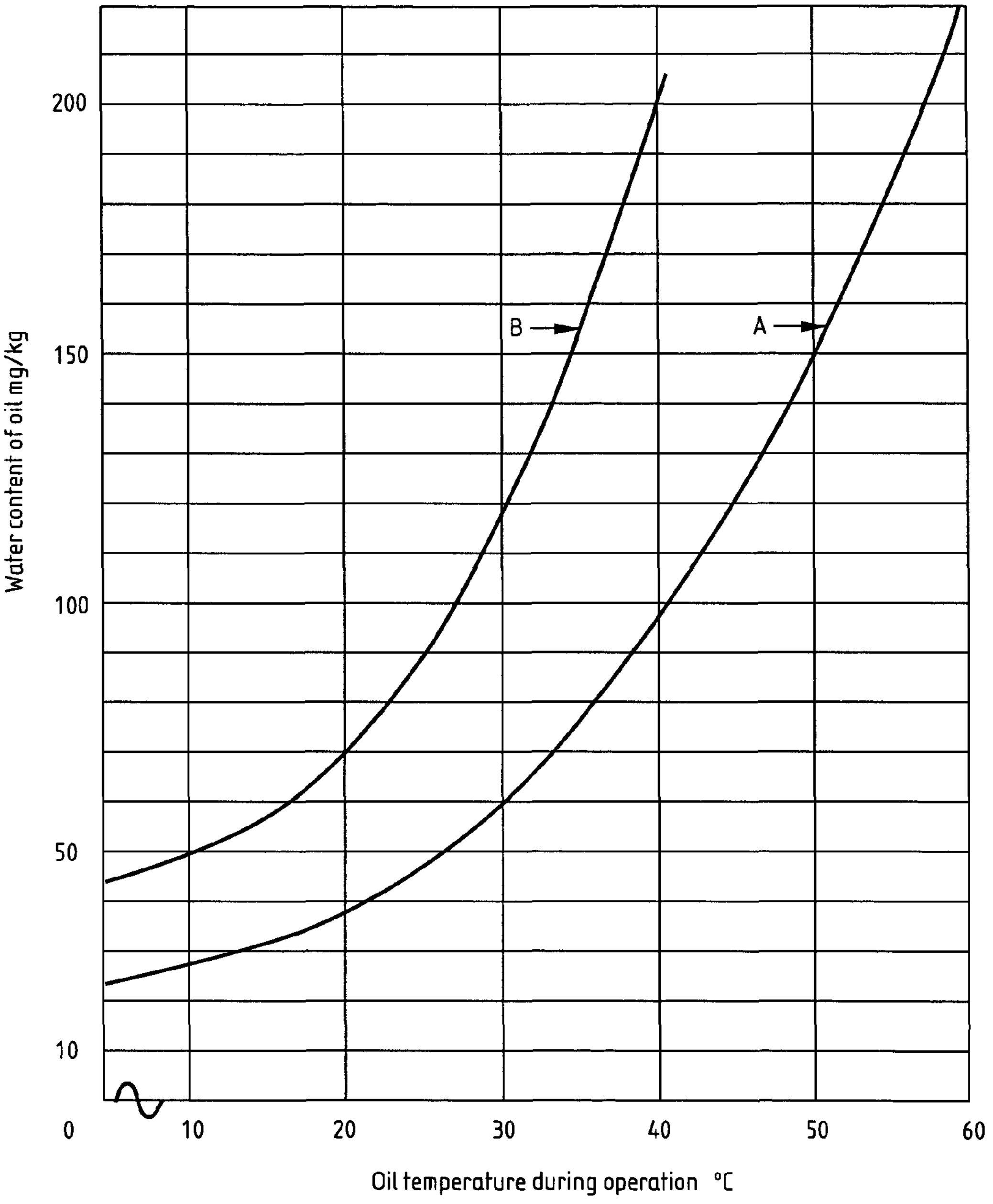
EXAMPLE

Measured dissolved water content	10 mg/kg
Temperature of sample	40 °C
Multiplication factor (from Figure 2)	0.45
Corrected dissolved water content	(10 × 0.45) 4.5 mg/kg

The limiting values for water content which are recommended in Table 6 are intended to control the water content in cellulosic insulation, including insulating paper, within acceptable limits and are related to normal (oil) operating temperatures of 40 °C to 60 °C. For consistency, oil temperature should be measured from the oil stream as the sample is being taken.

Where significant amounts of paper are not present, such as in switches, tap changers and diverters, temperature has a relatively small effect on the measured amount of dissolved water in the oil (expressed in milligrams of water per kilogram of oil). In these cases the correction to 20 °C is not valid and how close the oil is to saturation with water is a more important parameter. Instruments are available to measure the relative water saturation of the oil. This information can also be useful when paper is present.

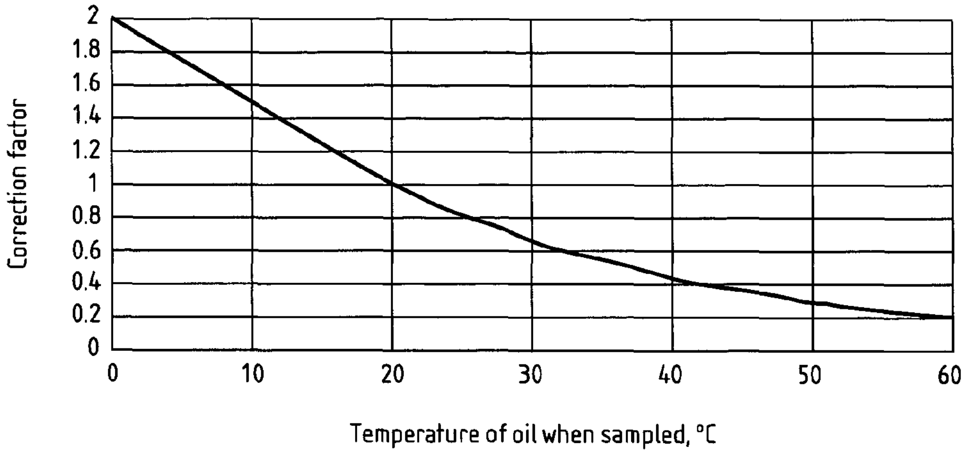
High water content accelerates the chemical deterioration of insulating paper and is indicative of undesirable operating conditions. Using a graphical method, it is possible to obtain, at a given temperature, an estimate of the water content of the paper from the measured water saturation level of the oil, assuming equilibrium conditions. A method for determining the percentage water saturation of insulating oil at temperatures up to 60 °C is given in BS 6522.



Curve A: Saturation water content in unused oil

Curve B: Typical saturation water content in oxidized oil with a neutralization value of 0.3 mg KOH/g

Figure 1 — Example of the variation in saturation water content with oil temperature for insulating oil conforming to BS 148



NOTE Where significant amounts of paper are not present, such as in switches, tap changers and diverters, temperature has a relatively small effect on the measured amount of dissolved water in the oil. In these cases the correction to 20 °C is not valid (see **4.4**).

Figure 2 — Example of factors to correct the measured water content of oil to 20 °C in the presence of paper insulation

4.5 Neutralization value (acidity)

The neutralization value of an oil is a measure of the acidic constituents or contaminants in the oil.

The neutralization value increases as a result of oxidative ageing and is 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.

4.6 Sediment and sludge

This test distinguishes between sediment and sludge.

Sediment is insoluble material present in the oil.

Sediment includes:

a) insoluble oxidation or degradation products of solid or liquid insulating materials;

b) solid products arising from the conditions of service of the equipment; carbon, metal, metallic oxides;

c) fibres, and other foreign matter, of diverse origins.

Sludge is polymerized oxidation products of solid and liquid insulating material. Sludge is soluble in oil up to a certain limit. At sludge levels above this the sludge comes out of solution, contributing an additional component to the sediment.

The presence of sediment and sludge may change the electrical properties of the oil, and in addition, deposits may hinder heat-exchange, thus encouraging deterioration of the insulating materials.

4.7 Dielectric dissipation factor (DDF) and resistivity

These parameters are very sensitive to the presence in the oil of soluble polar contaminants, ageing products or colloids. Changes in the levels of the contaminants can be monitored by measurement of these parameters even when contamination is so slight as to be near the limit of chemical detection.

Acceptable limits for these parameters depend largely upon the type of apparatus and application. However, high values of the dielectric dissipation factor may deleteriously effect the power factor and/or the insulation resistance of the electrical equipment.

There is generally a relationship between DDF and resistivity at elevated temperature, with resistivity decreasing as DDF increases. It is normally not necessary to conduct both tests on the same oil. Resistivity is temperature dependent and Figure 3 illustrates typical changes of resistivity with temperature for insulating oils which are virtually free from solid contamination and moisture.

Useful additional information can be obtained by measuring resistivity or DDF at both ambient temperature and a higher temperature such as 90 °C. A satisfactory result at 90 °C coupled with an unsatisfactory value at the lower temperature is an indication of the presence of water or degradation products precipitable in the cold without any significant amount of chemical deterioration or general contamination. See line C in Figure 3. Unsatisfactory results at both temperatures indicate a greater extent of contamination and that it may not be possible to restore the oil to a satisfactory condition by reconditioning.

4.8 Interfacial tension

The interfacial tension between oil and water provides a means of detecting soluble polar contaminants and products of deterioration. This characteristic changes fairly rapidly during the initial stages of ageing but levels off when deterioration is still moderate. For this reason, results are rather difficult to interpret in terms of oil maintenance. However, oils with interfacial tension values at or near the lower limit value given in Table 6 should be further investigated.

4.9 Dissolved gas content

For most applications of mineral insulating oil, the determination of dissolved gas content normally has little significance for assessing the quality and serviceability of the oil. However, for certain types of electrical equipment, a maximum gas content is sometimes specified for the oil when filling apparatus or in service. Additionally, the levels of dissolved gas and/or changes in these levels can be an indicator of incipient fault conditions or air ingress into the oil and can also indicate the condition of the paper insulation (see 4.15).

Gas-in-oil analysis for condition monitoring is dealt with in BS EN 60567 (sampling and analysis) and BS EN 60599 (interpretation of results).

4.10 Flash-point

A low flash-point is an indication of the presence of volatile combustible products in the oil.

Breakdown of the oil associated with arcing or prolonged exposure to very high temperature may produce sufficient quantities of low molecular weight hydrocarbons to cause a lowering of the flash-point of the oil.

4.11 Pour-point

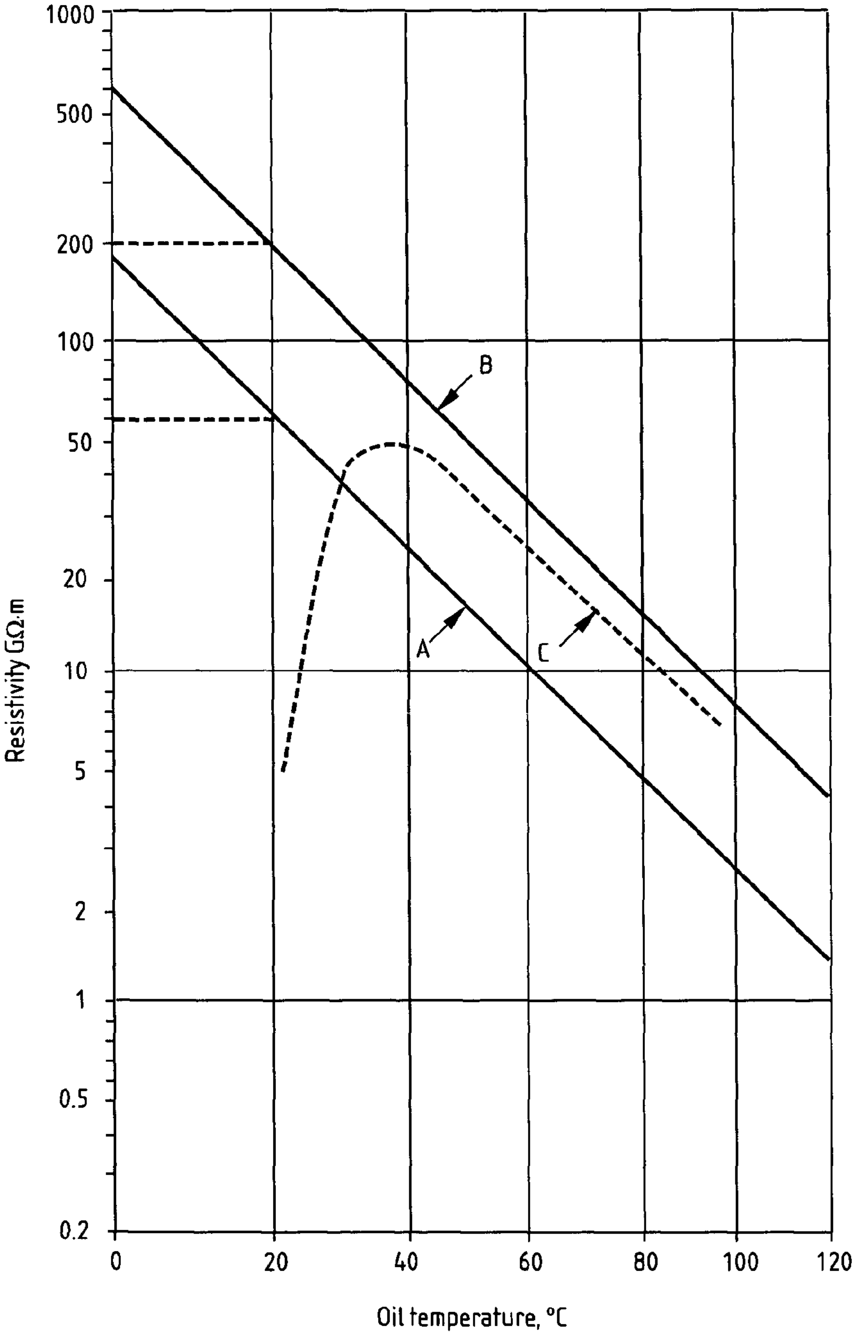
Pour-point is a measure of the ability of the oil to flow at low temperature. There is no evidence to suggest that the property is affected by normal oil deterioration. Changes in pour-point can normally be interpreted as the result of topping-up with a different type of oil.

4.12 Density

Density may be useful for type identification. In cold climates, the density of oil may be pertinent in determining its suitability for use. For example, ice crystals formed from separated water may float on oil of high density and lead to flashover on subsequent melting. However, density is not significant in comparing the quality of different samples of oil.

4.13 Viscosity

Viscosity is an important controlling factor in the dissipation of heat. Ageing and oxidation of the oil tend to increase viscosity.



Line A: Dry oil having a resistivity of 60 GΩ·m at 20 °C
Line B: Dry oil having a resistivity of 200 GΩ·m at 20 °C
Line C: Wet oil, with a saturation temperature of 35 °C

Figure 3 — Variation of resistivity with temperature for insulating oils

4.14 Inhibitor content and oxidation stability

Inhibited oils deteriorate more slowly than un-inhibited oils so long as active oxidation inhibitor is present. However, once the oxidation inhibitors are consumed the "inhibited" oil may oxidise at a greater rate than would an "un-inhibited" oil. For a given oil/inhibitor pair, the induction period is generally proportional to the active oxidation inhibitor content and depends on the presence and proportion of oxidation promoters.

The degree of protection provided by the oxidation inhibitor is a function of base oil chemistry and inhibitor concentration. The determination of residual oxidation inhibitor in service-aged inhibited oil permits an assessment of the rate of inhibitor depletion.

The oxidation test for unused inhibited oil (given in BS EN 61125:1993, method C) enables the induction period of an oil to be easily measured by means of the determination of volatile acids developed. This test, applied to a used oil previously tested will indicate to what extent the induction period has been reduced. The anti-oxidant content of an oil in service can be measured in accordance with BS 5984.

4.15 Cellulose degradation products

One of the most important factors in limiting the lifetime of a transformer is the thermal degradation or ageing of the paper insulation used in transformer construction. The ageing process of paper is accompanied by the production of several oil soluble by-products. These by-products are carbon monoxide, carbon dioxide, water and furanic compounds. The production of carbon monoxide and carbon dioxide can be monitored by dissolved gas analysis (see **4.9**). The production of carbon oxides can arise from either paper or insulating oil ageing. Trend analysis of the levels of furanic compounds in the oil may provide an early indication of paper degradation.

4.16 Compatibility of insulating oils

Compatibility tests may be needed to determine the feasibility of mixing unused oils of different type and origin, with oil in service. The main characteristics of the mixture, including oxidation stability, should not be less favourable than those of the worst individual oil. Reference to the oil supplier is recommended if any doubts concerning compatibility arise.

After mixing, oils should be tested in accordance with BS EN 61125:1993, method C.

4.17 Polychlorinated biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) are a family of synthetic hydrocarbons which have good thermal and electrical properties. These properties combined with excellent chemical stability made them useful in numerous commercial applications. However their chemical stability and resistance to biodegradation has given cause for concern in terms of environmental pollution. This increasing concern over the environmental impact of PCBs has progressively restricted their use since the early 1970s and their use in new plant and equipment was banned by international agreement in 1986. The use of common handling facilities has led to widespread contamination of mineral insulating oil throughout the industry.

NOTE Attention is drawn to the Environmental Protection (Destruction of Polychlorinated Biphenyls and Other Injurious Substances) Regulations 1999 [1].

Oils should be tested for PCBs in accordance with BS EN 61619.

5 Sampling of oil from equipment

It is essential that every effort is made to ensure that samples are representative of the insulating oil in equipment. Experience indicates that oil is sometimes rejected unjustifiably because inadequate care has been taken in sampling. Careless sampling procedure or contamination in the sample container will lead to erroneous conclusions concerning quality and incur waste of time, effort and expense involved in obtaining, transporting and testing the sample.

It is strongly recommended that sampling is done by an experienced person who has received adequate training and that the procedures and precautions outlined in BS 5263 be closely followed. It is advisable to carry out a risk assessment of the method to be used.

NOTE Attention is drawn to the following legislation:

- Health and Safety at Work etc. Act 1974 [2];
- Management of Health and Safety at Work Regulations 1992 [3];
- Use of Personal Protective Equipment Regulations 1992 [4].

Sampling for the determination of low water content (less than 15 mg/kg) and for the analysis of dissolved gases should be done in accordance with BS EN 60567.

Sampling from equipment should preferably be carried out while the equipment is operating normally or very shortly after de-energization. This is particularly necessary when water content, or characteristics dependent on it, are to be measured and in these cases the temperature of the oil at the time of sampling should be recorded.

Where available, manufacturer's instructions should be followed. This is especially necessary with certain types of electrical equipment, such as instrument transformers, in view of the relatively limited oil content as well as the specific design. In the case of small volume electrical equipment (e.g. bushings) oil will need to be replaced after sampling in accordance with the manufacturer's instructions.

Oil samples (the volume of which is dependent on the number and type of tests needed) are normally drawn from the sampling valve or the bottom drain valve. The following general rules are considered to be the minimum necessary for successful sampling.

a) Sampling outdoors in rain, fog, snowfall or strong wind should be avoided. If sampling has to be carried out under such weather conditions, it is essential that special precautions be taken.

b) Only dry, clean sample containers should be used, such as glass bottles (with a polycone screw cap). (Samples should be protected to avoid unnecessary exposure to light.)

c) The sampling point should be thoroughly cleaned prior to the sample being taken. (The use of low fibre-shedding wipers is considered essential.)

d) It is essential that care is taken at all times to avoid environmental pollution due to spillage of oil.

NOTE 1 Attention is drawn to the Environmental Protection Act 1990 [5].

e) The following procedure should be used when taking a sample.

1) Run off a sufficient quantity of oil to remove any contaminants that may have accumulated at the sampling orifice. Do not adjust the sampling tap in any way until the sampling has been completed.

2) Rinse the containers and caps with the oil being sampled.

NOTE 2 In the case of samples for dissolved gas analysis the techniques described in BS EN 60567 should be employed.

3) Fill the containers, if possible allowing the liquid being sampled to flow against the side of the containers, thus avoiding trapped air. During the filling process measure the temperature of the sample from the oil stream.

4) Ensure that each container is filled to about 95 % of its capacity to avoid the possibility of leakage due to expansion of the oil during transportation.

5) After sampling, carefully close the sampling valve and re-clean to avoid environmental pollution.

6) Clean the outside of the sample containers and package (see note 3).

7) Label the samples, including at least the following information:

— adequate site and equipment identification;
— sampling point;
— temperature of the oil during sampling;
— date of sampling;
— testing requirements;
— contact name and phone number.

NOTE 3 Attention is drawn to the following legislation:

— Health and Safety at Work etc. Act 1974 [2];
— Environmental Protection Act 1990 [5];
— Carriage of Dangerous Goods (Classification, Packaging and Labelling) and Use of Transportable Pressure Receptacles Regulations 1996 [6];
— Carriage of Dangerous Goods by Road Regulations 1996 [7];
— Carriage of Dangerous Goods by Rail Regulations 1996 [8].

It is essential that packaging intended to transport sample containers is strong enough to protect the sample container against breakage from mechanical shock. It is also essential that packages are properly labelled to identify the substance being conveyed and state where additional information can be obtained.

6 Categories of equipment

In order to take account of different user requirements, equipment has been placed in various categories as shown in Table 2.

Table 2 — Equipment categories

Category	Type of equipment
Category O	Power transformers/reactors with a nominal system voltage of 400 kV and above
Category A	Power transformers/reactors with a nominal system voltage above 170 kV and below 400 kV which conform to BS 171. Also power transformers of any rated voltage where continuity of supply is vital and similar equipment for special applications operating under onerous conditions
Category B	Power transformers/reactors conforming to BS 171 with a nominal system voltage above 72.5 kV and up to and including 170 kV (other than those in Category A)
Category C	Power transformers/reactors with a nominal system voltage up to and including 72.5 kV (other than those in Category A) Oil-filled circuit breakers with a nominal system voltage exceeding 72.5 kV Oil-filled switches, a.c. metal-enclosed switchgear and controlgear with a nominal system voltage greater than or equal to 16 kV
Category D	Instrument/protection transformers with a nominal system voltage above 170 kV
Category E	Instrument/protection transformers with a nominal system voltage up to and including 170 kV
Category F	Diverter tanks of on-load tap-changers, including combined selector/diverter tanks
Category G	Oil-filled circuit breakers with a nominal system voltage up to and including 72.5 kV Oil-filled switches, a.c. metal-enclosed switchgear and controlgear with a nominal system voltage less than 16 kV

NOTE 1 Separated selector tanks of on-load tap-changers belong to the same category as the associated transformer.

NOTE 2 Oil-impregnated paper bushings and other hermetically sealed equipment may be placed in Category D if a routine monitoring programme is desired. Any tests considered necessary would be specialized in nature and need separate consideration. The manufacturer's instructions should be referred to.

NOTE 3 Small power transformers rated up to 1 MVA and 36 kV are not included in this classification. A routine monitoring programme is normally considered uneconomical for this type of equipment. Where a monitoring programme is required for these transformers, the guidelines given for Category C are considered to be adequate.

NOTE 4 Regardless of size or voltage, a risk assessment on certain strategically important equipment may justify condition monitoring techniques usually appropriate to a higher classification.

7 Evaluation of mineral insulating oil in new equipment

A substantial proportion of mineral oil is supplied to the final user already filled into electrical equipment. In such cases, as it has already come into contact with insulating and other materials, it can no longer be considered as "unused oil" as defined in BS 148 and its properties should be regarded as those applicable to "used oil".

The extent of the changes in properties may vary with the type of equipment owing to the different types of material and ratios of liquid-to-solid insulation, and should be kept within acceptable limits through proper oil-processing techniques and careful selection of materials.

Oil properties, such as breakdown voltage and water content should be adequate for the category and functions of the equipment.

The characteristics of oil in new equipment are integral parts of the equipment design and the user may require these characteristics to be definitely better than minimum standards for reliable service. The characteristics listed in Table 4 and Table 5 are based on the experience of many years of operating practice and are given for guidance.

8 Evaluation of used oil

8.1 Frequency of examination of oils in service

It is impossible to lay down a general rule for the frequency of examination of oils in service which will be applicable to all possible situations that might be encountered.

The optimum interval will depend on the type, function, power, construction and service conditions of the equipment. A compromise may often have to be found between economic factors and reliability requirements.

By way of a guide, a suggested frequency of tests suitable for different types of equipment is given in Table 6. However, oil preservation systems designed to control exposure of the oil to atmosphere may permit less frequent testing.

Generally, check measurements should be carried out on the basis of the following criteria, which apply particularly to transformer oils.

- Characteristics should be checked periodically, at intervals as suggested in Table 6, unless otherwise defined by the manufacturer.
- If possible, characteristics that are determinable on site should be checked at more frequent intervals.
- Heavily loaded transformers may need more frequent testing.
- The frequency of examination should be increased where any of the significant properties approaches the limit recommended for continued service, or when trend analysis indicates significant changes.

8.2 Testing procedures

8.2.1 *General*

The venue of testing and the number and types of tests that can be carried out on a given sample of oil may vary depending on local circumstances and economic considerations.

Oil in service will vary widely in the extent of degradation and the degree of contamination. In general no one test can be used as the sole criterion for evaluating the condition of the oil sample.

Evaluation of condition should preferably be based upon the composite evaluation of significant characteristics determined in properly equipped laboratories. However, some users find it advantageous to carry out field screening tests.

8.2.2 *Field screening tests*

Some field tests are less accurate than laboratory tests. Field tests are usually limited to visual and olfactory inspection (colour and appearance, and odour), breakdown voltage, moisture content and, with less accuracy, neutralization value. These tests may sometimes be used for the assessment of service-aged oils in accordance with **8.3**, though, more often, field tests are carried out to identify oil samples requiring laboratory evaluation.

Experience has shown that breakdown voltage and moisture content tests carried out properly on site may produce results that are more reliable than those obtained in the laboratory because of possible changes during long-distance transportation and prolonged storage of oil samples. Portable test sets are available and have proved satisfactory.

Other testing methodologies including in-line techniques are available and may be employed for field testing. These include dissolved gas analysis (both instantaneous and monitoring). Such testing methodologies have proved to be of value for transformer condition monitoring.

8.2.3 *Laboratory tests*

The complete examination scheme includes all the tests listed in Table 1. Along with the evaluation of the general condition of the oil, consideration of all results together often enables the cause of degradation or the source of a contaminant to be recognized, so that the appropriate action can be taken to ensure the reliable operation of the equipment.

Quite often, laboratory testing merely seeks to establish the continued serviceability of the oil. The following tests are believed to be the minimum needed to meet this objective:

- — colour and appearance, and odour;
- — breakdown voltage;
- — neutralization value;
- — water content.

NOTE 1 In order to assess the continued serviceability of the oil, water content tests, while desirable in all cases, become particularly necessary when the breakdown voltage approaches the rejection level.

NOTE 2 Current transformers and certain designs of high voltage power transformers using high voltage to low voltage solid paper insulation require stricter control of dielectric losses. In these cases, dielectric dissipation factor or resistivity should also be measured routinely.

NOTE 3 For oil in switchgear, it may be sufficient to check breakdown voltage either periodically or after a given number of operations.

8.3 Classification of the condition of oils in service

It is virtually impossible to set hard and fast rules for the evaluation of oil in service or even to recommend test limits for all possible applications of insulating oil in service.

According to current industrial experience, oils in service can be placed in the following classification based on the evaluation of significant properties and/or their ability to be restored to the characteristics desired.

Group 1. This group contains oils that are in satisfactory condition for continued use. Oils with property values within the limits laid down in Table 6, for the appropriate category of equipment, are considered to belong to this group. It should be understood that these limits are indicative only. With the exception of breakdown voltage and water content, one or more properties outside the limits indicated do not require immediate action. However, if no action is taken, in the long run, the condition can eventually result in accelerated deterioration and shortened equipment life. In interpreting the data, account has to be taken of various factors such as conditions of use, age of equipment and general progression of oil characteristics.

Group 2. This group contains oils that require only reconditioning for further service. This condition will be usually indicated by higher water content and lower breakdown voltage while all other criteria are still satisfactory.

The oil may have a cloudy or dirty appearance. The appropriate treatment consists of the removal of moisture and insoluble matter by mechanical means. Treatment needs to be adequate to result in values of water content and breakdown voltage tending to those in Table 4 and Table 5 where applicable.

It should be appreciated that excessive water in the oil may be indicative of a potentially serious deterioration of the solid insulation with which it is in contact. In such cases the solid insulation needs to be thoroughly inspected and tested. Where such insulation is paper then tests for furanic compounds may provide valuable information about the condition of this insulation.

Group 3. This group contains oils in poor condition that can be restored to a satisfactory condition only after reclaiming. This poor condition will usually be indicated by evidence of insoluble or precipitable sludge and values of neutralization value and/or dielectric dissipation factor in excess of those indicated in Table 6. Insulating oils in this group should be either reclaimed or replaced depending upon economic considerations.

Group 4. This group contains oils in such poor condition that it is technically advisable to dispose of them. Usually many properties will be unsatisfactory.

8.4 Corrective action

The action to be taken is detailed in Table 6. The following recommendations should also be noted.

a) Where a test result is outside the recommended limits, it should be compared with previous results and, if appropriate, a fresh sample obtained for confirmation before any other action is taken.

b) As a general rule, several characteristics will have to be unfavourable in order to justify action. However, if the breakdown voltage is below, and the water content above, the limits given, irrespective of the values of the other characteristics, action as detailed in Table 6 is essential.

c) If rapid deterioration, or acceleration in the rate of deterioration, is observed, more frequent tests should be instituted and appropriate remedial action should be taken. It may be desirable to consult the manufacturer of the equipment.

9 Mutual compatibility of mineral insulating oils

Topping-up should preferably be with insulating oil conforming to BS 148. Under no circumstances should the properties of the oil added be worse than those of the in-tank oil.

Oils conforming to BS 148 and of the same class and containing no additives, are considered to be compatible with each other and can be mixed, in any proportion. Field experience indicates that no problems are normally encountered when fresh oil is added in small percentages, e.g. less than 5 %, to Group 1 used oils, though larger additions to heavily aged oil may cause sludge to precipitate.

Where refilling is required following oil treatment the equipment should be thoroughly flushed through with oil before refilling and then filled in accordance with the manufacturer's instructions.

Experience is very limited regarding the use of oil containing pour-point depressants as top-up for naturally low pour-point oils. However, laboratory investigations suggest that no significant deterioration of low temperature behaviour is likely to occur.

However, when substantial quantities of service-aged oils or of fresh and used oils are to be mixed, it is good practice to perform laboratory tests to determine if the properties of the blended oil are still satisfactory. Compatibility tests are particularly necessary in the case of oils containing additives.

The main characteristics, including oxidation stability and measurement of dielectric dissipation factor after ageing, are determined on a mixture of the component oils. The ratio of this mixture should be the same as that effectively chosen in practice or, if this is not known, a 50/50 ratio should be used.

The results obtained on the composite sample should not be less favourable than those of the worst individual oil.

Reference to the oil supplier or to the equipment manufacturer is recommended if any doubts concerning compatibility arise.

10 Handling and storage

CAUTION. Safe drum handling procedures need to be adopted.

NOTE Attention is drawn to the following legislation:

— Manual Handling Operations Regulations 1992 [9];
— Health and Safety at Work etc. Act 1974 [2];
— Management of Health and Safety at Work Regulations 1992 [3];
— Environmental Protection Act 1990 [5];
— Carriage of Dangerous Goods (Classification, Packaging and Labelling) and Use of Transportable Pressure Receptacles Regulations 1996 [6];
— Carriage of Dangerous Goods by Road Regulations 1996 [7];
— Carriage of Dangerous Goods by Rail Regulations 1996 [8].

To ensure satisfactory service, the utmost care in handling the oil is essential. Drums should be clearly marked to indicate whether they are for clean or for dirty oil and should be reserved for the type indicated. No type of product except mineral insulating oil should be placed in drums or bulk tankers, when intended for reclaiming.

Drums should be stored horizontally and placed in such a position that there is a head of oil on the stopper or plug. They should be stored under cover to minimize the ingress of moisture and exposure to sunlight. The use of plastic sheeting is not recommended unless great care is taken to avoid the drums "sweating" with condensation.

During transportation drums should be in the vertical position for stability and covered to prevent the ingress of moisture.

In practice, difficulty may be experienced in maintaining the purity of oil when it is transferred from one vessel to another owing to the possibility of introducing contamination. Such practice is not recommended without strict adherence to quality control.

It is recognized that storage of oil in damaged drums is not always satisfactory and the transfer of oil from such containers to electrical equipment should be through a suitable treatment plant.

In locations with fixed oil-handling equipment, the pipe-work from the clean oil tanks to the electrical apparatus should be kept clean and free from moisture. Dehydrating breathers should be regularly inspected and maintained. Where portable oil-handling equipment is used, flexible pipe-work and hand pumps should be carefully inspected to ensure that they are free from dirt and water, and should be flushed with clean oil before use. If the clean oil is from drums, it should have been recently tested, and the filling orifices of the drums should be clean.

Hoses used for clean oil and hoses used for dirty oil should be clearly marked and provided with plugs for sealing the ends when not in use.

For specific problems, reference should be made to the equipment manufacturer's instructions.

11 Treatment

11.1 Reconditioning

11.1.1 *General*

Reconditioning is a process which is carried out at the user's site, employing physical means only, to remove contaminants from the oil. However this process does not always result in an oil which conforms to BS 148.

Reconditioning eliminates solid particles from the oil and decreases water content. This process may also remove some dissolved gases and other diagnostic components such as furanic compounds. New datum levels should be established after such a process.

The physical means that are used for removing water and solids from oil include several types of filtration, centrifuging and vacuum dehydration techniques.

If vacuum treatment is not employed it is advisable to limit the temperature to 60 °C. If vacuum treatment is employed, a higher temperature may be advantageous. However, at the vacuum used, the initial boiling point of the oil being treated should not be exceeded, to avoid undue loss of lighter fractions. If this information is not available, it is recommended that the oil should not be vacuum treated at temperatures over 70 °C.

NOTE 1 Processing inhibited mineral oil under vacuum and at elevated temperatures may cause partial loss of oxidation inhibitors. The common inhibitors, 2,6-di-tert-butyl-paracresol and 2,6-di-tert-butyl-phenol, are more volatile than mineral insulating oil. The selectivity for removal of water and air in preference to loss of inhibitor and oil is improved by use of a low processing temperature.

If it is desirable to reduce sludge or free water, cold treatment may be appropriate.

Filters deal efficiently with solid impurities, but are generally capable of removing only small quantities of free water. Where relatively large quantities of free water are present, most of it can, and should, be removed before filtration of the oil.

NOTE 2 Equipment used for filtering oils subject to the risk of contamination by carbon (e.g. from tapchangers) should not be used for other oils because of the risk of cross-contamination.

Centrifugal separators are, in general, satisfactory for removing free water from oil and can in any case deal also with any finely divided solid impurities.

If oil is purified whilst hot its viscosity is reduced and the throughput with certain types of purifier is greater. On the other hand, sludge and free water are more soluble in hot oil than in cold. Sludge and free water are, therefore, more effectively removed by cold treatment. Dissolved and suspended water and dissolved gases are effectively removed by hot vacuum treatment.

If the oil contains solid matter, it is advisable to pass it through some type of filter before processing it under vacuum.

To prevent loss of additives, conditions that have been found satisfactory for most inhibited mineral oil processing are as shown in Table 3.

Table 3 — Conditions for processing inhibited mineral oils

Temperature °C	Pressure Pa
40	5
50	10
60	20
70	40
80	100

11.1.2 *Reconditioning equipment*

11.1.2.1 *Filters*

Filtering equipment generally forces oil under pressure through absorbing material such as paper or other filter media. Filters of this type are preferentially used in removing contaminants in suspension. (The filter medium should be capable of removing particles larger than a nominal 10 µm.) These devices do not de-gas the oil.

The water-removing ability of a filter is dependent upon the dryness and quantity of the filter medium. When filtering oil containing water, the water content of the filter medium rapidly comes into equilibrium with the water content of the oil. A continuous indication of the water content of the outgoing oil is useful to monitor the efficiency of the process.

Care should be taken to ensure that paper filters are of the correct grade so that they do not shed fibres.

11.1.2.2 *Centrifuges*

In general, a centrifuge can handle a much greater concentration of contaminants than can a conventional filter but cannot remove some of the solid contaminants as completely as a filter.

Consequently, the centrifuge is generally found in use for rough bulk cleaning where large amounts of contaminated oil are to be handled.

Often the output of the centrifuge is put through a filter for the final clean-up.

11.1.2.3 *Vacuum dehydrators*

The vacuum dehydrator is an efficient means of reducing the gas and water content of a mineral insulating oil to very low values. (The use of a vacuum dehydrator to remove excessive moisture from insulation systems using oil circulation is not an efficient process. Special techniques may need to be considered.)

There are two types of vacuum dehydrator; both function at elevated temperature. In one method the treatment is accomplished by spraying the oil into a vacuum chamber; in the other, the oil flows in thin layers over a series of baffles inside a vacuum chamber. In both types the objective is to expose a maximum surface and minimum thickness of oil to the vacuum.

In addition to removing water, vacuum dehydration will de-gas the oil and remove the more volatile acids.

11.1.3 *Application to electrical equipment*

11.1.3.1 *Direct purification*

The oil is passed through a purifier and then stored in suitable clean containers. When the electrical equipment is to be refilled the oil is passed through the purifier again, and then directly into the equipment. This method can be used for switchgear. It is suitable, too, for the smaller transformer, but care is needed to ensure that the core, the windings, the interior of the tank and other oil-containing compartments are thoroughly cleaned. The oil-containing compartments of all equipment should also be well cleaned, by means of oil from the purifier.

11.1.3.2 *Purification by circulation*

The oil is circulated through the purifier, being taken from the bottom of the tank of the electrical equipment and re-delivered to the top. The return delivery should be made smoothly and horizontally at or near the top oil level to avoid, as far as possible, mixing cleaned oil with oil which has not yet passed through the purifier. The circulation method is particularly useful for removing suspended contaminants, but all adhering contaminants will not necessarily be removed.

Experience has shown that it is generally necessary to pass the total volume of oil through the purifier not less than three times, and equipment of appropriate capacity should be chosen with this in mind. The final number of cycles will depend on the degree of contamination, and it is essential that the process be continued until a sample taken from the bottom of the electrical equipment after the oil has been allowed to settle for a few hours, passes the breakdown voltage test.

The circulation should be performed with the electrical equipment disconnected from the power source, and this is essential when using a purifier which aerates the oil. In all cases, and especially when aeration has occurred, the oil should be allowed to stand for some time in accordance with the manufacturer's instructions before the equipment is re-energized.

Another technique is sometimes used for transformers, in which oil is continuously circulated during normal service through an adsorbent, such as a molecular sieve, thus keeping both oil and windings dry and removing many oil oxidation products. This is a specialized method not further considered in this standard.

11.2 Reclaiming

This is a process which eliminates soluble and insoluble contaminants from the oil by chemical and/or physical processing. This process will result in an oil originally conforming to BS 148 being restored to its original standard.

Reclaiming is a process normally performed by an oil refiner.

12 Replacement of oil

12.1 Replacement of oil in transformers rated below 72.5 kV and in switchgear and associated equipment

A small extra quantity of oil is needed to rinse the interior of the tank and the immersed parts. It is essential that the tank and the surfaces of conductors and insulators be kept free from fibres. Such fibres are readily introduced by the use of unsatisfactory cleaning materials during plant maintenance; in practice the only efficient and permissible materials are synthetic. It is also essential that the tank and other surfaces be kept free from moisture.

A final pressure flushing with clean oil of known quality followed by thorough extraction has proved beneficial in the removal of fibres and other extraneous material.

There should be as little aeration as possible during the filling of tanks and, as far as possible, the end of the delivery pipe should be held below the surface of the oil in order to avoid splashing; alternatively, the tanks should be filled from the bottom. There should be a standing period of not less than 12 h to allow de-aeration before commissioning transformers (1 h may be adequate for switchgear and 1 h to 2 h for power transformers with a nominal system voltage of less than 16 kV).

12.2 Replacement of oil in transformers rated 72.5 kV and above

Reference should be made to the equipment manufacturer.

Table 4 — Recommended limits for un-inhibited mineral insulating oils filled in new electrical equipment prior to energization

Property	Highest voltage for equipment		
	<72.5 kV	72.5 kV to 170 kV	>170 kV
Appearance	Clear, free from sediment and suspended matter		
Colour (on scale given in BS 2000-196:1997, Table A.2)	max. 2.0	max. 2.0	max. 2.0
Density at 20 °C (kg/dm^3)	As per appropriate BS 148 class		
Viscosity at 40 °C (mm^2/s)	As per appropriate BS 148 class		
Flash-point (°C)	As per appropriate BS 148 class		
Pour-point (°C)	As per appropriate BS 148 class		
Neutralization value (mg KOH/g)	max. 0.03	max. 0.03	max. 0.03
Water content (mg/kg)	—[a]	max. 15	max. 10
Interfacial tension (mN/m)	min. 35	min. 35	min. 35
Dielectric dissipation factor at 90 °C and 40 Hz to 60 Hz[b]	max. 0.015	max. 0.015	max. 0.010
Resistivity at 90 °C (GΩ·m)	min. 60	min. 60	min. 60
Breakdown voltage (kV)	min. 40	min. 50	min. 60
Oxidation stability for un-inhibited oil — Neutralization value (mg KOH/g) — Sludge (% by mass)	 As per BS 148 As per BS 148		
Total gas content (%)	Refer to manufacturer		

[a] For use in transformers under 72.5 kV class, the maximum water content should be agreed between supplier and user depending on local circumstances.

[b] Higher dielectric dissipation factor values may indicate excessive contamination, or the misapplication of solid materials used in manufacture, and should be investigated.

Table 5 — Recommended limits for inhibited mineral insulating oils filled in new electrical equipment prior to energization

Property	Highest voltage for equipment		
	<72.5 kV	72.5 kV to 170 kV	>170 kV
Appearance	Clear, free from sediment and suspended matter		
Colour (on scale given in BS 2000-196:1997, Table A.2)	max. 2.0	max. 2.0	max. 2.0
Density at 20 °C (kg/dm^3)	As per appropriate BS 148 class		
Viscosity at 40 °C (mm^2/s)	As per appropriate BS 148 class		
Flash-point (°C)	As per appropriate BS 148 class		
Pour-point (°C)	As per appropriate BS 148 class		
Neutralization value (mg KOH/g)	max. 0.08	max. 0.08	max. 0.08
Water content (mg/kg)	—[a]	max. 15	max. 10
Interfacial tension (mN/m)	min. 35	min. 35	min. 35
Dielectric dissipation factor at 90 °C and 40 Hz to 60 Hz[b]	max. 0.015	max. 0.015	max. 0.010
Resistivity at 90 °C (GΩ·m)	min. 60	min. 60	min. 60
Breakdown voltage (kV)	min. 40	min. 50	min. 60
Oxidation stability for inhibited oil	As per BS 148		
Induction period (h)	Similar value to that before filling		
Total gas content (%)	Refer to manufacturer		

[a] For use in transformers under 72.5 kV class, the maximum water content should be agreed between supplier and user depending on local circumstances.

[b] Higher dielectric dissipation factor values may indicate excessive contamination, or the misapplication of solid materials used in manufacture, and should be investigated.

Table 6 — Application and interpretation of tests

Property	Test venue (F = Field L = Laboratory)	Category of equipment (see clause **6**)	Frequency of tests	Recommended action limits	Action	Notes
Colour and appearance	L or F	O, A, B, C, D, E	In conjunction with other quantitative tests	Clear, without visible contamination	As dictated by other tests	
Breakdown voltage	L or F	O, A, B, C, D, E, F, G	O, A, B: After filling or refilling, prior to energizing. Then after 12 months; subsequently every 2 years C, D, E: After filling or refilling, prior to energizing. Then after 12 months; subsequently every 6 years F: After filling or refilling, prior to energizing. Then every 4 years or 70 000 operations, or as per manufacturer's instructions, whichever is the lower G: Refer to manufacturer's specifications (see **8.2.3**, note 3)	O, A, D: <50 kV B, E: <40 kV C, G: <30 kV F: Tap changer of neutral end tap changers O, A, B, C transformers: <25 kV Single phase or connected tap changer O, A, B transformers: <40 kV C transformers: <30 kV	O, A, B, C, D, E, F: Recondition oil, or alternatively, if more economical or other tests dictate, replace oil G: Increase frequency of testing and, if other tests dictate, recondition or replace oil	Refer to **8.3** and **8.4**

Table 6 — Application and interpretation of tests *(continued)*

Property	Test venue (F = Field L = Laboratory)	Category of equipment (see clause 6)	Frequency of tests	Recommended action limits	Action	Notes
Water content	L or F	O, A, B, C, D, E, G	O, A: After filling or refilling, prior to energizing. Then after 3 months and 12 months. Subsequently in conjunction with dissolved gas analysis B, D, E: After filling or refilling prior to energizing. Then after 12 months; subsequently every 6 years or in conjunction with dissolved gas analysis C, G: Not a routine test; only when breakdown voltage approaches the rejection level	O, A, D: >10 mg/kg[a] B: >20 mg/kg[a] E: >15 mg/kg[a] C: >30 mg/kg[a] G: >40 mg/kg[a]	O, A, B, C, D, E: Check source of water and consider reconditioning G: Check source of water, increase frequency of testing and, if other tests dictate, recondition or replace oil	O, A, B, D, E, G: The given values are applicable only where neutralization value does not exceed 0.1 mg KOH/g O, A, B, C, D, E: For variation of water content of BS 148 transformer oil with oil temperature and neutralization value, see Figure 1

[a] Correct to 20 °C, see 4.4.

Table 6 — Application and interpretation of tests *(continued)*

Property	Test venue (F = Field L = Laboratory)	Category of equipment (see clause **6**)	Frequency of tests	Recommended action limits	Action	Notes
Neutralization value	L	O, A, B, C, D, E, G	O, A, B: Every 3 years D, E: Not a routine test C: At normal maintenance frequency G: At normal maintenance frequency	O, A, B, D, E: >0.15 mg KOH/g C: >0.5 mg KOH/g G: >0.07 mg KOH/g	O, A, B, D, E: Replace or reclaim oil C: Replace or reclaim oil G: Replace or reclaim oil. Critical examination of electrical equipment to determine suitability for further service	O, A, B, D, E: Perform tests more frequently when neutralization value exceeds 0.1 mg KOH/g C: Perform tests more frequently when neutralization value exceeds 0.3 mg KOH/g G: Perform tests annually once service life of oil exceeds 9 years
Sediment and sludge	L	O, A, B, C, D, E	Not a routine test. As dictated by visual inspection or by neutralization value (see **8.2.3**)	No sediment or precipitable sludge should be detected. Results below 0.02 % by mass may be neglected	Where sediment is detected, recondition oil. Alternatively, if more economical, or other tests dictate, replace oil. Where precipitable sludge is detected consider replacing or reclaiming existing oil	

Table 6 — Application and interpretation of tests *(continued)*

Property	Test venue (F = Field L = Laboratory)	Category of equipment (see clause 6)	Frequency of tests	Recommended action limits		Action	Notes
Resistivity	L	O, A, B, C, D, E	O, A, B, D: After filling or refilling, prior to energizing then after 12 months and subsequently every 6 years	O, A, B, D:		O, A, B, D:	O, A, B, D:
				At 20 °C:	At 90 °C:		
				>200 GΩ·m	>10 GΩ·m	Continue normal sampling	Good
				20 GΩ·m to 200 GΩ·m	1 GΩ·m to 10 GΩ·m	More frequent sampling	Fair
				<20 GΩ·m	<1 GΩ·m	Change oil if other tests indicate	Poor
			C, E: Not a routine test	C, E:		C, E:	C, E:
				At 20 °C:	At 90 °C:		
				>60 GΩ·m	>3 GΩ·m	Continue normal sampling	Good
				4 GΩ·m to 60 GΩ·m	1 GΩ·m to 3 GΩ·m	More frequent sampling	Fair
				<4 GΩ·m	<1 GΩ·m	Change oil if other tests indicate	Poor

Table 6 — Application and interpretation of tests *(continued)*

Property	Test venue (F = Field L = Laboratory)	Category of equipment (see clause 6)	Frequency of tests	Recommended action limits	Action	Notes
Dielectric dissipation factor at 40 Hz to 60 Hz at 90 °C	L	O, A, B, C, D, E	O, A, B, D: After filling or refilling, prior to energizing. Then after 12 months, and subsequently every 6 years C, E: Not a routine test	O, A, D: >0.2 B, C: >1.0 E: >0.3	Investigate (see **8.2.3**, note 2). In case of increasing neutralization value this test should be conducted more frequently	Follow manufacturer's instructions if other frequency and limit are recommended
Interfacial tension	L	O, A, B, C, D, E	Not a routine test. May be done as required	Min: 18 mN/m	Investigate	
Dissolved gas content	L	O, A, B, D	As given in BS EN 60567 or as defined by the user	As given in BS EN 60599	As given in BS EN 60599	
Flash-point	L	O, A, B, C, D, E	Not a routine test. May be required when an unusual odour is noted, when an internal fault has occurred, or when a transformer is refilled	Maximum decrease: 15 °C	Replace oil. Equipment may require inspection	Used in conjunction with dissolved gas content tests (see also clause **11**)

Table 6 — Application and interpretation of tests *(continued)*

Property	**Test venue** (F = Field L = Laboratory)	**Category of equipment** (see clause **6**)	**Frequency of tests**	**Recommended action limits**	**Action**	**Notes**
Total furanic compounds	L	O, A, B C (excluding switchgear)	O, A, B: Every 2 years C: Not a routine test	Rate of change > 0.1 mg/kg per annum	Increase monitoring	
PCBs	L	All	See note to **4.17**	See note to **4.17**	See note to **4.17**	
Inhibitor content	L	All	Not a routine test	Consult oil supplier	Consult oil supplier	

Annex A (normative)
Determination of sediment and sludge

A.1 General

This method covers the determination of sediment and of precipitable sludge in used insulating oils.

NOTE 1 For the purposes of this method, sediment is any substance that is insoluble in both n-heptane and the solvent mixture detailed in **A.2.2**.

NOTE 2 For the purposes of this method, precipitable sludge is any substance that is insoluble in n-heptane but is soluble in the solvent mixture detailed in **A.2.2**.

A.2 Reagents

NOTE All reagents should be analytical grade.

A.2.1 *n-heptane.*

A.2.2 *Solvent mixture,* consisting of equal parts toluene, acetone and either ethanol 95 % or iso-propanol 95 %.

A.3 Apparatus

A.3.1 *Conical flask,* glass, with stopper.

A.3.2 *Sintered glass crucible,* porosity grade P10 in accordance with BS 1752.

A.4 Procedure

Thoroughly agitate the sample of used oil, in the original sample container, until any sediment is homogeneously suspended in the oil.

Weigh approximately 10 g of the oil, to the nearest 0.1 g, into a stoppered conical flask (**A.3.1**) and introduce a volume of n-heptane corresponding to 10 g for each gram of oil taken.

Thoroughly mix the oil sample and n-heptane and allow the mixture to stand, in the flask, in the dark, for 18 h to 24 h.

If a precipitate is observable, filter the solution through a dried and tared sintered glass crucible (**A.3.2**) with the assistance of a vacuum. Rinse the flask with fresh n-heptane to ensure complete transfer of the precipitate to the crucible. Wash the crucible and the precipitate with n-heptane until free from oil.

Allow any n-heptane to evaporate and then dry the crucible in an oven at 100 °C to 110 °C for 1 h. Cool the crucible in a desiccator and then reweigh. Calculate the increase in mass of the crucible as a percentage of the mass of oil taken. Record this value, representing the total insoluble material, comprising sediment and precipitable sludge, as A.

Dissolve the sludge in the crucible in the minimum possible quantity of solvent mixture (**A.2.2**) at approximately 50 °C, until no more will dissolve, and collect the washings in a dried and accurately tared flask. Evaporate off the solvent. Examine the contents of the flask. The presence of a residue indicates that precipitable sludge was present in the oil.

If a quantitative value is required, dry the flask in an oven at 100 °C to 110 °C for 1 h. Cool the flask in a desiccator and then reweigh. Calculate the mass of residue in the flask as a percentage of the mass of oil taken. Record this value as B.

The difference A minus B, if any, represents the percentage, by mass, of sediment in the oil.

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