Eskom	Standard	Technology

Title: **STANDARD FOR MINERAL INSULATING OILS (UNINHIBITED AND INHIBITED): PURCHASE, MANAGEMENT, MAINTENANCE, TESTING AND DISPOSAL**

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1 Introduction

Insulating mineral oil is widely used within Eskom and an integral material that is crucial to the generation, transmission and distribution of electricity within the Eskom group. The purchase, management and testing document focuses on the standard and requirements of both new oil and oil that is in service. In view of the growing demand for power and the reliability of transformer plant this standard serves as a minimum requirement.

2 Supporting clauses

2.1 Scope

This part of the 240-75661431 standard covers provisions for the purchase, management, maintenance and testing of new, regenerated and in-service mineral insulating oils for use in transformers, reactors, switchgear and similar electrical apparatus for insulation and heat transfer purposes.

2.1.1 Purpose

The purpose of this document is to specify the type, specific parameters to which suppliers are to supply insulating oil and the quality criteria expected from suppliers of insulating oil. It is also meant to address the minimum requirements during service, for the testing and monitoring of the material in which ever application.

2.1.2 Applicability

This document shall apply throughout Eskom SOC, its divisions, subsidiaries and entities wherein Eskom has a controlling interest.

2.2 Normative/informative references

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] IEC 60422, Mineral insulating oils in electrical equipment — Supervision and maintenance guidance.

[2] IEC 60296, Fluids for electrotechnical applications – Unused mineral insulating oils for transformers and switchgear.

[3] IEC 60666, Detection and determination of specified anti-oxidant additives in insulating oils.

[4] Doble TOPS, Doble transformer oil purchase specification.

[5] SANS 290, Mineral insulating oils – Management and handling of Polychlorinated biphenyls (PCBs).

[6] SANS 10229 part 1 and 2, Transport of dangerous goods: Packaging of large packaging of dangerous goods for road and rail transportation in South Africa.

[7] SANS 555 part 1, Fluids for electrotechnical applications Part 1: Unused inhibited mineral insulating oils for transformers and switchgear.

[8] SANS 555 part 2, Fluids for electrotechnical applications Part 2: Unused uninhibited mineral insulating oils for transformers and switchgear.

[9] SANS 555 part 3, Fluids for electrotechnical applications Part 3: Recycled inhibited mineral insulating oils for transformers and switchgear.

[10] SANS 555 part 4, Fluids for electrotechnical applications Part 4: Recycled uninhibited mineral insulating oils for transformers and switchgear.

[11] 240-84908008. Eskom. Polychlorinated Biphenyl Phase-out Standard. 2020

2.2.2 Informative

[12] Waste Act 59 of 2008, National Environmental Management.

[13] The National Environmental Management Amendment Act, No 108 of 2008.

[14] Chendong, X. Monitoring paper insulation aging by measuring furfural contents in oil. Proceedings of the 7th International Symposium on High Voltage Engineering. Aug 1991.

[15] NRS 054, Power transformers.

[16] NRS 079, Mineral insulating oils (uninhibited) Part 1: Purchase, management, maintenance and testing.

[17] Nynas. Transformer oil handbook. Available from World Wide Web: <http://www.nynas.com>.

[18] Sokolov, V. and Bassetto, A, et al. Transformer fluid – A powerful tool for the life management of an aging transformer population. Available from World Wide Web: <http://www.bmengenharia.com.br>.

[19] 240-108027030, Eskom. Health appraisal report for power transformers installed on the Transmission network as in 2019.

[20] IEEE. C57-104 IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers. 2015

2.3 Definitions

2.3.1 General

Definition	Description
Accredited staff	A person suitably trained and can demonstrate their knowledge against a known procedure or evaluation to certify their knowledge, also referred to as competent staff.
Age assessment tests	Age assessment test are done to determine the ageing characteristics of electrical equipment by means of chemical analysis of the insulating oil.
Annual type verification tests	Annual type verification tests refers to a batch of tests that is carried out to ensure the on-going product conforms to the original finger print and performance standard. These tests are carried out by Eskom petroleum laboratory. These tests are for Eskom's own internal use and not shared with any external parties.
Anti-oxidant additive	An organic compound added to retard the oxidation process in an insulating oil.
Clean up	Action of remediation that includes soil excavation, bioremediation, solvent soil wash, land farming or electrochemical treatment.
Decommission	Removal of an item of equipment from the network for an extended period (a period exceeding three months).
Decontaminate	In the context of this document decontaminate refers to the removal/reduction of PCB compounds in respect to PCB contaminated oil or electrical equipment.
Electrical equipment	Transformers (including a NEC, NECRT, voltage regulator current transformers, voltage transformers and reactors etc.), capacitor, re-closer, switchgear or cable that contains dielectric fluid.

Definition	Description
Inhibited	Insulating oil that has an antioxidant additive added to prevent oxidation. Typical values are between a minimum of 0.1 % to a maximum of 0.4 % anti-oxidant. **Note:** During the oxidation process, chemically unstable intermediate compounds are formed, with the production of final oxidation products such as organic acids and sludges. A product that can render this oxidation reaction inactive would be an inhibitor. Oils do contain a certain portion of natural inhibitors, but additional inhibitors may be added to oil. The most commonly used inhibitor is Di-isobutyl-para-cresol (DBPC), also known as Butylated hydroxytoluene (BHT).
Initial type acceptance approval	Initial type acceptance approval refers to a batch of tests that is carried out to ensure the insulating oil meets Eskom requirements and is fit for the application or intended use. These tests are performed prior to approval of the insulating oil. These tests are carried out by Eskom petroleum laboratory at the cost to the oil supplier.
Insulating oil	Mineral oil used in transformers and other electrical equipment for insulation and cooling.
Leak	Continuous dripping that will result in pooling of oil. **Note:** Leaking requires corrective action since the electrical equipment will have to be topped-up.
Naphthenic, paraffinic or aromatic insulating oil	Dependent on the relative proportions of the three molecular types, each of which conveys its own properties of the finished insulating oil. **Note:** Oil consists of hydrocarbon mixtures of three main types, i.e. naphthenes, paraffins and aromatics as well as small quantities of sulphur, nitrogen and oxygen.
New oil	Virgin oil or oil that has never been used in electrical equipment and that complies in all respects with new oil standard laid down in this document (see tables 5, 6 and 7).
Non-PCB	Oil or article that is classified as being of PCB level 1 to 3 (1 – 20 ppm).
Non-PCB material	Oil or article that is classified as being of PCB level 1 to 3 (1 – 50 ppm).
On-site	Own site, road or property that belongs to the owner of a particular item of electrical equipment.
Passivator	An additive that coats the copper surface to prevent the copper reacting with corrosive elements in the oil. A typical additive that is used is benzotriazole or methyl-1H-benzotriazole-1-methanamine.
PCB	Any one of a number of 209 congeners containing one to ten chlorine atoms attached to a biphenyl group, and are synthetic products not known to occur naturally. **Note:** New oil produced from crude oil does not contain PCB.
PCB contaminated material / oil	Oil or article that is classified as being of PCB level 4 (51 – 500 ppm).
PCB free material	Oil or article that is classified as being of PCB level 0 (non-detectable).
PCB material	Oil or article that is classified as being of PCB level 5 (< 500 ppm).
Quality tests	Tests carried out when insulating oil is delivered to the customer or end user. Quality tests in this document refer to tests carried out to ensure the insulating oil being received complies with the correct limits as set out in this document.
Regenerated oil	Reclaimed used oil that has been reprocessed to comply in all respects with reference to tables 14 and 15 of this document.

Definition	Description
Repeatability	Repeatability is the variability of the measurements obtained by one person while measuring the same item repeatedly using the same method of testing and instrument. This is also known as the inherent precision of the measurement equipment.
Reproducibility	The difference between two single and independent results obtained by different operators working in different laboratories on identical test material would, with correct application of the test method, exceed the values given. Mathematically, it is the variability of the average values obtained by several operators while measuring the same item.
Routine tests	Tests carried out while equipment is in service or about to be put into service – a group of tests performed on a regular basis.
Tetralin	Tetralin (1,2,3,4-tetrahydronaphthalene) is a hydrocarbon having the chemical formula $C_{10}H_{12}$. It is a partially hydrogenated derivative of naphthalene. It is a colourless liquid that is used as a hydrogen-donor solvent. Gassing tendency is the property of an oil to absorb or release hydrogen under thermal or electrical stress conditions and additives such as tetralin has been used to reduce the gassing tendency of some oils.
Uncertainty of measurement	The uncertainty of measurement is the margin of doubt or percentage of allowable error in results. This involves calibration, instrument accuracy, repeatability and reproducibility in which some error calculation is applied to reduce the error. Results and calculations will involve a degree to which the results can deviate. There must be some level which is allowable and acceptable (standard deviation).
Uninhibited	Insulating oil that has no anti-oxidant additive present in the oil but may have other additives.

2.3.2 Disclosure classification

Controlled disclosure: controlled disclosure to external parties (either enforced by law, or discretionary).

2.4 Abbreviations

Abbreviation	Description
ASTM	American Society for Testing and Material
BHT	Butylated hydroxytoluene
BTA	Benzotriazole
Cigre	Conseil International des Grands Réseaux Electriques
DBDS	Dibenzyl-disulphide
DGA	dissolved gas analysis
DP	Degree of polymerization
EIOSC	Eskom Insulation Oil Steering Committee
FTIR	Fourier Transform Infra-red
GC-FID	Gas Chromatography Flame Ionisation Detector
HPLC	High Performance Liquid Chromatography

Abbreviation	Description
IEC	International Electrotechnical Commission
IFT	Inter Facial Tension
ILAC	International Laboratory Accreditation Cooperation
LCSET	Lowest cold start energising temperature
mg KOH/g	Amount of potassium hydroxide, measured in milligrams, needed to neutralize the amount of acid in a weighed amount of oil
NEC	Neutral Earthing Compensator
NECRT	Neutral Earthing Compensator and Resistor transformer
OEM	Original Equipment Manufacturer
PAH	Polyaromatic hydrocarbon(s)
PCB	Polychlorinated biphenyl
PD	Partial discharge
ppm	Parts per million
RPVOT	Rotating Pressure Vessel Oxidation Test
SANAS	South African National Accreditation System
SANS	South African National Standards
SCOT	Steering Committee of Technologies
SHEQ	Safety Health Environmental Quality
UOM	Uncertainty of measurement

2.5 Roles and responsibilities

Management shall establish a mineral insulating oil quality management system as set out in the framework below. The responsibilities of management shall be to:

a) formulate a documented quality policy appropriate to the quality management of mineral insulating oils as delivered, in service, during storage, and at disposal,

b) document quality requirements,

c) delegate responsibilities for key functions, including quality assurance, quality control, and health and safety, to competent staff,

d) ensure that all staff who work with mineral insulating oil are made aware of the proper handling of oil and the effect of oil on the environment, and

e) provide resources to ensure a safe and hygienic work environment.

However, to ensure that these documents and policies are adhered to frequent audits shall be carried out.

2.6 Process for monitoring

This document and its relevance will be annually evaluated by the relevant SCOT Care Group.

2.7 Related/supporting documents

The approved oil basket list communicated as a practise note to the business shall form part of this standard.

3 Requirements

3.1 Insulating oil approval process

Eskom has adopted the following insulating oil approval process for suppliers to follow to get their products approved. The process will take place at intervals of 3 - 5 years, depending on changes in the market. After year 3 the cycle will commence and a call for products will be made via the Eskom commercial process. Products submitted will be tested during the 3rd year. Eskom will request 2 - 3 x 10 litre samples for evaluation. No ad-hoc testing will take place for any individual supplier. The initial step will be to check the interested supplier's technical data sheets against the Eskom standard. An Eskom test protocol based on various conditions expected in a transformer as well as field experience will be established during this stage newly developed test methods may be included. Any non-compliance will result in immediate exclusion. Qualifying samples are then analysed by an ILAC or ASTM approved international 3rd party laboratory for compliance to this Eskom standard. The compliant samples will then also be subjected to selective in-house testing as per established protocol and will include, but not limited to tests such as compatibility with other compliant products, gassing characteristics and fingerprinting. Compliant insulating oil suppliers will then be requested to do a formal presentation to the EIOSC on their facilities and logistics. The supplier facilities and logistics will be subject to initial Eskom SHEQ and Technical audits as well as further audits on an "as and when" required basis.

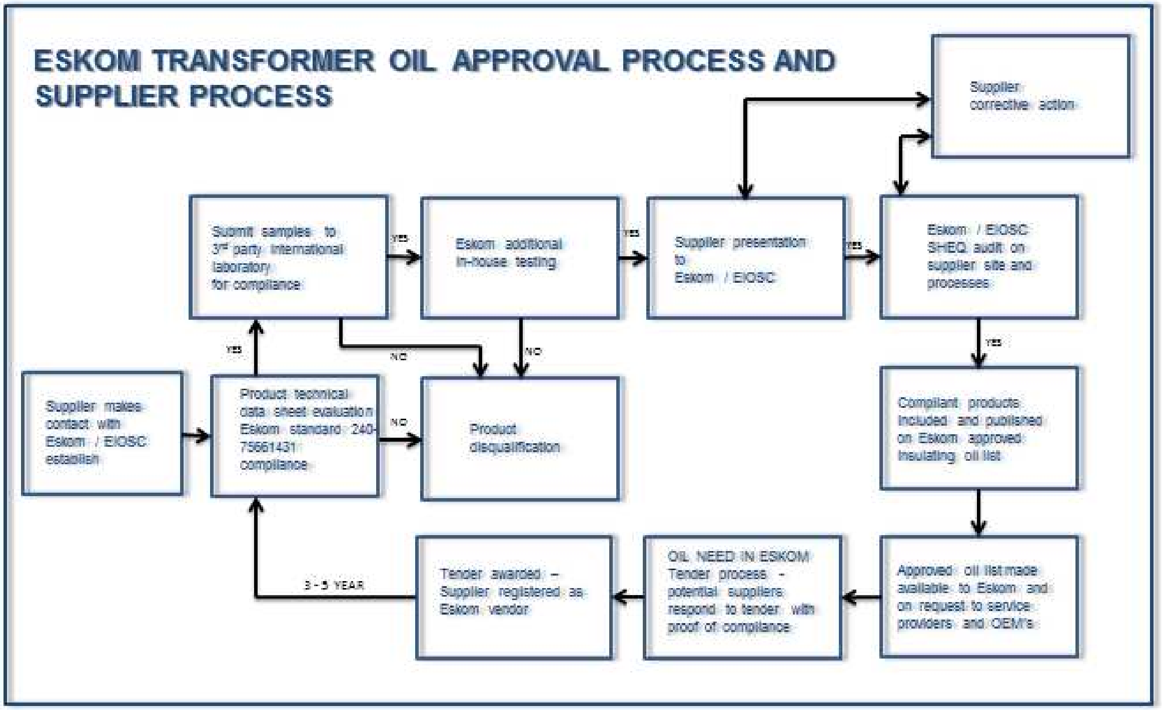


Figure 1: Supplier approval process for the supply of transformer oil to Eskom

In-house testing at the Eskom SANAS accredited petroleum laboratories will also be conducted on an "as and when" required basis. Additional requirements for in-service performance such as compatibility, stray gassing, fingerprinting and "undeclared" additives will also be conducted prior to final approval. No vendor registration is required until such time when a vendor submitted a successful tender on an open Eskom enquiry facilitated via the Eskom tender bulletin board accessible via internet.

Eskom has to deal with multiple oil types and a rigorous testing regime such as mentioned above is imperative in mitigating the insulating oil risk to plant. World market trends and OEM's are forcing Eskom to move towards using inhibited oil. In-service oil has also in some instances been treated for the presence of corrosive sulphur by the introduction of passivator to the oil in the transformers. Research has indicated that different oil types and additives may react differently to temperature, electrical and mechanical stresses within the transformer resulting in differing gassing characteristics. CIGRE has termed the unusual gassing behaviour as "stray gassing" and found that hydrogen was the most prominent gas showing increasing levels in transformers, where no apparent cause could be identified. Abnormal gassing at relatively low temperatures (below 120 ^{o}C) is thus termed stray gassing. Eskom utilises on-line gas analysers and depends on the gas production limits set on the on-line analysers for early warning alarms to be triggered. Variation in these levels will cause confusion and a similar norm needs to be adhered to in order to initiate corrective action.

This standard defines the minimum requirements for the site survey and assessment, design, design-review, manufacturing, factory testing, transporting, delivery to site, off-loading, assembly, installation, in-transit and on-site testing, and commissioning, and performance of the said transformers. The transformer shall as a minimum be designed for the environment where it will be utilised. The transformer manufacturer shall apply the best internationally benchmarked engineering and manufacturing practices to produce a transformer, including accessories, which in conjunction with minimal maintenance, will result in a safe and reliable service throughout the expected lifespan under the rigors of service in the Eskom power system. The transformer, when in service, shall not exhibit unsafe or any uncertain condition e.g. stray excessive gassing, partial discharge, etc. Engineering practices or techniques that have no measurable quality control shall not be accepted for correction of deviations.

The transformer and the associated accessories shall be risk free to Eskom.

3.2 Standard tests and oil analyses

3.2.1 Tests and analyses

Oil tests are categorised into different tests depending on the intention of the analysis. These analyses are described below in Table 1 and the sample container and volume requirements are stipulated in Table 2.

The analyses shown in Table 1 shall be performed on electrical equipment that contains mineral oil.

Table 1: Standard analyses with method references

Analysis	Test set as per Table 2	Recommended method of analysis	Sub-clause
Dissolved Gas Analysis (DGA)	1	ASTM D3612 method C / IEC 60628	3.3.1
Dielectric strength	1/2/3/4	ASTM D1816 / IEC 60156	3.3.2
Moisture content	1/2/3/4	ASTM D1533 / IEC 60814	3.3.3
Acidity	1/2/3/4	IEC 62021-1	3.3.4
Furanic analysis	2	IEC 61198	3.3.5
Colour	2/3/4	ASTM D1500	3.3.6
Dielectric dissipation factor (Tan delta)	2/3/4	BS 5737 or IEC 61620 and IEC 60247	3.3.7
Sediment and sludge	2/3/4	IEC 60422	3.3.8
Interfacial tension	2/3/4	ASTM D971	3.3.9
Particle sizing and counting	3/4	ISO 4406 (1999) / IEC 60970	3.3.10
Polychlorinated biphenyl (PCB)	3/4	IEC 60619 or EPA 600 or ASTM D4059	3.3.11
Carbon composition	3	ASTM D2140	3.3.15
Aromatics	3	ASTM D2140 / IEC 60590	3.3.16

Analysis	**Test set as per Table 2**	**Recommended method of analysis**	**Sub-clause**
Viscosity	3	ASTM D445 / ISO 3104	3.3.17
Corrosive sulphur	3/4	IEC 62535	3.3.12
Aniline point	3	ASTM D611	3.3.18
Silicon	3/4	ASTM D6595	3.3.19
Resistivity (DC Resistance)	3	IEC 60246	3.3.20
Inhibitor content/FTIR verification (1)	2/3/4	IEC 60666	3.3.14
Oxidation stability	3	ASTM D2440 / IEC61125 Method C / ASTM D2112 (RPVOT)	3.3.13
Flash point	3	ASTM D93 / ISO 2719 (Closed Cup)	3.3.21
Density	3	ASTM D1298 / ISO 3675 or 12185	3.3.22
Gassing tendency	3	ASTM D 2300 / IEC 60628 Method	3.3.23
Passivator content (2)	2/3/4	IEC 60666	3.3.24
Pour Point	3	ASTM D97	3.3.33
Polyaromatic Hydrocarbons (PAHs) / Polycyclic Aromatics (PCAs)	3	BS 2000 / IP 346	3.3.16 & 3.3.35
Appearance	3/4	IEC 60422	3.3.6
Stray gassing	3/4	ASTM D7150	3.3.28
Compatibility	3	In-house based on ASTM D7155	3.3.25
Fingerprinting	3/4	In-house GC-FID method	3.3.26
Dibenzyl disulphide content (DBDS)	3/4	IEC 62697	3.3.32
Sulphur by X-Ray	3/4	ASTM D2622	3.3.12

NOTE 1: Inhibitor content presence verified by FTIR, quantified by method IEC 60666 if added

NOTE 2: Passivator content if added

Table 2: Sample container requirements for various laboratory analyses

Test Set	**Description**	**Minimum Sample container required**
Test set 1	Routine/Basic	1 litre sampling tin OR 1 litre tin and 50 ml glass syringe **Note:** Syringe sampling is preferred for DGA samples
Test set 2	Age assessment / Long Term Plant Health Indicators (LTPHI)	1 litre tin
Test set 3	Initial approval and verification tests	2 X 10 litre tins (new aluminium containers) **Note:** More containers may be requested
Test set 4	Quality Assurance (QA)	• 2 X 1 litre sampling tins (new) 100 % full • 1 X 200 ml plastic bottle completely 100 % full • 1 X 200 ml 80 % full – new plastic bottle • 1 X ISO Certified clean glass bottle 80 % full

3.2.2 Oil classes

The insulating oil classes are based on the additive present and will follow the rules as laid down in this standard.

Type U insulating oil: insulating oil without any additives (uninhibited). (Coded as U)

Type I insulating oil: insulating oil with an inhibitor additive added to the level between a minimum of 0.1 and a maximum 0.4 % per litre of oil. (Coded as I)

Note: This standard does not make provision for partially inhibited oil. (Doble TOPS Type I and IEC 60296 Class 2). Any Eskom oil (in-service or after regeneration) found to contain traces of inhibitor will be classed as inhibited oil and if levels of inhibitor are below 0.1 %, inhibitor will be added to a level of 0.4 %.

3.3 Properties of insulating oil

3.3.1 Gas in oil

Dissolved gas analysis is a valuable technique for detecting and identifying faults that occur in transformers and reactors. Heat and electrical discharges that occur inside the unit lead to the decomposition (breakdown) of the insulating oil and other insulating materials (paper, barrier board, resin, etc.). Slow generation of gas may allow absorption of gas into the oil whereas a sudden large release of gas will result in gas that does not dissolve in the oil and this will cause the Buchholz relay to activate. New oils or in service passivated oils may initially have an increase of gases that stabilises after some time and which are not related to electrical or thermal faults. The fault gases ethane, ethylene and acetylene are not generated for this reason. Initial and routine/basic sampling is recommended to obtain a base line.

3.3.1.1 Gas chromatography

By separating, identifying and quantifying (measuring) the gases found dissolved in the oil, it is possible to identify the presence of an incipient fault (early warning). The amounts and types of gas found in the oil are indicative of the severity and type of fault that occurs in the transformer. The rate of gas generation is one of the most important variables and this obviously requires more than one sample to be taken at specified intervals.

It is important to note that the results are generally given as a concentration per oil volume and that the total oil volume is therefore important. The separation, identification and quantification of gas require the use of sophisticated laboratory equipment and technical skills and can therefore only be conducted by a suitably equipped and approved laboratory.

Note: "Approved" in this context means compliance with customer requirements.

The key gases produced are:

a) hydrogen (H_2),

b) methane (CH_4),

c) ethane (C_2H_6),

d) ethylene (C_2H_4),

e) acetylene (C_2H_2),

f) carbon monoxide (CO), and

g) carbon dioxide (CO_2).

Higher hydrocarbon gases are produced but they are not generally considered when the gas analysis data are being interpreted.

3.3.1.2 Origin of gases in transformer oil

The following fault conditions have been identified:

a) Fault gases are caused by corona (partial discharge), thermal heating (pyrolysis) and arcing. Partial discharge is a fault of low-level energy, which usually occurs in gas-filled voids surrounded by oil-impregnated material. The main cause of decomposition in partial discharges is ionic bombardment of the oil molecules. The major gas produced is hydrogen and the minor gas produced is methane.

b) Thermal faults. A small amount of decomposition occurs at normal operating temperatures. As the fault temperature rises, the formation of the degradation gases change from methane (CH_4) to ethane (C_2H_6) to ethylene (C_2H_4).

A thermal fault at “low” temperature (< 300 °C) produces mainly methane and ethane and some ethylene. A thermal fault at “higher” temperature (> 300 °C) produces ethylene. The higher the temperature becomes, the greater the production of ethylene.

c) Arcing is a fault caused by high energy discharge (fault temperature > 1000 ºC). The major gas produced during arcing is acetylene with associated hydrogen. Power arcing can cause temperatures of over 3 000 °C.

Note: If cellulose material (insulating paper, etc.) is involved, carbon monoxide and carbon dioxide are generated.

A normally ageing, conservator type transformer with normal Kraft paper should have a CO_2/CO ratio of about 7. Any CO_2/CO ratio above 11 or below 3 should be regarded as perhaps indicating fault involving cellulose provided that the other gas analyses results also indicate excessive oil degradation. This may be slightly different for upgraded paper and does not apply to Nomex type insulation.

3.3.2 Dielectric strength

3.3.2.1 In transformers, oil is used in conjunction with oil-impregnated paper to provide insulation. However, oil is not as strong as the oil-impregnated paper. The dielectric constant of oil is less than that of paper so that the oil tends to be more stressed than the paper. As a result of this, it may be stated that oil is the weak link in the transformer and that the condition of the oil is of great importance. The maintenance of the oil is paramount to maintain the dielectric strength properties of the oil. Dielectric strength is therefore the insulation property that the oil inherently displays.

3.3.2.2 Moisture content and dielectric strength are related and have an inverse relationship, i.e. if the concentration of moisture in the oil is high; the dielectric strength is normally low and vice versa. When the moisture concentration remains low and the dielectric strength is also low, the maintenance practitioner should take note. If this occurs there are normally other contaminants present in the oil and these could be from other sources in the transformer tank. Carbon (from the tap-changer), paper, wood and other material particles are common. These contaminants should be removed as soon as possible to recover the dielectric strength of the oil. In this case oil filtration or replacement of the oil with regenerated/new oil is essential.

3.3.2.3 Particles in oil decrease the dielectric strength of the oil. The degree of decrease depends on the particle type involved, the particle size and the moisture content of the oil. Paper, copper, iron, wood and dust particles might be found in oil. All these particles are detrimental to the dielectric strength of oil. Paper particles in conjunction with appreciable amounts of moisture can be especially detrimental to the dielectric strength, as these particles absorb moisture from the oil and become semi-conductive. The temperature of the oil also plays a vital role. As the viscosity (thickness of the oil) decreases with the rise in temperature, the particles tend to settle to the bottom of the tank. However, if there is a high concentration of particles at a lower temperature, the particles are held in suspension by the higher viscosity and decrease the dielectric strength of the oil.

3.3.2.4 Oil used in switching applications produce carbon particles through its normal operation. Equipment used in these applications is designed to operate under these conditions. Typical applications are tap changer diverters, switch gear, etc.

3.3.2.5 In extreme cases the carbon from the tap-changer diverter might reach levels detrimental to the tap-changer diverter and cause a flashover. Typical dielectric strength withstands values for diverter oil ranges are between 30 kV / 2.5 mm to 40 kV / 2.5 mm. The oil from the tap-changer or diverter and the main tank should never come into contact with each other, since the carbon will deposit itself on the windings and cause tracking and eventual failure of other insulation.

3.3.3 Moisture content

3.3.3.1 Moisture, even in minute quantities, is harmful in power transformers and power equipment because water is attracted to places of the greatest electrical stress where it has the greatest detrimental effect. Moisture accelerates the deterioration of both the insulating oil and the insulating materials used inside the transformer. Once deterioration has been initiated, more moisture is produced. This is a self-supporting cycle and once the paper has been degraded, it can never be returned to its original condition. Moisture either on its own or in conjunction with cellulose particles also has a detrimental effect on the dielectric properties of oil. Where concentrations are high enough, free water can also be generated in the transformer, which can lead to electrical breakdown. Moisture can be readily removed from the oil, however, due to the fact that most of the moisture in a transformer is located in the paper, the removal of moisture is not effective without first removing the moisture in the paper. Therefore, there is no “quick fix” solution in the case of a transformer with high levels of moisture. Oil can be damaged during this process and it is best to test the oil after regeneration to ensure compliance with tables 14 and 15.

Moisture can originate from the following two sources:

a) the atmosphere – if the transformer is free breathing with poorly functioning or leaking drying equipment (breathers); or/and

b) internal sources – by the degradation of cellulose and by-products of heated insulating oil. This is the greatest source of moisture in a transformer.

3.3.3.2 The presence of moisture will not only deteriorate the dielectric strength of the oil, but could increase the partial discharge tendency as the water content rises. However, it shall be noted that the highest stress points are adjacent to the hottest parts of the structure and the current-carrying conductor, thus they have the lowest water content. Therefore during operating under normal loading the moisture is not a problem as such, but when the unit is de-energized for long periods, the moisture is evenly distributed throughout the paper insulation and the situation is aggravated when the oil carries an excess of water. Once the transformer is re-energized there is a high risk of the transformer developing partial discharge at the high stress points with probable catastrophic damage.

3.3.3.3 With the migration of moisture from the insulation to the oil as the transformer operating temperature rises, the oil will become "wetter". As the temperature of the oil increases so does its ability to receive moisture (this phenomenon where the moisture is dissolved in the oil to the point of saturation where water particles start to form, is referred to as the saturation point curve). As the oil ages, the capability of the oil to hold more moisture increases. Thus the saturation point curve shifts higher. This is normally not a problem, until the oil cools down. It is at this time the oil and water separate and water droplets form. The distribution of moisture in a transformer is a function of the overall temperature of the transformer. As the temperature increases, the moisture moves from the paper to the oil and as it cools down it moves from the oil back into the paper. At any given time the paper holds approximately 90 % of the total moisture content of the transformer. The paper/oil equilibrium forms the basis of relative analysis of the moisture content (percentage by weight) of the paper by measuring the moisture content of the oil.

Note: Equilibrium can take longer than a week of operation at a constant temperature to be achieved.

For many years a standard of 20 ppm was used to indicate that the transformer was wet, however it has been known that temperature has had an influence on the amount of water present in the oil. Further, the age of the oil plays a vital role in the amount of moisture present in the oil. To assess moisture in oil see moisture calculations in section 3.10.2.

The moisture in paper (cellulose insulation) levels for new units after dry out are specified by various Eskom standards on transformers as well as in the IEC 60422 and should be less than 0.5 % for larger and strategic units and less than 1 % for smaller distribution units.

3.3.4 Acidity or neutralization value

3.3.4.1 The neutralization value of the oil is a measure of the presence of acidic compounds in the oil. An increase in the neutralization number will normally indicate oxidation of the oil. The presence of acids is negligible in new or virgin oil, but increases as a result of oxidative ageing. Acidity is normally used as a measure to decide when oil should be replaced or reclaimed. Failure to proceed with these actions will cause the oil to become corrosive and produce dissolved sludge and finally sludge deposits. These deposits can result in overheating and the acid will further weaken the solid insulation material, resulting in eventual failure. The acids will also increase the solubility of moisture in the oil and paper, due to the polar nature of these compounds.

Note: Inhibited oil, thus oil containing an anti-oxidation additive, will tend to indicate no ageing (no acid formation) due to the reaction of the added inhibitor with the ageing products. In the case of inhibited oil – the inhibitor content should be checked on a routine basis, rather than the acidity value of the oil. Replenishment of the inhibitor content may be necessary from time to time.

3.3.4.2 From the moment new oil is introduced into the transformer, it starts to age. The oil is subjected to heat, oxygen and moisture in the transformer. The oil will be oxidized, resulting in the formation of sludge, acids and other oxidation products such as peroxides, ketones and alcohols. Heat, electrical fields, ultraviolet light and mechanical sheering normally trigger the oxidation reaction. It has been proven that the acid content is directly proportional to the amount of oxygen absorbed by the oil. Peroxides are formed as intermediate products. These products are very unstable and will further react with the oil and paper. A mechanically weak oxy-cellulose compound will form; this compound lacks mechanical strength, and weakens the paper or cellulose. The final stage of this process is the formation of sludge. Sludge is normally a solid resin-like substance and has been found to contain materials such as metal oxides, varnishes, paints as well as carbon and even silica derivatives. The sludge will evolve out of solution (dissolved sludge) and form deposits which will settle on the walls of the tank and the insulation.

3.3.4.3 The method for the removal of acid from oil is a process commonly known as regeneration. This process normally entails the passage of the oil over a bed of Fuller's earth or activated carbon, or both. Other compounds such as active bentonite clay, diatomaceous earth, white bauxite, alumina, zeolite, etc., are also used in some plants. The exact configuration and mixtures remain a secret. These compounds will remove the moisture and particulate materials from the oil. In addition, it will also remove all oxidation products from the oil and the acid, correcting the chemical properties of the oil basically to its original state.

3.3.4.4 A process such as the one mentioned above chemically interacts with the oil and it is thus vital that all the properties of the oil be checked after the process. This will normally involve accelerated ageing and the analysis of the acid content of the oil. The acid content of the oil after the accelerated ageing process should comply with respective standards or customer requirements for oil following reclamation.

3.3.5 Furanic analysis

One of the products formed during cellulose insulation breakdown is furaldehyde also referred to as furans or furanics. This mainly refers to 2-furaldehyde (2-FAL), although a number of others may also be formed under certain conditions.

3.3.5.1 Preventative insulation condition monitoring has been proven to be a valuable tool in the life extension of power equipment. These analyses are based on the detection of the products of insulation degradation, which are dispersed between the liquid and the solid insulation. Most of these products are polar in nature and will contribute to the occurrence of harmful currents in the electrical and magnetic fields of the transformer insulation system.

3.3.5.2 The analysis of dissolved gases produced in transformer oil, due to internal faults, is probably the most important analysis. The presence of carbon monoxide and carbon dioxide, detected with gas analysis, may be attributed to the degradation of the cellulose system of a transformer. The presence of these compounds may however not be specifically associated with the paper insulation degradation, since long-term oxidation of the oil, specifically in the case of free breathing apparatus, will also be responsible for the production of these gases. The utilization these compounds alone, to predict the state of the cellulose, is thus not reliable.

3.3.5.3 The paper insulation comprises of cellulose, which is a polymer that consists of long chains of glucose rings, joined by glycosidic bonds. The number of these glucose rings is referred to as the degree of polymerization (DP) of the cellulose. Cellulose decomposition results in the formation of glucose, moisture, carbon monoxide, carbon dioxide and some organic acids. Glucose tends to be unstable and has a very low solubility in transformer oil. The dehydration of the glucose molecules is responsible for the production of furanic derivatives, which are partially soluble in the oil.

3.3.5.4 The analysis of the levels of total furanic compounds present in the oil has been proven to be a more reliable technique for the estimation of the state of the solid insulation system. Various analytical techniques have been adopted for this purpose, with the utilization of High Performance Liquid chromatography (HPLC) being the most common. This technique is based on the extraction of the furanic compounds from the oil with an organic solvent, or an alternative method, the utilization of a solid adsorbent from which the furanics are recovered with an organic solvent. The organic solvent is then quantitatively analysed with HPLC for the presence of furanics.

3.3.5.5 The information obtained from the quantification of the furanics in the oil is related back to the degree of polymerization which will give an average indication of the level of deterioration of the solid insulation system. Cellulose degradation is accelerated by the presence of moisture, oxygen and temperature, which are all available to the cellulose in the environment of the transformer. As an oil sample is easier to obtain this is more common practise and thus found more useful in the assessment of transformers.

3.3.5.6 A word of caution needs to be expressed regarding transformer maintenance processes such as regeneration of the oil by a fuller’s earth process, which will remove the furanic compounds totally and a vacuum treatment process, which will remove the furanic compounds partially. Prior to any major oil processing it is recommended to take a sample for furanic analysis to ensure that the furanic history is not impaired. These treatments will render the analysis of furanics suspect; however, the rate of production trended over an uninterrupted period of time is of great value. The benefit of this analysis is to establish a maintenance programme to stall the rate of degradation or to take the unit off-line for immediate action before a failure. In transformers with thermally upgraded paper the concentrations of furanic compounds are much smaller than with normal “Kraft” paper. Furanic monitoring does not apply to Nomex type insulation.

3.3.5.7 A number of views and equations exist on the processing of furanic data to estimate the degree of polymerisation (DP) value of the cellulose insulation. As mentioned earlier the furanic results is an average of the cellulose system, hence there may be areas with DP values lower than the estimate, but there may also be areas with DP values higher than the estimate. Eskom is currently using the Chendong equation to estimate the DP.

$$DP = \log (2\text{-}FAL) - 1.51/-0.0035$$

3.3.6 Colour and appearance

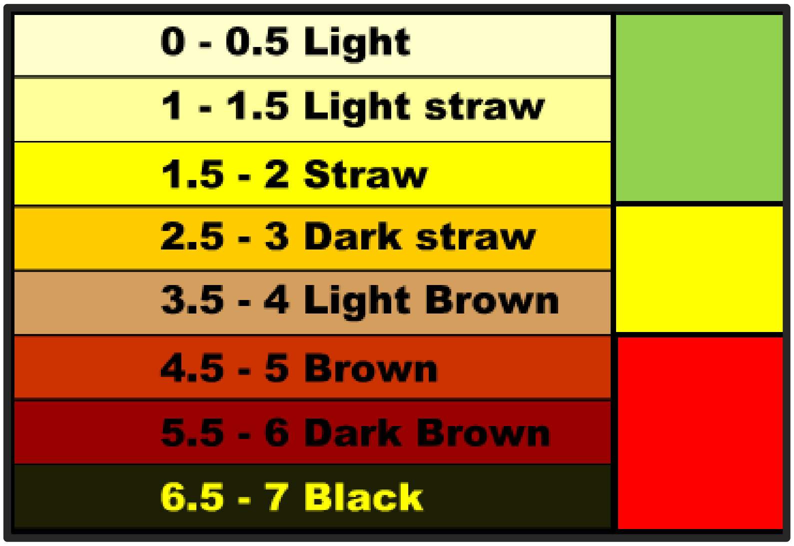
3.3.6.1 The colour of an oil will give the observer quick information on-site. Abnormalities or rapid changes over a short period of time in the condition of the equipment will be observed. It is not a critical test, but is very useful for a comparative evaluation. A greenish colour is normally indicative of the presence of arcing, such as in the case of a diverter of a tap-changer sample. A very pale yellow to yellow (light to straw) oil will normally indicate new or good oil. Virgin/New oil currently available to the market may also be totally colourless. A bright yellow to amber (straw/dark straw to light brown) colour will indicate a marginal to bad oil. A brown to black colour will indicate a very bad to extremely bad oil. Systematic documentation of these observations is vital to track trends and provide meaningful information to the observer.

3.3.6.2 Rapidly changing colour may be an indication of oil deterioration or contamination. Colour combined with smell can give further information. Colour change can be due to normal ageing, oxidation or burning. A dark oil colour will indicate that the oil has started to deteriorate and will be the first phase in the formation of free sludge. Arcing and thus cracking of the oil can contribute to a bad burning smell. Cloudiness or sediment will normally appear indicating the presence of free water, insoluble sludge, carbon, cellulose or fibres, dirt, etc. Oil will start to oxidize as soon as it is exposed to ultraviolet light. The ultraviolet light triggers a reaction between the oil and available oxygen, resulting in various products referred to as oxidation products. A colour change will be observed within a short period of time (hours).

Heat will have the same effect on the oil. These processes also take place inside the transformer, but in addition cellulose will also contribute to the amount of products in the oil. All these factors result in colour change, with the degree of change dependant on the severity of the processes involved.

3.3.6.3 Purification that consists of oil circulation, oil dehydration, degasification as well as filtration will not change the oil colour. The only process that will succeed in changing the colour, is the process normally referred to as regeneration of the oil. This is a process that implies the use of a chemical or adsorbent. The most common adsorbent is fuller's earth, but a number of others are also used, such as activated alumina and bauxite. These products act as adsorbents and any polar compounds such as oxidation by-products will adsorb onto these products, remove them from the oil and improve the colour of the oil. In order to optimize the life expectancy of power equipment, long-term rectification measures should be considered. These measures include the minimization of available oxygen and the reduction of heat, which will result in the formation of oil and cellulose oxidation products; this can be achieved by the modification of a free-breathing transformer to a sealed unit as well as the reduction of the temperature setting at which the cooling fans are automatically activated.

In Figure 2, the initial digits indicate the American Standard Technical Method colour codes (see ASTM D1500) for the specific colours as shown in the figure. The green, yellow and red indicate Eskom alarm levels when action may have to be considered.



0 - 0.5 Light	🟩
1 - 1.5 Light straw	
1.5 - 2 Straw	
2.5 - 3 Dark straw	🟨
3.5 - 4 Light Brown	
4.5 - 5 Brown	🟥
5.5 - 6 Dark Brown	
6.5 - 7 Black	

Figure 2: American Standard Technical Method (ASTM) colour codes

3.3.7 Dielectric dissipation factor or tan delta

3.3.7.1 The tan delta test is also known as the dielectric dissipation factor or the loss tangent measurement. Tan delta can be defined as the measurement of the cosine of the phase angle or the tangent of the loss angle. It is basically the measurement of the leakage current through the oil, which in turn is a measure of the contamination or deterioration of the oil. The oil is non-polar and most contaminants are polar, enabling a dipole action, which this test depends upon. A normal degree of refining will result in a low value for the power factor. The presence of contaminants such as engine oil will easily be detected with this parameter.

3.3.7.2 New oil should have a very low tan delta value which will increase with the use of the oil. Water will not affect this property, but might form stable complexes, which will give higher, tan delta values. As oil ages, the oxidation of oil will affect the tan delta and an increase in the tan delta value will be observed. The oxidation process entails the formation of oxides, which forms acids, and these acids are responsible for the degradation of the cellulose material or paper insulation as well as the metal components of the transformer. New oil will have a tan delta of less than 0.005 at 90 ℃ and 50 Hz. Tan delta will give an indication of the degree of cleanliness of new oil. Oxidation products will have an effect but so will lacquers and other materials that have dissolved in the oil.

3.3.7.3 Many factors will affect the tan delta value of the oil. These factors include ageing or impurities that form during the transformer operation and the intrinsic properties of the oil itself. The cause of the increase of tan delta and its instability was found to be mainly due to the colloid formation of liquid-phobic gel. In theory voltage and current should be 90° shifted in phase, but in effect this does not happen, as the leading reactive current is not the only current present. An active current will also be flowing and this can be caused in liquids, owing to the following three effects:

a) the transport of carrier (ions) through the electric field, which is also temperature dependent – with higher temperature the losses increase as a result of the ion mobility that increases with a decrease in viscosity;

b) the loss by rotation of electric dipoles (orientation polarization). This can be explained as follows: a water molecule has a permanent dipole moment due to the molecular orientation. This molecule will orientate itself according to the electrical field. With an alternating-current circuit voltage the orientation of the field strength changes corresponding to the frequency of the adjacent alternating-current voltage. The water molecules will shift 180° and a loss will be incurred in the form of friction heat. With mineral oils, the maximum polarization losses take place approximately at −30 ℃, and at higher temperatures the polarization losses decrease; and

c) partial discharges in gas bubbles or pockets which are responsible for localised energy dissipation give rise to an increase in the active current.

3.3.8 Sediment and sludge

3.3.8.1 The oil forms an integral part of the overall insulation system in the transformer. The insulation system consists of the transformer insulating oil in conjunction with the solid oil-impregnated paper, providing insulation between windings and from the windings to the ground. The dielectric constant of transformer oil is less than that of the solid insulation paper, thus the oil tends to be stressed more than the paper. Hence the condition of the transformer oil becomes a crucial factor in the maintenance of a transformer. The combined effect of oxidation products such as acid and sludge can be detrimental to a transformer in service. Acid in the oil will trigger chemical decomposition of the insulation system (paper and oil) and sludge will restrict efficient cooling, due to its accumulation on and between windings and cooling surfaces; this will cause further oxidation resulting in more acid and sludge.

3.3.8.2 The oxidation process culminates with the formation of sludge which:

a) as a suspended impurity, decreases the fluid dielectric withstand strength in a manner similar to that in the case of particles,

b) as a semi-conductive sediment, decreases the insulation dielectric withstand strength and may provide for tracking, or

c) when extremely acidic, will aggressively age both the oil and the cellulose insulation.

3.3.8.3 The conditions under which sludge will form are not always readily apparent. In the presence of a strong electrical field, sludge may form even though the acidity is low. A number of sludge deposits have been found on local insulation zones where the electric field strengths are quite high.

3.3.8.4 Transformer oil consists of in excess of 3 000 hydrocarbons of which 2 % to 14 % are aromatic. Sludge is defined as thick, greasy mud, slushy sediment or deposit. The sludge that forms in transformers is however of questionable formation and composition. The greatest factor in the formation of sludge is the oxidation of the transformer oil, whether naturally or in-service. Transformer oil contains natural oxidation inhibitors or added synthetic inhibiters. In the event of these inhibitors becoming exhausted, the oxidation process rapidly increases. The oxidation components act upon each other and on the original oil resulting in the formation of sludge. The sludge formed is a resinous polymeric substance that eventually becomes insoluble in the transformer oil. Insolubility is reached when consecutive hardened layers are formed. The sludge formed is partially conductive, hygroscopic, and acts as a heat insulator. Normal ageing of transformer oil also results in sludge formation, this being all the solid residue collecting at the bottom of the transformer. Sludge will appear quicker in a heavily loaded, hot running and badly maintained transformer. The rate of oxidation is increased by the presence of moisture and oxygen and temperature (the rate is doubled by every 6 – 8 ºC rise), acting as catalysts.

As the sludge build-up increases, consecutive layers with varying degrees of hardness are formed, depending on how the unit has been operating. Oil oxidation is also increased by various secondary factors, i.e. heat, vibration, shock loading, surge voltages and high electrical stresses.

3.3.9 Interfacial tension

3.3.9.1 New oil should have a high value of interfacial tension, which will decrease with the use of the oil. The interfacial tension (IFT) of mineral insulating oil is related to the deterioration of the oil. The mineral insulating oil is essentially a non-polar saturated hydrocarbon; however, when the oil ages, oxygenated species such as carboxylic acids, which are hydrophilic, are formed.

The presence of these materials in the insulating oil can affect the chemical (acidity), electrical (dielectric strength), and physical (interfacial tension) properties of the oil. In this procedure one measures the surface tension of the oil against that of water, which is highly polar. The more the two liquids are alike in their polarity, the lower the value of the surface tension between them. Thus the higher the concentration of hydrophilic materials in the insulating oil, the lower will be the interfacial tension of the oil measured against that of water. There are several methods that can be used to measure the interfacial tension of oil against that of water. Interfacial tension is one of the critical insulating properties of oil and a decrease in the IFT will promote heat build-up since the used oil is more conductive due to the presence of oxidation products. This in turn will result in sludge formation, with higher temperatures and an eventual thermal fault.

3.3.9.2 Interfacial tension between the water and oil is used to measure the molecular attractive force between the molecules of water and oil. The molecular attractive force is expressed in dynes per centimetre or in millinewtons per metre and is measured using a platinum ring tensiometer. A planar platinum ring is first placed in the interface of water and oil and then it is lifted, using a torsion wire, into the oil. The force required to lift the ring from the interface is proportional to the interfacial tension. Interfacial tension is extremely useful for the determination of the presence of polar contaminants and oil decay products.

Good oil will have an interfacial tension of between 40 mN/m and 50 mN/m. Oil oxidation products lower the interfacial tension (IFT) and have an affinity for both water (hydrophilic) and oil. This affinity for both substances lowers the IFT. At the interface oil oxidation products extend across to the water, thus a vertical force is exerted reducing the lateral tension. The greater the concentration of contaminants, the lower the IFT, with a badly deteriorated oil having an IFT of 22 mN/m or less.

3.3.10 Particle contamination

3.3.10.1 Insulation problems involve predominantly impairment of insulation conditions in service. A general ageing problem is the accumulation of conductive and polar particles in oil, as well as the deposit of these particles on the surface of the insulation material. This was noticed as adsorption of insoluble ageing products in areas of high electrical stress. The surface contamination can cause distortion of the electrical field, as well as the reduction in the electrical strength of the insulation system. Typical faults that can occur are flashing over in high-voltage windings under the effect of switching surges and lightning impulses due to contamination of surfaces with conductive particles and polar oil ageing products.

3.3.10.2 Particles in oil decrease both the a.c. and d.c. breakdown voltages of the oil. The breakdown voltage is dependent on both the particle size and the conductivity of the particles. With conducting metal or partially conductive particles such as carbon and wet cellulose fibres, the decrease of the breakdown strength is significantly greater in the case of direct voltage. Small particles can agglomerate to form larger particles. These larger agglomerates can again break up under mechanical and electrical stresses to form smaller particles, resulting in contradictory test results obtained in some laboratory analyses.

3.3.10.3 In the analysis of particles in oil, repeatability and reproducibility of results is an important factor. Depending on the method of analysis there are some variations in both areas. Thus the interpretation of the results cannot be assessed by just looking at the particle count, but rather the ISO classification. Although a desired ISO 4406 (1986) classification for new oil would be 10/7 or ISO 4406 (1999) 13/10/7, there are some variations in the results. Thus the factor of reproducibility will need to be 1 for both sizes and the unacceptable limit would thus become an ISO 4406 (1986) code 11/8 or ISO (1999) code of 14/11/8 refer to Annex C for further information.

3.3.11 Polychlorinated biphenyl (PCB)

3.3.11.1 Polychlorinated biphenyl (PCB) is the generic term for a broad class of fire-resistant synthetic insulating liquids composed of Polychlorinated biphenyls, sometimes with the addition of polychlorinated benzenes. PCB is a synthetic substance not known to occur naturally. It was first described in technical literature in 1881 and commercial production commenced in the late 1920s. PCB is any one of a number of 209 possible variations in which one to ten chlorine atoms are attached to a biphenyl group. PCB was produced under a number of trade names by a number of manufacturers. In the electrical field, askarels have mainly been used as insulants in power transformers and power capacitors.

3.3.11.2 PCB is soluble in most organic solvents, but insoluble in water. It is denser than water and when added to water will sink to the bottom. Most PCB mixtures are non-volatile at a temperature around 40 ℃, with a flash point at a temperature exceeding 300 °C. Overheating of electrical equipment can produce emissions of irritating and toxic vapours. PCB is completely destroyed under extreme heat conditions, such as in temperatures exceeding 1 100 ℃. PCB can only be found in equipment where it had been intentionally placed or accidentally mixed in. It comes from an external source; it is not produced or "grown" within the transformer. The presence of PCB in mineral insulating oil is due to contamination during top-ups, purification, filtration or oil replacement. PCB is listed on the United Nations' Persistent Organic Pollutant (POP) list.

3.3.12 Copper sulphide and corrosive sulphur

There are different types of sulphur compounds found in refined transformer oil but not all types are considered to be corrosive or reactive. These are:

Table 3: Sulphur Groups

Sulphur Groups	**Comment**
Elemental (free) sulphur	Very Reactive
Mercaptans (thiols)	Very Reactive
Sulphides (thio-ethers)	Reactive
Disulphides	Stable
Thiophenes	Very Stable

Some sulphur compounds can actually aid in the oxidation stability of the transformer oil and may also act as metal passivators and deactivators reducing the catalytic effect on oil oxidation in transformers.

Corrosive and reactive sulphur compounds can react on contact with copper and other metals. Copper in a transformer is by far, the least resistant metal to a sulphur attack. In oxygen deficient environments as those with copper, aluminium, and other metals to form various compounds such as copper sulphides found in sealed, gas blanked and sealed conservator transformers, corrosive and reactive sulphur species combine with copper, aluminium and other metals to form various compounds such as copper sulphide.

Copper sulphide is graphite grey, dark brown or black in colour. Copper sulphide may be formed both on the outside and on the inside of the paper.

Non-corrosive sulphide can become corrosive after being exposed to elevated temperatures on hot metal surfaces and thus produce metal sulphides. This attack would corrode the metal surfaces.

Oil is not the only material that contains sulphur. Sulphur compounds are also present in the gaskets, some water-based glues, copper and paper insulation used in the manufacture of transformers. Sulphur can also be introduced into the transformer through accidental means such as through the use of incompatible hoses.

The effects of corrosive/reactive sulphur not only adversely affect the conductor material and other metal surfaces but also can have drastic effect on insulating materials such as paper. Serious contamination due to sulphur-containing surfaces can drastically reduce the dielectric strength of the paper insulation while no or very little change has taken place in the mechanical strength of the paper as measured by DP.

Identifying the sources of sulphur contamination and being able to monitor concentrations of corrosive and reactive sulphur will help detect problem areas earlier. Other than draining and flushing with new oil, a commercially-viable remedial process has not been developed which can remove corrosive and reactive sulphur species from the oil. Sulphur corrosive oils are not accepted in Eskom.

3.3.13 Oxidation stability

Oxidation stability is a very important characteristic of insulating oil. Due the fact that this oil functions under stressful temperature conditions to provide cooling (other applications such as diverter and switchgear are excluded), oil needs to withstand the oxidation process that occurs. It is mainly due to the presence of oxygen and temperature, thus it is generally good practice to exclude (seal from atmospheric air) the oxygen from the oil. The oxidation stability test aims to test the oil's resilience to the oxidation process. However, with addition of anti-oxidants to the oil, the testing method is different.

During the oxidation process acids and sludge are formed in the oil that attack materials within the transformer causing the materials to eventually fail. The function of the oxidation stability test is to determine how long the process would take before unacceptable levels of acids and sludge are reached. The longer the oil can withstand the oxidation process the better it will be for the sensitive materials used in the manufacture of transformer units. Inhibited oils will indicate a good oxidation stability as long as inhibitor is present, but will deteriorate rapidly once the inhibitor has depleted. Monitoring of the inhibitor should thus be included in the maintenance schedule.

Oxidation stability is measured in the laboratory by exposing the oil at higher temperature for 164 hours of time in the presence of oxygen or air, followed by the measurement of the levels of sludge, acid and deterioration in dissipation factor. For inhibited oil the time period has to be extended from 164 hours to 500 hours. The risk involved with the 500 h analysis is that test conditions are subject to variables (such as power outages and oxygen supply) and for to this reason Eskom decided to incorporate the Rotating Pressure Vessel Oxygen Test (RPVOT) for a quick oxidation test.

3.3.14 Anti-oxidant levels and testing

An inhibitor or anti-oxidant additive has the effect of slowing down the oxidation of oil and thus the formation of by-products in the form of sludge and acidity. It is important to know whether and in what proportion antioxidant additive has been added in order to monitor additive depletion rate during service. 2,6-di-tertry-butyl-paracresol (DBPC) is the most commonly used anti-oxidant, but others are also used.

Detection and measurement of defined anti-oxidant additives shall be determined in accordance with IEC 60666. The type and quantity of each anti-oxidant additive present in the oil shall be stated in the quality certificate as acceptance criteria. If co-stabilizers are used during the refining process, their presence and nature shall be documented by the supplier prior to any batch of oil being accepted by the purchaser of the product.

The approach to inhibitor management in-service would be based on the decision to use inhibited oil or not. Due to the strategy to use uninhibited oil in Eskom for many years, to avoid the management and additional cost of monitoring and management of inhibitors, the bulk of oil in Eskom is not inhibited.

Oils containing less than 0.1 % in-service, should be regarded as not intentionally inhibited and may have been contaminated through topping-up, filter plant carry over etc. Any oil in-service with a monitored level of > 0.1 % should be replenished and maintained at a level of inhibitor > 0.3 % - < 0.4 %.

Regenerated oil with any traceable levels of inhibitor shall be inhibited prior to dispatch or use to the levels as stated in this document – refer to table 14.

NOTE: Transformers containing inhibited oil shall be labelled as such.

3.3.15 Carbon composition

Different mixtures of distillates make up insulating oil. Although this standard calls for naphthenic type oil, all oil is made up of a mixture of constituents with naphthenic, paraffinic and aromatic combinations. In order to understand oil being purchased the user needs to stipulate the carbon composition in order to ensure consistent batch types and composition. However, it must be noted that there is an unavoidable variation in crude and processing of mineral oils that calls for an allowable variation in carbon composition. Eskom stipulates oil derived from naphthenic crudes and reserves the right to decline products containing in excess of 50 % paraffin's. New technology may be considered on a case-by-case basis and will be subject to performance and compatibility testing.

Carbon Type Composition (ASTM D2140). The carbon type composition characterizes insulating oil in terms of the percentage of aromatic, naphthenic, and paraffinic carbons. It can be used to detect changes in oil composition and to relate certain phenomena that have been demonstrated to be related to oil composition.

3.3.16 Aromatics

Aromatics relate to hydrocarbon cyclic compounds. An aromatic hydrocarbon is typically a benzene structure and/or other benzene related hydrocarbons. Polyaromatic hydrocarbon are usually minimised due to the carcinogenic related tendencies.

3.3.17 Viscosity

Viscosity is the resistance of oil to flow under specified conditions. The viscosity of oil used as a coolant influences heat transfer rates and consequently the temperature rise of an apparatus. The viscosity of oil also influences the speed of moving parts in tap changers and circuit breakers. High viscosity oils are less desirable, especially in cold climates. Standard viscosity curves can be generated using ASTM Method D341 by measuring two or three data points and plotting the data. The resulting curve can be used to interpolate or extrapolate values at temperatures where the viscosity is not measured directly.

3.3.18 Aniline point

The aniline point is the temperature at which a mixture of aniline and oil separates. It provides a rough indication of the total aromatic content, and relates to the solvency of the oil for materials which are in contact with the oil. The lower the aniline point, the greater the solvency effect of the oil – this is in particular important when the oil will be used for desludging.

3.3.19 Silicon/Silicone oil

Silicon, a naturally occurring substance (sand/dust) often contaminates insulating oil, but is not harmful to the unit. However, silicone oil contamination causes excessive foaming under the right conditions. For the class O and A transformers that use forced oil cooling there be may a problem with cavitation on the forced oil cooling pumps. Due to the ease of cross contamination, any oil that is returned to storage or for regeneration needs to tested for silicone (oil or silicone based releasing agents) contamination.

3.3.20 Resistivity

Resistivity is derived from the dissipation factor (tan delta) test. Resistivity is the resistance component in the dissipation factor test result. Resistivity of oil, in essence, is the resistance of the oil over a fixed distance. It is normally measured by the same instrument used to measure the tan delta of oil.

3.3.21 Flash Point

The flash point is the minimum temperature at which heated oil gives off sufficient vapour to form a flammable mixture with air. It is an indicator of the volatility of the oil as well as the presence of contaminates such as solvents.

3.3.22 Density

The specific gravity of oil is the ratio of the weight of equal volumes of oil and water determined under specified conditions. In extremely cold climates, specific gravity has been used to determine whether ice, resulting from the freezing of water in oil-filled apparatus, will float on the oil and possibly result in flashover of conductors extending above the oil level. The specific gravity of mineral oil influences the heat transfer rates. Oils of different specific gravity may not readily mix when added to each other and precautions should be taken to ensure mixing.

3.3.23 Gassing Tendency

The gassing tendency is defined as the rate of gas evolved or absorbed by insulating oil when subjected to electrical stress of sufficient intensity to cause ionization. The laboratory test is performed in a blanket of hydrogen gas above the oil sample tested. The characteristic is positive if gas is evolved and negative if gas is absorbed. Hydrogen is also produced by the decomposing oil that is subjected to electrical stress. The active species formed in both the gas and the oil processes hydrogenate aromatic species in the condensate phase at a rate that is limited by the concentration and type of aromatics present. If the rate of hydrogen uptake is slower than the rate produced the oil will be evolving and if the rate of uptake is faster than the production rate, the oil will be absorbing. The aromatic content of the oil is decreasing in the gas evolution phenomena. Hydrogen is the main degradation product formed during low energy discharges. Hydrogen has a low solubility in oil and gas bubbles will readily form in the area of the discharge. The presence of gas bubbles can increase partial discharge as well as initiate further breakdown in highly stressed areas due to the fact that gas bubbles have been shown to be weak dielectric. The likelihood of damage to the insulation system in a transformer by low energy discharges is clearly higher in oil in which a high gas evolution rate is a measured. The effect of partial discharges may thus be mitigated by the usage of gas absorbing oil, especially in equipment such as cables, bushings, instrument transforms and certain capacitors. This is considered an important property if the insulating oil purchased is to be used over a wide range of applications.

3.3.24 Passivator content

Passivators have been shown to mitigate or retard sulphur corrosion. There are both sulphur and nitrogen based passivators that can be used, but for the electrical insulating oils nitrogen based compounds have been employed. The one that most people are familiar with is benzotriazole that was used for suppression of static electrification by some transformer manufacturers. More recently more oil soluble derivatives of benzotriazole have been used. The passivator molecules take up the active sites on the metal such as copper to retard corrosion reactions.

NOTE: Transformers containing passivated oil shall be labelled as such. New transformers must only have non-corrosive oils.

3.3.25 Compatibility of insulating oils

Unused insulating oil complying to this standard as well as IEC 60296 with the same classification (class, group and LCSET as stated in IEC 60296) as that already in service should be used for topping up and/or refilling electrical equipment. Field experience indicates that problems are not normally encountered when unused oil is added in small percentage, e.g. less than 5 %, to used oils classified as ‘good’ (refer to IEC 60422) though larger additions to heavily aged oil may cause sludge to precipitate.

Eskom regards compatibility tests necessary to determine the feasibility of mixing unused oils of different origins as well as with oil in service. For mixing used oils, a compatibility study will be performed by Eskom and only oils indicating total compatibility will be considered for use in the Eskom equipment. Reference to the oil supplier is recommended if any doubts concerning compatibility arise.

In the compatibility study, as described below, the characteristics of the mixture should not be less favourable than those of the worse individual oil. Oils should be mixed in the same proportions as in the application, or if not known in a 10:90, 50/50 and 90:10 ratio.

The following functional tests are recommended for each individual oil and for the mixture:

- foaming;
- oxidation stability, including acidity, sludge and tan delta after ageing
- corrosive sulphur and/or potential corrosive.

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

Compatibility tests are particularly necessary in the case of oils containing additives. Again, reference to the oil supplier or to the equipment manufacturer is recommended.

3.3.26 Identification

Oil identification must be stipulated on the vessel that contains the product. Although this may not be practical for transformer units that are already in service, new transformers and transformers that will be retro-filled need the insulating fluid to be identified on the equipment. This only applies to volumes of above 5 litres.

The sole purpose of this is to aid the field service personnel to handle the contents in the correct manner and to avoid cross contamination. This will also enable Eskom to address any problems relating with the oil with the correct supplier. Eskom has developed a gas chromatographic fingerprinting method that may be used to identify the oil type, brand and thus supplier. This criteria is becoming more crucial with the international adoption of natural and synthetic phosphate esters or “green oils”.

3.3.27 Uncertainty of Measurement

Within the standard, there is some uncertainty of measurement. In assessment of results for compliance the uncertainty of results must be taken into consideration. In general terms the combined uncertainty of measurement should be used and can be obtained from the laboratory upon request. The general evaluation of results with regards to this standard shall be within 95 % that the result measured is within 2 standard deviations (U) of the true value.

Combined uncertainty takes into consideration the following aspects, but is not limited to the list below:

- Accuracy of the instrument
- Repeatability
- Reproducibility
- Environmental aspects e.g. temperature, atmospheric pressure, humidity etc.
- Sampling method

3.3.28 Stray Gassing

Stray gassing is the term used to describe gassing of oils not related to fault conditions within the transformer or electrical equipment. It is gas produced at modest temperatures – from as low as 60 ºC up to temperatures around 200 ºC. It is defined as the production of gases in an insulating liquid due to heating, contamination or in combination. The gas normally produced under these conditions is mainly hydrogen, methane and carbon dioxide. The gas produced during this initial increased temperatures will increase until reaching a plateau dependent on the type of oil.

3.3.29 Fingerprinting

Fingerprinting refers to the gas chromatogram obtained for oil following analysis on a gas chromatograph with a flame ionisation detector (GC-FID) or gas chromatograph equipped with a mass spectrometer (GC-MS). This technique assists the end user to identify, with some degree of certainty, the type, the supplier as well as, to some extent, the insulating oil product supplied. It furthers confirm the presence of certain additives such as certain types of oxidation inhibitors and/or passivators.

3.3.30 Fire point

The fire point of oil is the lowest temperature at which the vapour of that oil will continue to burn for at least 6 seconds after ignition by an open flame of standard dimension. At the flash point, a lower temperature, a substance will ignite briefly, but vapour might not be produced at a rate to sustain the fire.

3.3.31 Smoke point

The smoke point, also referred to as the burning point, is the temperature at which an oil or fat begins to produce a continuous bluish smoke that becomes clearly visible, dependent upon specific and defined conditions. Smoke point values can vary greatly, depending on factors such as the volume of oil utilized, the size of the container, the presence of air currents, the type and source of light as well as the quality of the oil and its acidity content, otherwise known as free fatty acid (FFA) content. The more FFA an oil contains, the quicker it will break down and start smoking. The higher the quality of the oil and the lower the FFA, the higher the smoke point will be. It is important to consider, however, that the FFA only represents typically less than 1 % of the total oil and consequently renders smoke point a poor indicator of the capacity of a fat or oil to withstand heat. This test is conducted by carefully heating the oil under specified conditions until the first consistent appearance of vapours is detected. The temperature of the oil at that time is recorded as the smoke point.

3.3.32 Dibenzyl disulphide (DBDS)

DBDS is potentially corrosive to copper surfaces at normal transformer operating temperatures and may form copper sulphide under certain conditions. Among corrosive sulphur compounds DBDS appears to play a predominant role in the problem of corrosion. Identified as a major sulphur compound in several mineral insulating oils, it is present in most corrosive insulating oils produced and blended after 1988-1989 (although they passed the corrosive tests of their time). There seem to be very few oils introduced or produced after 2006 that contain DBDS in detectable amounts. It should be noted that there are also oils in service that are corrosive despite the absence of DBDS.

Note: Dibenzyl disulphide is a sulphur compound used as an antioxidant additive in rubber compounds, a stabilizer for petroleum fractions and an additive for silicon oils.

3.3.33 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 this property is affected by normal oil deterioration. Changes in pour point can normally be interpreted as the result of topping-up with a different oil.

3.3.34 Electro Static Charging Tendency (ECT)

Electro Charging Tendency (ECT) of oil is an important property for certain designs of HV and EHV transformers which have oil pumping rates that can give rise to the build-up of electrostatic charge. This charge in the oil can result in energy discharge causing transformer failure.

3.3.35 Polycyclic Aromatic content (PCAs)

Some PCAs also referred to as Polyaromatic Hydrocarbons (PAHs) are classified to be carcinogens and therefore need to be controlled to an acceptable level in mineral insulating oil. The total amount of PCAs can be measured by extraction with DMSO (dimethylsulfoxide) under the conditions of IP 346.

Note: Acceptable limits of total or individual PCAs are specified in national and local regulations.

3.4 Packaging and bulk deliveries

It is recommended that oil supplied in drums (210 litres) is supplied in white drums. White drums is the colour of choice as darker colours such as black or dark blue is known to have a reflectance value of Zero (0) and absorbs all light and heat, whilst white a reflectance value of nearly 100 and will thus remain cooler. Black colouring will thus contribute to ageing of the oil in storage. The drums should further be marked as OTE (electric transformer oil) with an orange lightning bolt.

The bulk containerization is controlled largely by the current road regulations and need to be adhered to. See SANS 10229.

The oil supplier shall guarantee that new oil delivered complies with the “zero count PCB” requirement. This guarantee shall be in the form of a certificate and records thereof shall be kept for auditing purposes.

The oil supplier shall guarantee that, at the point of loading into certified clean supplier/Eskom tankers, the oil conforms to the requirements of “new oil” or “regenerated oil” as defined in tables 5, 6 or 7 for new and table 14 or 15 for regenerated oil. This guarantee shall be in the form of a certificate, of which a copy shall accompany the delivery note. Records thereof shall be kept for auditing purposes.

a) Oil supplied in tankers/ISO tanks

On delivery at site, and before transfer to Eskom containers (i.e. drums, bags, electrical apparatus, ISO tanks etc.), the oil shall be tested according to test set 4 (see table 1 and 2).

b) Oil supplied in drums

Drums are sealed at the point of loading by the supplier and a batch certificate shall be supplied and will conform to table 5, 6 or 7. If the oil is correctly stored for longer than 1 week the oil shall be re-tested for water content and dielectric strength.

Transportation and storage: Drums shall be positioned either with the two bungs in a horizontal line position or upside down i.e. bungs down. Preference will be given to covered storage, on a solid surface in a bund area. The drums should also be raised from surface Note: If there is any doubt as to the oil condition the oil must re-tested prior to use.

c) Regeneration of oil

Only batch regeneration is acceptable. The oil shall be regenerated batch-wise to comply in all respects with table 14 or 15 and be tested to the requirements of table 14 or 15, with the exception that prior to use, the oil shall comply with the dielectric strength and water content requirements of this document. Certification of compliance shall be kept on each batch of oil regenerated for audit purposes.

Note: Irrespective of who supplies the oil, the oil will be tested and certified by a SANAS accredited laboratory for the relevant tests by the entity contracted to supply the oil prior to Eskom accepting the oil; test set 4 shall be applied.

3.5 Electrical equipment classification

In order for this part of 240-75661431 to be applicable to all electrical equipment in industry, classification of electrical equipment is necessary. The classification shown in table 4 will apply (Ref 1).

Table 4: The classification of electrical equipment

Category	**Classification**	**Recommended Oil**
Category O	Power transformers and reactors with a nominal system voltage ≥ 400 kV.	Inhibited Oil (Type I)
Category A	Power transformers and reactors with a nominal system voltage > 132 kV and < 400 kV. Also includes power transformers of any related voltage where continuity of supply is vital and similar equipment for special applications where equipment is required to operate under onerous conditions.	Inhibited Oil (Type I)

Category	**Classification**	**Recommended Oil**
Category B	Power transformers and reactors with a nominal system voltage ≥ 44 kV and ≤ 132 kV (other than those in Category A).	Uninhibited oil (Type U) (1)
Category C	Power transformers and reactors for medium voltage and low-voltage auxiliary, neutral earthing compensators, neutral earthing resistors, earthing resistors and earthing transformers, including diverter tanks of on-load tap changers application, e.g. of nominal system voltages < but excluding 44 kV and traction transformers (other than those in Category A).	Uninhibited oil (Type U)
Category D	Instrument, bushing, or protection transformers and oil-filled circuit-breakers with a nominal system voltage > 132 kV.	Uninhibited oil (Type U)
Category E	Instrument, bushing, or protection transformers with a nominal system voltage ≤ 132 kV. Oil-filled circuit-breakers with a nominal system voltage > 44 kV ≤ 132 kV.	Uninhibited oil (Type U)
Category F	Diverter tanks of on-load tap changers, including combined selector/diverter tanks and transformers with a nominal system voltage ≥ 44 kV.	Uninhibited oil (Type U) (1)
Category G	Oil-filled circuit-breakers with a nominal system voltage > 11 kV ≤ 44 kV.	Uninhibited oil (Type U)
Category H	Oil-filled switches, a.c. metal-enclosed switchgear and control gear with a nominal system voltage ≤ 11 kV.	Uninhibited oil (Type U)

Note 1: Type I or Type U classification may need to be altered according to user requirements.

Note 2: Separated selector tanks of on-load tap changers belong to the same class as the transformer that they are installed on.

Note 3: Oil-impregnated paper bushings and other hermetically sealed units will form part of Category D. Inception testing will be performed on these units and thereafter testing will only be performed when these units are out of service. No intrusive testing will be performed on these units.

Note 4: Regardless of the size or voltage of a unit, a risk assessment, or strategic consideration, may justify condition monitoring frequency or analyses requirements of a higher classification.

Note 5: For practical reasons, some owners of electrical equipment can decide that their equipment up to 1 MVA are not included in this classification. Routine monitoring programmes cannot be considered economical for this type of equipment.

3.6 Oil requirements before commissioning

3.6.1 Oil can enter the process as virgin oil supplied to a site, or as oil that has been recycled through a regeneration process, or as oil supplied in the equipment when purchased new or after a repair. There may thus be slight differences in the oil in different items of equipment. Regenerated oil may contain low levels of PCB since nearly all the oil in South African equipment contains low levels of PCB contamination. New or regenerated oil that has been placed in the equipment will contain tiny particles due to the exposure to the cellulose insulation. It is hence vital that the various stages of oil life be defined by different applicable criteria.

Tables 5, 6, 7, 14 & 15 show recommended limits for the various oil types, given the process background. These are the requirements that must be met when oil is in the last container before filling the intended unit. Once the oil is transferred to another container, the results are no longer valid until confirmed on a new container. There is however also limits on delivery as indicated in the tables.

Note: All oil should be degassed and tested prior to filling to avoid any doubt or concern after energising due to remnant gas. (See table 8).

3.7 Additive and formulation changes

3.7.1 The supplier shall notify and declare to the EIOSC any formulation changes that is introduced as this may affect the seals, gaskets, insulation or cooling performance and/or its compatibility with existing equipment and/or existing insulating oil and describe the nature of the change.

Compatibility testing, due to any of the above condition shall be carried out by Eskom at the cost of the supplier.

3.7.2 The supplier shall inform and declare to EIOSC any additives and the nature of the additive in the oil. Consideration shall be given to the need of a monitoring and replenishment program, the removal of the additive from the oil due to regeneration, in-line drying units as well as the reaction of these products with seals, gaskets, paints and other material and compounds present in the oil. The use of these additives in switchgear will also be assessed.

3.8 Insulating oil purchase requirements

Table 5: Recommended limits for oil properties of new (virgin) inhibited oils (Type I)

1	2	3	4
Oil	**Unit**	**Specification**	**Reference and/or test method**
Oil type		**Naphthenic Type I**	**(Type I) Inhibited**
Colour	ISO units	≤ 0.5 max	ASTM D1500
Inhibitor	%	Inhibited (see Anti-oxidant additives)	IEC 60666
Appearance		Clear, free of sediment and suspended matter	IEC 60422
Density @ 20 °C	kg/dm^3	≤ 0.895 max	ISO 3675 / ISO 12185 / ASTM D1298
Kinematic viscosity @ 40 °C	mm^2/s	≤ 12 max	ASTM D445 / ISO 3104
Flash point	ºC	≥ 140 min	ASTM D93 / ISO 2719 (closed cup)
Pour point	ºC	≤ –20 max	ASTM D97
Aromatic content	%	6 to 14 max	ASTM D2140 / IEC 60590
Total fufural and furans	mg/kg	0.1 max	IEC 61198
Polyaromatic hydrocarbons	%	≤ 3.0 max	BS 2000 / IP 346
Aniline point	°C	63 to 84	ASTM D611
Interfacial tension @ 25 ºC	mN/m	≥ 40 min	ASTM D971
Neutralization value	mg KOH/g	≤ 0.01 max	IEC 62021-1
Corrosive sulphur		Non-corrosive	IEC 62535
Moisture	mg/kg	≤ 10 max (1) ≤ 20 max (2) ≤ 10 max (3)	IEC 60814 and ASTM D1533
Anti-oxidant additives	% by mass	0.3 min – 0.4 max	IEC 60666
Oxidation stability RPVOT	minutes	220 min	ASTM D2112
Dielectric strength	kV/2.5 mm	≥ 70 min (1)	IEC 60156

1	2	3	4
Oil	**Unit**	**Specification**	**Reference and/or test method**
		≥ 60 min (2) ≥ 70 min (3)	
Dissipation factor @ 90 ºC		≤ 0.005 max	BS 5737 / IEC 61620 / IEC 60247
Gassing tendency	mm^3/min	≤ +10	IEC 60628 (Method A)/ASTM D2300
Maximum particulate contamination per 100 ml Particles : > 6 µm and > 14 µm	Prior to filling:	(ISO rating) 11/8 ± 1/1 (4) Max 12/9	ISO 4406 (1999)/IEC 60970/IEC 60422
	On Delivery :	(ISO rating) 16/13 ± 1/1 (4) Max 17/14	
Silicon/silicone Content	ppm	Not detectable (< 2)	ASTM D6595
Polychlorinated biphenyl	mg/kg	Not detectable (≤ 1)	IEC 60619 / EPA 600 / ASTM D4059
Note 1: Prior to transportation **Note 2:** On delivery **Note 3:** Prior to filling **Note 4:** The uncertainty of measurement.			

Table 6: Recommended limits for oil properties of new (virgin) oil for uninhibited oils of units ≤ 132kV (Type U)

1	2	3	4
Oil	**Unit**	**Specification**	**Reference and/or test method**
Oil type		Naphthenic Type U	(Type U) Uninhibited
Colour	ISO units	≤ 0.5 max	ASTM D1500
Inhibitor		Uninhibited	IEC 60666
Appearance		Clear, free of sediment and suspended matter	IEC 60422
Density @ 20 °C	kg/dm^3	≤ 0.895 max	ISO 3675 / ISO 12185 / ASTM D1298
Kinematic viscosity @ 40 °C	mm^2/s	≤ 12 max	ASTM D445 / ISO 3104
Flash point	ºC	≥ 140 min	ASTM D93 / ISO 2719 (closed cup)
Pour point	ºC	≤ –20 max	ASTM D97
Aromatic content	%	6 to 14 max	ASTM D2140 / IEC 60590
Total fufural and furans	mg/kg	0.1 max	IEC 61198
Polyaromatic hydrocarbons	%	≤ 3.0 max	BS 2000 / IP 346

1	2	3	4
Oil	**Unit**	**Specification**	**Reference and/or test method**
Aniline point	°C	63 to 84	ASTM D611
Interfacial tension @ 25 ºC	mN/m	≥ 40 min	ASTM D971
Neutralization value	mg KOH/g	≤ 0.01 max	IEC 62021-1
Corrosive sulphur		Non-corrosive	IEC 62535
Moisture	mg/kg	≤ 10 max (1) ≤ 20 max (2) ≤ 10 max (3)	IEC 60814 / ASTM D1533
Anti-oxidant additives	% by mass	No additives	IEC 60666
Oxidation stability acidity after 164 h @ 120 ºC	mg KOH/g	≤ 1.2 max	IEC 61125 method C
Oxidation stability sludge after 164 h@ 120 ºC	% by mass	≤ 0.8 max	IEC 61125 method C
Dielectric strength	kV/2.5 mm	≥ 70 min (1) ≥ 60 min (2) ≥ 70 min (3)	IEC 60156
Dissipation factor @ 90 ºC		≤ 0,005 max	BS 5737 / IEC 61620 / IEC 60247
Gassing tendency	mm^3/min	≤ +10	IEC 60628 (method A)/ASTM D2300
Maximum particulate contamination per 100 ml Particles : > 6 µm and > 14 µm	Prior to filling :	(ISO rating) 11/8 ± 1/1 (4) Max 12/9	ISO 4406 (1999)/IEC 60970/IEC 60422
	On Delivery :	(ISO rating) 16/13 ± 1/1 (4) Max 17/14	
Silicon/silicone Content	ppm	Not detectable (< 2)	ASTM D6595
Polychlorinated biphenyl	mg/kg	Not detectable (≤ 1)	IEC 60619 / EPA 600 / ASTM D4059
Note 1: Prior to transportation **Note 2:** On delivery **Note 3:** Prior to filling **Note 4:** The uncertainty of measurement.			

Table 7: Recommended limits for oil properties of new (virgin) oil for uninhibited oils of units >132kV (Type U)

1	2	3	4
Oil	**Unit**	**Specification**	**Reference and/or test method**
Oil type		Naphthenic Type U	(Type U) Unihibited
Colour	ISO units	≤ 0.5 max	ASTM D1500

Inhibitor		Uninhibited	IEC 60666
Appearance		Clear, free of sediment and suspended matter	IEC 60422
Density @ 20 ℃	kg/dm^3	≤ 0.910 max	ISO 3675 / ISO 12185 / ASTM D1298
Kinematic viscosity @ 40 ℃	mm^2/s	≤ 11 max	ASTM D445 / ISO 3104
Flash point (closed cup)	ºC	≥ 140 min	ASTM D93 / ISO 2719
Pour point	ºC	≤ –20 max	ASTM D97
Aromatic content	%	6 to 14 max	ASTM D2140 / IEC 60590
Total fufural and furans	mg/kg	0.1 max	IEC 61198
Polyaromatic hydrocarbons	%	≤ 3.0 max	BS2000 / IP 346
Aniline point	°C	63 to 84	ASTM D611
Interfacial tension @ 25 ºC	mN/m	≥ 40 min	ASTM D971
Neutralization value	mg KOH/g	≤ 0.01 max	IEC 62021-1
Corrosive sulphur		Non-corrosive	IEC 62535
Moisture	mg/kg	≤ 10 max (1) ≤ 20 max (2) ≤ 10 max (3)	IEC 60814 / ASTM D1533
Anti-oxidant additives	% by mass	No additives	IEC 60666
Oxidation stability acidity after 164 h @ 110 ºC	mg KOH/g	≤ 0.6 max	ASTM D2440-2004
Oxidation stability sludge after 164 h @ 110 ºC	% by mass	≤ 0.3 max	ASTM D2440-2004
Dielectric strength	kV/2.5 mm	≥ 70 min (1) ≥ 60 min (2) ≥ 70 min (3)	IEC 60156
Dissipation factor @ 90 ºC		≤ 0.005 max	BS 5737 / IEC 61620 / IEC 60247
Gassing tendency	mm^3/min	≤ +10	IEC 60628 (method A)/ASTM D2300
Maximum particulate contamination per 100 ml Particles : > 6 µm and > 14 µm	Prior to filling :	(ISO rating) 11/8 ± 1/1 (4) Max 12/9	ISO 4406 (1999) / IEC 60970/IEC 60422
	On Delivery :	(ISO rating) 16/13 ± 1/1 (4) Max 17/14	
Silicon/silicone Content	ppm	Not detectable (< 2)	ASTM D6595
Polychlorinated biphenyl	mg/kg	Not detectable (≤ 1)	IEC 60619 / EPA 600 / ASTM D4059

Note 1: Prior to transportation

Note 2: On delivery

Note 3: Prior to filling

Note 4: Due to the uncertainty of measurement the standard indicates an unacceptable level.

3.8.1 Gas in oil limits

In essence there should be no gases present in new or regenerated oil. However, due to the sampling and testing parameters some traces of these gases may present in the oil when tested.

The table below indicates the acceptable limits for all oil commencing, oil returning to service after a repair and oil that remains in new units following factory testing.

Table 8: Recommended gas in oil limits

Gas	Symbol	Detected new oil (vpm)	Oil returning to service (vpm) (2, 3) IEEE C57-104	Units after factory test (vpm) (1)
Hydrogen	H_2	15 max	100 max	100 max
Oxygen	O_2	< 10000		
Nitrogen	N_2	< 30000		
Methane	CH_4	4 max	120 max	120 max
Carbon Monoxide	CO	15 max	350 max	350 max
Carbon Dioxide	CO_2	< 150		
Ethylene	C_2H_4	1 max	50 max	50 max
Ethane	C_2H_6	1.5 max	65 max	65 max
Acetylene	C_2H_2	0.5 max	1 max	1 max

Note 1: New oil and new units delivered with oil should normally contain non-detectable levels of hydrogen and hydrocarbon gases. Low levels of these gases should be removed by a degassing process, however if this cannot be done, the values achieved should be viewed as the base line values for trending purposes.

Note 2: Oil removed from a unit for repair purposes may contain gases due to the fault situation. The presence and circumstances as well as type and amount of these gases should be considered on a case by case basis. The oil should not be condemned based on table 8, consultation with a specialist in cases such as these are strongly recommended. The gas levels detected prior energising must be used as the baseline.

Note 3: Degassing of the oil is required to achieve the listed values as per table 8. Degassing should be performed prior to introduction or re-introduction into the transformer's tank or while the oil is being processed in the tank. After a fault or repair there are normally residual gases present in the oil and this gas should be removed to obtain a low base line. However, due to other factors this may not be practical, thus if the oil is not degassed it is recommended that a base line sample is taken prior to the transformer being re energised.

3.8.2 Regeneration of oil

In the interests of keeping the oil pool's integrity the following testing shall be applied prior to the oil being regenerated. Oil not conforming to the limits stated in the table below shall be disposed of following the prescribed disposal procedures.

Note: All used oil originating from tap changers or switchgear will be sold as scrap oil not to be re-used as transformer oil. This oil has been subjected to extreme conditions and is thus considered as expended.

Table 9: Criteria "scrap oil" should comply with to be regarded as suitable for regeneration

Test description	Unit	Specification	Test method/Reference
Polychlorinated biphenyl	ppm	≤ 20 (1)	EPA 600
Silicon contamination	ppm	< 3 (2)	ASTM D6595
Foaming @ end of 5 minutes	ml	300/0	ASTM D892-03
Acidity	mg KOH/g	0.3	IEC 62021-1

Test description	Unit	Specification	Test method/Reference
Polyaromatic hydrocarbon	%	≤ 3.0 max	BS 2000 part 346
Inhibitor Content (4)	% by mass	Dependant on Type - No additives Type U or trace amounts of inhibitor Type I	IEC 60666
Passivator	ppm	Not detected (5)	IEC 60666
Corrosive sulphur		Non-corrosive (3)	IEC 62535

Note 1: Refer to the Eskom 240-84908008 Polychlorinated biphenyl Phase-out Standard.

Note 2: Higher values may be accepted subject to the foaming tests being acceptable.

Note 3: Analyse oil for the presence of corrosive sulphur and if positive scrap the oil.

Note 4: When the base oil was operated with insufficient inhibitor the condition may not allow the oil to be regenerated economically.

Note 5: Analyse oil for passivator to determine levels and if present scrap the oil.

Table 10: Oil removed from service prior to re-conditioning (filtration or regeneration)

Test description	Unit	Specification	Test method/Reference
Polychlorinated biphenyl	ppm	≤ 20 (1)	EPA 600
Silicon contamination	ppm	< 3 (2)	ASTM D6595
Foaming @ end of 5 minutes	ml	300/0	ASTM D892-03
Acidity	mg KOH/g	> 0.12 Regenerate the oil	IEC 62021-1
Polyaromatic hydrocarbon	%	≤ 3.0 max	BS 2000 part 346
Interfacial Tension	mN/m	≤ 30 Filter the oil ≤ 22 Regenerate the oil	ASTM D971
Dissipation factor at 90 °C		> 0.06 max. Regenerate the oil	BS 5737 / IEC 61620 / IEC 60247
Inhibitor Content (4)	% by mass	Dependant on Type - No additives Type U or inhibited Type I	IEC 60666
Passivator content (5)	ppm	Only if passivator is added Minimum level < 25 ppm	IEC 60666
Dielectric strength (6)	kV/2.5 mm	< 60 min < 50 min	IEC 60156
Moisture (6)	mg/kg	> 20 max	IEC 60814 / ASTM D1533
Corrosive sulphur		Non-corrosive (3)	IEC 62535

Note 1: Refer to the Eskom 240-84908008 Polychlorinated Biphenyl Phase-out Standard.

Note 2: Higher values may be accepted subject to the foaming tests being acceptable.

Note 3: Consider scrapping or re-passivation of the oil.

Note 4: When the base oil was operated with insufficient inhibitor the condition may not allow the oil to be regenerated economically.

Note 5: Analyse oil for passivator to determine levels and scrap oil or re-passivate after regeneration.

Note 6: Subject to transformer Category as per Table 4 and Table 19.

3.8.3 Guideline on the evaluation of in-service oil condition for maintenance intervention

The mineral insulating oil is used in transformers and reactors mainly for insulating purposes. In transformers (equally in reactors), oil is used in conjunction with the paper to form the insulation system. However, oil is not as resilient as the oil-impregnated paper. The dielectric constant of oil is less than that of paper so that the oil tends to be more stressed than the paper for the AC voltages. During the service life of a transformer this insulating oil will age chemically. The aged oil would have lost some of its insulating characteristics and/or possessing some chemical substances (e.g. the acid) that are harmful to the solid insulation. If these changes in the oil properties and condition are not carefully controlled and managed, they can easily cause a transformer failure.

Note: It is strongly recommended that these aspects should not be considered in isolation but other transformer related and plant health conditions should also be taken into account prior to embarking on any intervention.

3.8.3.1 Scoring

The scoring shall be derived as given in the table below:

Table 11: Plant Health Indicator scoring

Factors	**Indicators**	**Specifics**		**Score**				
				0	**1**	**2**	**3**	**Units**
Harmful by-products	Acidity			< 0.1	0.1	0.15	0.2	mg KOH/g
	Sludge			None	Traces	Present	Significant	-
Other by-products	Furans	Furanics in Oil	Rate	< 0.05	0.050	0.075	0.100	mg/kg/year
	IFT			> 40	40	30	22	Dynes/cm
	Colour			< 5	5	6	> 6	-
	Tan delta			< 0.15	0.15	0.2	0.3	%
Corrosive sulphur				None		Corrosive	Passivated Previously corrosive	

3.8.3.2 Weighting

The evaluation of oil condition shall be decided on the following parameters and the given weighting

Table 12: Parameter Weighting

Ageing Parameter	**Weight in**
Acid	25 %
Sludge	20 %
Corrosive Sulphur	20 %
Dissipation factor (Tan delta) / Resistivity	15 %
IFT	15 %
Colour	5 %

3.8.3.3 Risk Rating

The rating of the oil risk shall be determined by multiplying each ageing parameter score by the corresponding weight. The action required will be as follows:

Table 13: Parameter risk rating

Risk Rating (R)	Action Required in terms of oil
R ≤ 0.25	Oil is usable, passivate if corrosive and monitor as per Table
0.25 < R ≤ 0.8	Oil is usable but a plan is required within the next 5 years, passivate if corrosive
0.8 < R ≤ 1.6	Oil must be regenerated and passivated if corrosive
R > 1.6	The oil must be scrapped and be replaced with new oil

Note: No matter what is the level on the other parameters, if the oil is corrosive and is going to be re-used or remain in service, it must be passivated.

For regenerating the oil, the time and the cost should be weighed against those of buying new oil plus the criticality of the unit to return into service.

See Annex B for examples of calculations.

Table 14: Recommended limits for oil properties of regenerated oils (previously inhibited) Type I

Oil	Unit	Specification	Reference and/or test method
Oil type		Naphthenic Type I	(Type I) Inhibited
Colour	ISO units	≤ 1.0 max	ASTM D1500
Appearance		Clear, free of sediment and suspended matter	IEC 60422
Density @ 20 ℃	kg/dm^3	≤ 0.895 max	ISO 3675 / ISO 12185 / ASTM D1298
Kinemetic viscosity @ 40 ℃	mm^2/s	≤ 16,5 max	ASTM D445 / ISO 3104
Flash point	ºC	≥ 140 min	ASTM D93 / ISO 2719 (closed cup)
Pour point	ºC	≤ – 20 max	ASTM D97
Aromatic content	%	6 to 14 max	ASTM D2140 / IEC 60590
Total fufural and furans	mg/kg	0.1 max	IEC 61198
Polyaromatic hydrocarbons	%	≤ 3.0 max	BS2000 / IP 346
Aniline point	°C	63 to 84	ASTM D611
Interfacial tension @ 25 ºC	mN/m	≥ 40 min.	ASTM D971
Neutralization value	mg KOH/g	≤ 0,03 max.	IEC 62021-1
Corrosive sulphur		Non-corrosive (7)	IEC 62535
Moisture	mg/kg	≤ 10 max (1) ≤ 20 max (2) ≤ 10 max (3, 4, 5, 6)	IEC 60814 / ASTM D1533
Anti-oxidant additives	% by mass	Re inhibited to 0.4 %	IEC 60666
Oxidation stability after addition of Inhibitor	minutes	220 min	ASTM D2112
Passivation (7)	ppm	100 ppm	IEC 60666
Dielectric strength	kV/2.5 mm	≥ 70 min (1) ≥ 60 min (2) ≥ 70 min (3, 4, 5, 6)	IEC 60156

Oil	Unit	Specification	Reference and/or test method
Dissipation factor @ 90 ºC		≤ 0,005 max	BS 5737 / IEC 61620 / IEC 60247
Maximum particulate contamination per 100 ml Particles : > 6 µm and > 14 µm	Prior to filling :	(ISO rating) 11/8 ± 1/1 (9) Max 12/9	ISO 4406 (1999) / IEC 60970/IEC 60422
	On Delivery :	(ISO rating) 16/13 ± 1/1 (9) Max 17/14	
Silicon/silicone Content	ppm	< 3 ppm	ASTM D6595
Polychlorinated biphenyl	mg/kg	≤ 20 max(8)	IEC 60619 / EPA 600 / ASTM D4059

Note 1: Prior to transportation
Note 2: On delivery
Note 3: Prior to filling
Note 4: After circulation
Note 5: Before top up
Note 6: After dry out
Note 7: Older oils may have a corrosive sulphur component that is not removed in the regeneration process. Consider adding a passivator. Or if the oil was passivated previously, the oil must have the passivator re-introduced.
Note 8: In the interests of minimising the Polychlorinated biphenyl levels in the electricity supply industry any oil that is regenerated must have a contamination level of ≤ 20 ppm prior the regeneration process. (Refer to the Eskom 240-84908008 Polychlorinated Biphenyl Phase-out Standard).
Note 9: Due to the uncertainty of measurement the standard indicates an unacceptable level.

Table 15: Recommended limits for oil properties of regenerated oil (previously uninhibited) (Type U)

Oil	Unit	Specification	Reference and/or test method
Oil type		Naphthenic Type U	(Type U) Uninhibited
Colour	ISO units	≤ 1.0 max	ASTM D1500
Appearance		Clear, free of sediment and suspended matter	IEC 60422
Density @ 20 ℃	kg/dm^3	≤ 0.895 max	ISO 3675 / ISO 12185 / ASTM D1298
Kinemetic viscosity @ 40 ℃	mm^2/s	≤ 16,5 max	ASTM D445 / ISO 3104
Flash point	ºC	≥ 140 min	ASTM D93 / ISO 2719 (closed cup)
Pour point	ºC	≤ – 20 max	ASTM D97
Aromatic content	%	6 to 14 max	ASTM D2140 / IEC 60590
Total fufural and furans	mg/kg	0.1 max	IEC 61198
Polyaromatic hydrocarbon	%	≤ 3.0 max	BS2000 / IP 346
Aniline point	°C	63 to 84	ASTM D611
Interfacial tension 25 ºC	mN/m	≥ 40 min	ASTM D971
Neutralization value	mg KOH/g	≤ 0.03 max	IEC 62021-1

Oil	Unit	Specification	Reference and/or test method
Corrosive sulphur		Non-corrosive (7)	IEC 62535
Moisture	mg/kg	≤ 10 max (1) ≤ 20 max (2) ≤ 10 max (3, 4, 5, 6)	IEC 60814 / ASTM D1533
Anti-oxidant additives	% by mass	No additives	IEC 60666
Passivation(7)	ppm	100 ppm	IEC 60666
Oxidation stability acidity after 164 h @ 120 ºC	mg KOH/g	≤ 1.2 max	IEC 61125 method C
Oxidation stability sludge after 164 h @ 120 ºC	% by mass	≤ 0,8 max	IEC 61125 method C
Dielectric strength	kV/2.5 mm	≥ 70 min (1) ≥ 60 min (2) ≥ 70 min (3, 4, 5, 6)	IEC 60156
Dissipation factor @ 90 ºC		≤ 0,005 max	BS 5737 / IEC 61620 / IEC 60247
Maximum particulate contamination per 100 ml Particles : > 6 µm and > 14 µm	Prior to filling :	(ISO rating) 11/8 ± 1/1 (9) Max 12/9	ISO 4406 (1999) / IEC 60970 / IEC 60422
	On Delivery :	(ISO rating) 16/13 ± 1/1 (9) Max 17/14	
Silicon/Silicone Content	ppm	< 3 ppm	ASTM D6595
Polychlorinated biphenyl	mg/kg	≤ 20 max (8)	IEC 60619 / EPA 600 / ASTM D4059

Note 1 Prior to transportation

Note 2: On delivery

Note 3: Prior to filling

Note 4: After circulation

Note 5: Before top up

Note 6: After dry out

Note 7: Older oils may have a corrosive sulphur component that is not removed in the regeneration process. Consider adding a passivator. Or if the oil was passivated previously, the oil must have the passivator re introduced.

Note 8: In the interests of minimising the Polychlorinated biphenyl levels in the electricity supply industry any oil that is regenerated must have a contamination level of ≤ 20 ppm prior the regeneration process. (Refer to 240-84908008, Eskom Polychlorinated Biphenyl Phase-out Standard).

Note 9: Due to the uncertainty of measurement the standard indicates an unacceptable level.

3.8.3.4 Only virgin oil shall be used when equipment is being topped up, particularly in equipment that contains new paper insulation.

3.8.3.5 Under no circumstances shall PCB values be increased by adding oil with a greater PCB concentration than the existing concentration level in any item of equipment.

3.8.3.6 Under no circumstances shall PCB values be allowed to increase in the regenerated pool by adding oils of higher PCB concentration than the existing concentration level in the oil pool.

3.8.3.7 Under no circumstances shall virgin oil (zero ppm PCB) be used to dilute PCB values in contaminated oil in accordance with SANS 290.

Note: Used oil shall be disposed of according to the approved Eskom commercial process.

Table 16: Recommended limits for new mineral oil after filling, in new / refurbished /stored electrical equipment prior to energising

Parameter(s)	Unit	Categories C, G (H where applicable)	Categories O, A, B, D, E, F
Appearance		Clear, free of sediment and suspended matter	Clear, free of sediment and suspended matter
Colour (1)	ISO scale	< 2	< 1.5
Interfacial tension (1) **at 25 °C**	mN/m	≥ 35	≥ 35
Neutralization value (1) **(acidity)**	mg KOH/g	≤ 0.03	≤ 0.03
Dissolved gas analysis	ppm	See Table 8	See Table 8
Moisture (2) (not normalised)	mg/kg	≤ 20 ≤ 30 (3)	≤ 10
Dielectric strength (2)	kV/2.5 mm	≥ 40 ≥ 30	≥ 70 ≥ 60 (4)
Resistivity (1) **at 90 °C**	GΩm	> 10	> 10
Dissipation factor (1) **at 90 °C and 40 Hz – 60 Hz**		≤ 0.015	≤ 0.010
Total fufural and furans (1)	mg/kg	Not detectable	Not detectable
Maximum particulate contamination per 100 ml (1, 6)	Particles : > 6 µm and > 14 µm	(ISO rating) 14/10 ± 1/1 (7) Max 15/12	(ISO rating) 14/10 ± 1/1 (7) Max 15/12
Polychlorinated biphenyl (1)	mg/kg	≤ 20 (5)	≤ 20 (5)
Inhibitor present (8)	FTIR	Yes or No	Yes
Oil Fingerprint – verify brand/product		Verify only	Verify only
Note: This table applies to new and repaired items of equipment, where repaired items have been decommissioned and complies with the relevant oil type (I or U).			

Parameter(s)	Unit	Categories C, G (H where applicable)	Categories O, A, B, D, E, F
Note 1: Ad hoc. **Note 2**: Compulsory. **Note 3:** Applies to Category H only. **Note 4:** Applies to Category F only. **Note 5**: See the latest national legislation. In the interests of minimising the Polychlorinated biphenyl levels in the electricity supply industry. All oil of 0 – 20 ppm will remain in the system (oil pool), but oil placed into a transformer will not increase the level of the initial PCB Classification. **Note 6**: If for any reason the transformer was filled and the oil was drained into the original “clean container” these values will apply and not as per Tables 5, 6, 7, 14 and 15. **Note 7**: Due to the uncertainty of measurement the standard indicates an unacceptable level. **Note 8:** Inhibitor content presence verified by FTIR, quantified by method IEC 60666 if added			

Table 16: Recommended limits for used mineral oil after filtration only

Parameter(s)	Unit	Categories C, G (H where applicable)	Categories O, A, B, D, E, F
Appearance		Clear, free of sediment and suspended matter	Clear, free of sediment and suspended matter
Colour $^{(1)}$	ISO scale	< 2	< 1.5
Interfacial tension $^{(1)}$ at 25 °C	mN/m	≥ 35	≥ 35
Neutralization value $^{(1)}$ (acidity)	mg KOH/g	≤ 0.03	≤ 0.03
Dissolved gas analysis	ppm	See Table 8	See Table 8
Moisture $^{(2)\ (not\ normalised)}$	mg/kg	≤ 20 ≤ 30 $^{(3)}$	≤ 10
Dielectric strength $^{(2)}$	kV/2.5 mm	≥ 40 ≥ 30	≥ 70 ≥ 60 $^{(4)}$
Dissipation factor $^{(1)}$ at 90 °C and 40 Hz – 60 Hz		≤ 0.015	≤ 0.010
Total fufural and furans $^{(1)}$	mg/kg	Not detectable	Not detectable
Maximum particulate contamination per 100 ml $^{(6)}$	Particles : > 6 µm and > 14 µm	(ISO rating) 14/10 ± 1/1 $^{(7)}$ Max 15/12	(ISO rating) 14/10 ± 1/1 $^{(7)}$ Max 15/12
Polychlorinated biphenyl $^{(1)}$	mg/kg	≤ 20 $^{(5)}$	≤ 20 $^{(5)}$
Inhibitor present $^{(1,\ 8)}$	FTIR	Yes	Yes or No
Note: This table applies to in-service and repaired items of equipment, where repaired items have been decommissioned and complies with the relevant oil type (I or U).			

Note 1: This property will not improve with filtration of in-service oil – value before and after filtration will remain the same – even if lower than the listed value

Note 2: Compulsory.

Note 3: Applies to Category H only.

Note 4: Applies to Category F only.

Note 5: See the latest national legislation. In the interests of minimising the Polychlorinated biphenyl levels in the electricity supply industry. All oil of 0 – 20 ppm will remain in the system (oil pool), but oil placed into a transformer will not increase the level of the initial PCB Classification.

Note 6: If for any reason the transformer was filled and the oil was drained into the original "clean container" these values will apply and not as per Tables 5, 6, 7, 14 and 15.

Note 7: Due to the uncertainty of measurement the standard indicates an unacceptable level.

Note 8: Inhibitor content presence verified by FTIR, quantified by method IEC 60666 if added

3.9 Frequency of evaluating oil in service

3.9.1 Oil in service is subjected to various conditions, ranging from copious amounts of oxygen in free-breathing equipment, to very high temperatures in heavily loaded equipment, moisture produced by the deterioration of the oil and the presence of cellulose, and possible leaks etc. All these conditions will affect the properties of the oil, rendering regular in-service assessment of the condition of the oil is imperative.

3.9.2 Eskom's insulating oil analyses or tests are classified as follows:

a) Care; which relates to day to day operation and maintenance of the transformer. The analyses include hydrolysis (moisture in oil), pyrolysis (temperature), relative moisture saturation (derived from moisture) and dielectric strength.

b) Defects Status; which relates to the gassing condition of the transformer. The analyses include hydrogen, methane, ethane, ethylene, acetylene, carbon monoxide and carbon dioxide and derived from the gas analysis, total combustible gas and gas ratios.

c) Age; which relates to the long term ageing effects such as oxygen content. The analyses include depolymerisation (derived from the furanics), oxidation, acidity, sludge, furanic content, interfacial tension, colour and dissipation factor.

Overall score combines Care, Status and Age into a single score using weights for each aspect.

3.9.3 All data pertaining to each transformer are subjected to limits, rules and diagnostics as defined by the user. These rules and diagnostics may be generic for all Eskom transformers. Alarm states are presented in the following colours:

a) Green – good condition; which implies action required

b) Yellow – degradation present or fault developing; which implies check specifics; increase monitoring frequency

c) Red – equipment out of specified limits; which implies a state of alarm

The results shall be interpreted by competent personnel. The interpretation is based on best international and local practices for evaluation of trends, characteristic values for specific types of equipment and oil.

The analyses are performed to assist with risk minimization and management, as well as life cycle analysis. In order to prevent total loss of large or strategic equipment, an ideal situation would be to do continuous monitoring of the equipment by means of on-line monitoring. However, this is a concept that is costly to obtain, maintain and has many practical problems stage, it is further limited to certain analyses, and is still very costly where it does exist. The frequency of analyses is thus dependent on equipment type, strategic nature, voltage, construction and service conditions.

3.9.4 The frequency of testing should increase if certain analyses indicate degradation of the insulation due to reasons such as overloading or faults.

3.9.5 The recommended frequency of insulating oil analyses on electrical equipment (sampling frequency per classification) is shown in table 18.

Table 17: Recommended frequency of insulating oil analyses on electrical equipment (2)

Condition	Category O	Category A	Category B	Category C	Categories D, E, G and H	Category F
After commissioning/ **Re commissioning** **Routine/basic tests** **(Test set 1)**	48 h after, 1 week after, 1 month after, 3 months after	48 h after, 1 week after, 1 month after, 3 months after	48 h after, 1 month after, 3 months after	48 h after, 1 month after, 6 months after	Special request	Annually or risk dependent (DGA – by special request)
Routine/basic tests **(Test set 1)**	6 monthly	6 monthly to yearly	6 monthly to yearly (1)	Yearly (1) or risk dependant	Special request	Special request
Inhibitor (anti-oxidant) additive (part of Test set 2 and 4)	Prior to filling 6 months after filling and every 2 years (if added) as part of LTPH	Prior to filling 6 months after filling and every 2 years (if added) as part of LTPH	Prior to filling (if stipulated)/ every 2 year as part of LTPH /Not tested if not present	Not tested unless inhibitor is introduced.	Not tested	Not tested
Corrosive sulphur & Passivator **(part of Test set 2 and 4)**	1 week after addition 6 months to monitor consumption There after every year or at least as part of LTPH. After filtration or regeneration. (If added)	1 week after addition 6 months to monitor consumption There after every year or at least as part of LTPH. After filtration or regeneration. (If added)	1 week after addition 6 months to monitor consumption There after every year or at least as part of LTPH. After filtration or regeneration. (If added)	1 week after addition 6 months to monitor consumption There after every year or at least as part of LTPH. After filtration or regeneration. (If added)	Not tested	Not tested
Ageing assessment/Long Term Plant Health (LTPH) (Test set 2)	Every second year	Every second year	Dependant on application	Not tested	Not tested	Not tested
Special investigations **(Test set 3)**	Special request	Special request	Special request	Special request	Special request	Special request
Note 1: For practical reasons, some owners of electrical equipment may decide that their equipment is not included in this classification. Routine monitoring programmes may vary depending on economic feasibility studies, but should not exceed a three year interval for this type of equipment. **Note 2:** These frequencies refer to a normal routine test programme and if any of the properties indicate significant deterioration, these periods should be shortened accordingly.						

3.10 Evaluation of oil in service

3.10.1 It is almost impossible to compile a set of regulations that will be applicable to all equipment. Some equipment is more tolerant of unfavourable conditions, where others will be very sensitive. It is always recommended to take a second sample, before taking action, in order to ensure that the results obtained are in actual fact a true reflection of the state of the electrical equipment. The recommended limits and actions for oil in service are shown in table 19.

Note: In order to make an assessment of the oil tests it is recommended that the limits published in table 19 be seen as values that are not desired and in many cases the parameter should be addressed earlier. Refer also to section 3.3.27 on uncertainty of measurement.

Table 19: Recommended limits and actions for oil in service

Analysis	Category	Action limits	Recommended action
Breakdown voltage, kV/2.5 mm	O and A	< 60	Resample and identify any trend. Recondition oil by means of filtration.
	B	< 50	
	F	< 40	
	C	< 30	
Moisture content, mg/kg or ppm (normalised to 20 °C)	O and A	> 10	Resample and identify any trend. Recondition oil by means of filtration or purification (or both).
	B	> 15	
	F	> 25	
	C	> 30	
Acidity, mg KOH/g oil	O and A	> 0.10	Resample and identify any trend. Recondition oil by means of regeneration if IFT, colour and sludge also deteriorate.
	B	> 0.15	
	C	> 0.20	
Passivator	All Categories	< 25 ppm	The passivator needs to be topped up to 100 ppm when the level drops below the prescribed limit.
Anti-oxidant/Inhibitor	O and A$^{(1)}$	< 0.1 %	The inhibitor needs to be topped up to 0.4 % when the level drops below the prescribed limit.
Furanic analysis, mg/kg per year	O and A	Increase of > 0.05 and estimated DP < 300	This process cannot be rectified. Conditions such as high temperature, overloading and high oxygen content should be avoided.
	B and C	Increase of > 0.05 and estimated DP < 250	
Colour and appearance	O and A	Not clear and free of visible contamination	Resample and identify any trend. Recondition oil by means of regeneration if IFT, acid and sludge also deteriorate.
	B and C		
	F		
Dielectric dissipation factor at 90 °C, 40 Hz to 60 Hz	O and A	> 0.1	Resample and identify any trend. Recondition oil by means of regeneration.
	B and C	> 0.2	
Sediment and sludge	O and A	Sediment or precipitable sludge present	Resample and identify any trend. Recondition oil by means of regeneration if IFT, colour and acid also deteriorate.
	B and C	Sediment or precipitable sludge present	

Analysis	Category	Action limits	Recommended action
Interfacial tension, **mN/m at 25 ℃**	O and A	< 22	Resample and identify any trend. Recondition oil by means of regeneration if acid, colour and sludge also deteriorate.
	B and C	< 22	
Particle contamination per 100 ml > 6 µm and > 14 µm	O and A	(ISO rating) 14/10 ± 1/1 (3) Max 15/12	Recondition oil by means of filtration.
	B and C	(ISO rating) 16/13 ± 1/1 (3) Max 17/14	
Polychlorinated biphenyl, mg/kg or ppm (2)	All	> 50 (2)	Dispose of or if an approved process exists then decontaminate and regenerate during repair, and reuse in same equipment. Reclassify after 3 months.
Resistivity GΩm	HVDC units	< 10	Resample and identify any trend. Recondition oil by means of regeneration.

Note 1: Categories D, E, G and H will only be tested on inception and after repair; no intrusive testing will be performed.
Note 2: Depending on application Category B equipment may be included
Note 3: Refer to Eskom 240-84908008 Polychlorinated Biphenyl Phase-out standard.
Note 4: Due to the uncertainty of measurement the standard indicates an unacceptable level.

3.10.2 Normalised moisture

$$f = 2.24e^{(-0.04t_s)}$$

where: f is the correction factor;

t_s is the oil sampling temperature, in degrees Celsius.

Note: This formula is not applicable in the case of temperatures below 20 ℃ or for tap changers, diverters or any other non-paper containing equipment.

In the case of temperatures below 20 ℃, a limit of ≤ 10 ppm moisture applies.

3.10.3 Relative saturation

If a more accurate interpretation is required, the water solubility of that specific oil will be used and the percentage of water saturation can be calculated from that.

To calculate the Relative Saturation value the following calculation is used:

$$RS\ (\%) = \frac{\text{Concentration @ } T_1}{\text{Solubility @ } T_2} \times 100\ \%$$

where: T_1 = Laboratory test Temperature (Normally 22 – 24 ºC)

T_2 = Time of sampling Temperature (i.e. top oil temperature)

The solubility of water in oil at different temperatures follows a logarithmic curve as in the equation below.

$$\text{Log } S_0 = -\frac{1567}{K} + 7.0895$$

The temperature *"K"* is in Kelvin and needs calculated by adding 273 to the transformer top oil temperature at the time of sampling.

$$K= 273 + T_2$$

3.11 Legislation pertaining to Handling and Transportation of oil

New insulating oil and thus also used oil is classified as hazardous according to Regulation (EC) 1272/2008 as amended.

Procedure used to derive the classification according to Regulation (EC) No. 1272/2008 [CLP/GHS] is as follows:

Classification Justification: Asp. Tox. 1, H304

H304 ASPIRATION HAZARD - Category 1, determined by the Calculation method. H304 May be fatal if swallowed and enters airways.

The process involving the conditioning of the handling of in-service or used oil needs to be interpreted in accordance with the **National Environmental Management: Waste Act (NEM:WA) No 59 of 2008,** which defines waste as follows:

'waste' means –

a) any substance, material or object, that is unwanted, rejected, abandoned, discarded or disposed of, or that is intended or required to be discarded or disposed of, by the holder of that substance, material or object, whether or not such substance, material or object can be re-used, recycled or recovered and includes all wastes defined in Schedule 3 to this Act;

It also needs to be read in conjunction with the amendments in which used insulating oil is pre-defined according to:

NATIONAL ENVIRONMENTAL MANAGEMENT: WASTE ACT 59 OF 2008 as amended by: National Environment Laws Amendment Act 14 of 2013 and National Environmental Management: Waste Amendment Act 26 of 2014,

SCHEDULE 3 ; Defined Wastes ; CATEGORY A:

Hazardous Waste - "hazardous waste" means any waste that contains organic or inorganic elements or compounds that may, owing to the inherent physical, chemical or toxicological characteristics of that waste, have a detrimental impact on health and the environment and includes hazardous substances, materials or objects within business waste, residue deposits and residue stockpiles as outlined.

Item 12. Oil wastes and wastes of liquid fuels (except edible oils); (c) waste insulating and heat transmission oils

NEM:WA Government Notice GN 921 prescribes the activities in respect of when a waste management licence is required and includes the following applicable requirements.

(2) The reuse and recycling of hazardous waste in excess of 1 ton per day, excluding reuse or recycling that takes place as integral part of an internal manufacturing process within the same premises.

(4) "The treatment of Hazardous waste in excess of 1 ton per day calculated as monthly average; using any form of treatment excluding the treatment of effluent, waste water or sewage"

NEM:WA Government Notice GN 926, the National Norms and Standards for the storage of waste prescribe that for hazardous waste storage facilities several conditions apply of which the following are most applicable:

5:(1) all new storage facilities to be registered.

7:(3) must have impermeable chemical resistant floors

7:(5) maintain a drainage and containment system

8:(1) must have effective access control

The transportation of oil is also affected by the new legislation. Transportation is covered under SANS 10228, SANS10229 and SANS 10231.

According to the Deputy Director: Dangerous goods Department of Transport; - Oil does classify as Dangerous goods and it falls within class 9 because of it being an environmental hazard.

In terms of Regulation 115 (1)(f), the driver of the Dangerous goods vehicle below 3500 kg does NOT need to carry Professional Driving Permit however, he need to attend training pertaining to dangerous goods at an approved Training Body. The candidate will be issued with a certificate after completion of training. This certificate is valid for 1 year.

Section 45 (1) provides that vehicles with the GVM below and over 3500 kg (light and heavy vehicles) must be registered and licensed as Dangerous goods vehicles and 2 disc's will be issued to the operator/owner which are Licence and Roadworthy Certificates and lastly Operator Card Category "D" and must be displayed on the vehicle.

In conclusion to this background, all personnel working on electrical equipment handling the oil should be trained and competent in the handling of hazardous waste and all drivers of vehicles, transporting oil in excess of 3500 kg should also undergo the necessary training and be in possession of valid certification.

4 Authorisation

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5 Revisions

Date	Rev	Compiler	Remarks
July 2020	2	A. Lombard	This revision revised definitions and includes new methodology, Gassing Tendency value was raised from 5 to 10 mm^3/min, Section 3 updated with latest Eskom procurement process, Table 4 “Class” changed to Category, Table 8 was modified to add two more columns for in/out of service oil and after factory tests, Table 10 and Annex C were added. Section 3.11 was added to address environmental legislation, Long Term Plant Health Indicator (LTPHI) was reviewed to be in line with Eskom practises
July 2014	1	A. Lombard	Process followed in compilation of The Eskom approved transformer oil list Long Term Plant Health Indicator (LTPHI) added

6 Development team (Working Group)

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8 Glossary

energising

soaking, off load, when service voltage is being applied

filtered oil

purified oil, polished or reconditioned oil, oil that has been filtered to improve the dielectric strength as well as decrease the moisture and particulate content

flushing

action of rinsing a drum or sample container with an approximate volume of 10 % of hot finished product

reclassifying

retesting of the oil following actions of reducing (or increasing) the PCB concentration or contamination levels, thereby changing the PCB classification of electrical equipment

special request tests

group of tests required for investigative purposes

topping-up

action of correcting the oil level as specified by the manufacturer

Annex A – Test groupings (Test Sets)

Table A.1: Test Set 1 – Routine/Basic oil analysis

Analysis	Test set	Recommended method of analysis	Sub-clause
Dissolved Gas Analysis (DGA)	1	IEC 60628 / ASTM D3612 method C	3.3.1
Dielectric strength	1	IEC 60156	3.3.2
Moisture content	1	IEC 60814 and ASTM D1533	3.3.3
Acidity	1	IEC 62021-1	3.3.4

Table A.2: Test Set 2 – Long term plant health indicators (LTPHI)

Analysis	Test set	Recommended method of analysis	Sub-clause
Dielectric strength	2	IEC 60156	3.3.2
Moisture content	2	IEC 60814 and ASTM D1533	3.3.3
Acidity	2	IEC 62021-1	3.3.4
Furanic analysis	2	IEC 61198	3.3.5
Colour	2	ASTM D1500	3.3.6
Dielectric dissipation factor (Tan delta)	2	BS 5737 or IEC 61620 and IEC 60247	3.3.7
Sediment and sludge	2	IEC 60422	3.3.8
Passivator content (2)	2	IEC 60666	3.3.24
Interfacial tension	2	ASTM D971	3.3.9
Inhibitor content	2	IEC 60666	3.3.14
NOTE 1: Only if Inhibitor has been added. **NOTE 2**: Only if passivator is added to the oil.			

Table A.3: Test Set 3 – Purchase of new oil

Analysis	Test set	Recommended method of analysis	Sub-clause
Dielectric strength	3	IEC 60156	3.3.2
Moisture content	3	IEC 60814 and ASTM D1533	3.3.3
Acidity	3	IEC 62021-1	3.3.4
Colour	3	ASTM D1500	3.3.6
Dielectric dissipation factor (Tan delta)	3	BS 5737 or IEC 61620 and IEC 60247	3.3.7
Sediment and sludge	3	IEC 60422	3.3.8
Interfacial tension	3	ASTM D971	3.3.9
Particle quantification	3	ISO 4406 (1999)/IEC60970	3.3.10
Polychlorinated biphenyl (PCB)	3	IEC 60619 or EPA 600 or ASTM D4059	3.3.11
Carbon composition	3	ASTM D2140	3.3.15

Analysis	**Test set**	**Recommended method of analysis**	**Sub-clause**
Aromatics	3	ASTM D2140/IEC 60590	3.3.16
Viscosity	3	ASTM D445/ISO 3104	3.3.17
Corrosive sulphur	3	IEC 62535	3.3.12
Aniline point	3	ASTM D611	3.3.18
Silicon/silicone	3	ASTM D6595	3.3.19
Resistivity	3	IEC 60246	3.3.20
Inhibitor content/FTIR verification	3	IEC 60666	3.3.14
Oxidation stability	3	ASTM D2440/IEC61125 Method C /ASTM D2112 (RBOT)	3.3.13
Flash point	3	ASTM D93 /ISO 2719 (Closed Cup)	3.3.21
Density	3	ISO 3675 or 12185/ASTM D1298	3.3.22
Gassing tendency	3	IEC 60628 Method A/ASTM D2300	3.3.23
Passivator content	3	HPLC method (NT 24)	3.3.24
Pour Point	3	ASTM D 97	3.3.33
Polyaromatic hydrocarbons	3	BS 2000 / IP 346	3.3.16 & 3.3.35
Appearance	3	IEC 60422	3.3.6

Table A.4: Test 4 – Quality Assurance

Analysis	**Test set**	**Recommended method of analysis**	**Sub-clause**
Dielectric strength	4	IEC 60156	3.3.2
Moisture content	4	IEC 60814 and ASTM D1533	3.3.3
Acidity	4	IEC 62021-1	3.3.4
Colour	4	ASTM D1500	3.3.6
Appearance	4	IEC 60422	3.3.6
Dielectric dissipation factor (Tan delta)	4	BS 5737 or IEC 61620 and IEC 60247	3.3.7
Sediment and sludge	4	IEC 60422	3.3.8
Interfacial tension	4	ASTM D971	3.3.9
Particle quantification	4	ISO 4406 (1999)/IEC60970	3.3.10
Polychlorinated biphenyl (PCB)	4	IEC 60619 or EPA 600 or ASTM D4059	3.3.11
Corrosive sulphur	4	IEC 62535	3.3.12
Silicon/silicone	4	ASTM D6595	3.3.20
Inhibitor content/FTIR verification	4	IEC 60666	3.3.14
Fingerprinting	4	In house method	3.3.26

Annex B – Examples of determining the oil Risk Rating (R)

Example B1

Parameter	**Results**	**Score**	**Risk Rating (R)**	**(R)**
Acid	0.03	0	0 x 0.25 =0	**0.15** ***Comment: This requires no action***
Sludge	none	0	0 x 0.2	
Corrosive sulphur	Non corrosive	0	0 x 0.2	
Tan delta (dissipation factor) / Resistivity	0.16	1	1 x 0.15	
IFT	42	0	0 x 0.15	
Colour	0	0	0 x 0.05	

Example B2

Parameter	**Results**	**Score**	**Risk Rating (R)**	**(R)**
Acid	0.12	1	1 x 0.25 =0	**0.6**
Sludge	none	0	0 x 0.2	
Corrosive sulphur	Non corrosive	0	0 x 0.2	
Tan delta (dissipation factor)/ Resistivity	0.16	1	1 x 0.15	
IFT	35	1	1 x 0.15	
Colour	5	1	1 x 0.05	

Example B3

Parameter	**Results**	**Score**	**Risk Rating (R)**	**(R)**
Acid	0.18	2	2 x 0.25 =0	**1.95** ***Comment: This requires the oil to be replaced***
Sludge	3	3	3 x 0.2	
Corrosive sulphur	Non corrosive	0	0 x 0.2	
Tan delta (dissipation factor) / Resistivity	0.24	2	2 x 0.15	
IFT	22	3	3 x 0.15	
Colour	6	2	2 x 0.05	

Annex C – ISO cleanliness code vs particle amount in 100 ml sample

Scale number	More Than	Up to and Including
24	8,000,000	18,000,000
23	4,000,000	8,000,000
22	2,000,000	4,000,000
21	1,000,000	2,000,000
20	500,000	1,000,000
19	250,000	500,000
18	130,000	250,000
17	64,000	130,000
16	32,000	64,000
15	16,000	32,000
14	8,000	16,000
13	4,000	8,000
12	2,000	4,000
11	1,000	2,000
10	500	1,000
9	250	500
8	130	250
7	64	130
6	32	64
5	16	32
4	8	16
3	4	8
2	2	4
1	1	2

EXAMPLE: Oil in-service may have an: ISO code of **8/15**

This implies that the code for:

>6 µm particles is **8** and for;

>14 µm particles is **15**

Thus for >14 µm the amount of particles was between 16,000 and 32,000, hence code **15**

And for > 6 µm the amount of particles was between 130 and 250, hence code **8**