



*Mineral insulating oils in electrical
equipment – Supervision and
maintenance guidance
(IEC 60422)*

David Walker – SP Energy Networks, UK
(Tee) ShengJi Tee – SP Energy Networks, UK

1 February 2024

Introduction



IEC IEC 60422

INTERNATIONAL STANDARD
NORME INTERNATIONALE

Edition 4.0 2013
→ Edition 5.0 2024

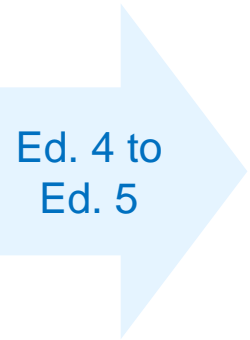
Mineral insulating oils in electrical equipment – Supervision and maintenance guidance
Huiles minérales isolantes dans les matériels électriques – Lignes directrices pour la maintenance et la surveillance

- Revision work commenced on 19 October 2020
- Edition 5.0 CDV approved on 18 July 2023
- In this presentation, we will summarise the changes from Edition 4.0 (2013) to the latest Edition 5.0 (2024)

Summary of Technical Changes

Edition 4

FOREWORD	4
INTRODUCTION	6
1 Scope	8
2 Normative references	8
3 Terms and definitions	9
4 Properties and deterioration/degradation of oil	10
5 Oil tests and their significance	11
6 Sampling of oil from equipment	22
7 Categories of equipment	23
8 Evaluation of mineral insulating oil in new equipment	23
9 Evaluation of oil in service	24
10 Handling and storage	32
11 Treatment	33
12 Replacement of oil in electrical equipment	39
13 Passivation	40
Annex A (informative) Evaluating water in oil and insulation	41
Annex B (informative) Particles	43
Annex C (informative) Test method for determination of sediment and sludge	44
Bibliography	45



Edition 5

FOREWORD	5
INTRODUCTION	7
1 Scope	9
2 Normative references	9
3 Terms and definitions	11
4 Properties and deterioration or degradation of oil	12
5 Categories of equipment	12
6 Sampling of oil from equipment	13
7 In-service oil diagnostic tests	14
8 Evaluation of mineral insulating oil in new equipment	28
9 Evaluation of oil in service	29
10 Interpretation of results	35
11 Handling and storage	45
12 Replacement of oil in electrical equipment	46
13 Addition of metal passivators to in-service oil	47
14 Treatment	47
Annex A (normative) Criteria for reclamation and treatments	58
Annex B (informative) General guideline for moisture %RS for continuous online monitoring	61
Annex C (informative) Normalizing water in oil for comparison and trending	62
Annex D (informative) Material compatibility	64
Annex E (informative) Test method for determination of sediment and sludge	66
Annex F (informative) Contamination of oils with silicone	67
Annex G Bibliography	68

- Oil tests and their significance now called *In-service oil diagnostic tests*.
- Corrective action Table/s now in *Interpretation of results*.
- *Categories of equipment* now updated and repositioned in the document.
- *Treatment* section much larger and repositioned in the document.
- Edition 5 – Four new Annexes added.
- Edition 4 – Annex B Table on particles now removed and replaced with detailed guidance in Section 7 of Edition 5.

Summary of Technical Changes

- This new edition represents a major revision of the fourth edition, bringing this document **in line with the latest developments in oil condition monitoring**.
- **New interpretation tables** have been created, containing limits for oil parameters **specific to plant type** with suggested corrective actions in the tables and new test methods.
- **The action limits for all oil tests have been revised** and changes made where necessary to enable users to use current methodology and comply with requirements and regulations affecting safety and environmental aspects.
- **Category O has been removed** and is now **incorporated within Category A**.
- **Online moisture interpretation** is now incorporated.
- More **guidance on oil treatment (including reclamation criteria)** is now available.
- Guidance has been updated regarding **corrosive sulphur**.
- In addition, this document **incorporates changes introduced in associated standards** (e.g. IEC 60296:2020) since the fourth edition (2013) was published.

Equipment Categorisation

Table 2 – Categories of equipment

Category	Type of equipment
Category O	Power transformers/reactors with a nominal system voltage of 400 kV and above
Category A	Power transformers/reactors with a nominal system voltage above 170 kV and below 400 kV. Also power transformers of any rated voltage where continuity of supply is vital and similar equipment for special applications operating under onerous condition
Category B	Power transformers/reactors with a nominal system voltage above 72,5 kV and up to and including 170 kV (other than those in Category A)
Category C	Power transformers/reactors for MV/LV application e.g. nominal system voltages up to and including 72,5 kV and traction transformers (other than those in Category A). Oil-filled circuit breakers with a nominal system voltage exceeding 72,5 kV. Oil-filled switches, a.c. metal-enclosed switchgear and control gear with a nominal system voltage greater than or equal to 16 kV
Category D	Instrument/protection transformers with a nominal system voltage above 170 kV
Category E	Instrument/protection transformers with a nominal system voltage up to and including 170 kV
Category F	Diverter tanks of on-load tap-changers, including combined selector/diverter tanks
Category G	Oil-filled circuit breakers with a nominal system voltage up to and including 72,5 kV. Oil-filled switches, a.c. metal-enclosed switchgear and control gear with a nominal system voltage less than 16 kV

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

NOTE 2 Oil-impregnated paper bushings and other hermetically sealed equipment may be placed in Category D or E if a routine monitoring programme is desired. The manufacturer's instructions should be referred to.

NOTE 3 Regardless of size or voltage, a risk assessment may justify condition-monitoring techniques usually appropriate to a higher classification.

NOTE 4 For practical and economical reasons, some electrical utilities may decide that their small transformers up to 1 MVA and 36 kV are not included in this classification. Routine monitoring programmes may not be considered economical for this type of equipment. Where a monitoring programme is required for these transformers, the guidelines given for category C should be adequate.



Table 1 – Categories of equipment

Category	Transformers and reactors
Category A	Power transformers and reactors with an U_m above 170 kV. Power transformers of any rated voltage where continuity of supply is vital and similar equipment for special applications operating under onerous condition
Category B	Power transformers and reactors with an U_m above 72,5 kV and up to and including 170 kV (other than those in Category A)
Category C	Power transformers and reactors for MV/LV application, e.g. U_m up to and including 72,5 kV (distribution transformers) and traction transformers (other than those in Category A).
Instrument and protection transformers	
Category D	Instrument and protection transformers with an U_m above 170 kV
Category E	Instrument and protection transformers with an U_m up to and including 170 kV
Tap-changers	
Category F	Diverter tanks of on-load tap-changers, including combined selector and diverter tanks
Circuit breakers and switchgear	
Category G	Oil-filled circuit breakers, oil-filled switches, AC metal-enclosed switchgear and control gear with an U_m exceeding 72,5 kV
Category H	Oil-filled circuit breakers, oil-filled switches, AC metal-enclosed switchgear and control gear with an U_m up to and including 72,5 kV
Oil filled and OIP bushings	
Category K	Bushings with an U_m above 170 kV
Category L	Bushings with an U_m up to and including 170 kV

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

NOTE 2 Regardless of size or voltage, a risk assessment can justify condition-monitoring techniques usually appropriate to a higher classification.

NOTE 3 For practical and economic reasons, some electrical utilities can decide that their small transformers up to 1 MVA and 36 kV are not included in this classification. Routine monitoring programmes can be considered uneconomical for this type of equipment. Where a monitoring programme is required for these transformers, the guidelines given for Category C should be adequate.

NOTE 4 U_m is the highest voltage for equipment. This was referred to as "nominal system voltage" in previous editions.

- **Category O is now incorporated within Category A** (the same application and interpretation of tests even in Ed. 4, 2013).
 - End users with liquid filled electrical equipment operating under special environmental or operating stresses such as solar, offshore, or nominal system voltage of 400 kV or above (Category O transformers in previous edition) should carry out an evaluation as per the guidance above and set sample frequency periods and limit values in accordance with their internal risk assessment and maintenance policy; this can result in more frequent testing or onerous limits than the guidance provided in Table 4 and Table 5 to Table 9.
- **Clearer grouping**, i.e. power transformers and reactors, instrument and protection transformers, CBs, switchgear.
- **Inclusion of oil filled and OIP bushings** (growing interest and knowledge sharing among international community).
- **Clearer definition of voltage reference**, i.e. **highest voltage vs nominal system voltage**.

Frequency of Testing

Table 4 – Recommended frequency of testing ^a

Property ^b	Equipment category ^c							
	O	A	B	C ^d	D ^e	E ^e	F	G
Group 1 (routine tests) ^f – years	1 to 2	1 to 3	1 to 4	2 to 6	1 to 2	2 to 6	2 to 6	2 to 6
Group 2 (complementary tests)	^g							
Group 3 (special investigative tests)	^h							
Group 3 (passivator content)	6 months or less, depending on the rate of decrease and the absolute value.							

^a These proposed periods refer to a normal routine maintenance programme. Should one or more of the measured properties indicate that the oil is in a fair or poor condition or if an abnormal ageing trend is observed, these periods should be shortened according to the importance of the equipment. These periods may also be shortened in the case of oils contaminated by PCB in order to minimize any potential environmental impact caused by malfunctioning equipment.

^b Groups 1, 2 and 3 are defined in Clause 3 and as a footnote to Table 1.

^c Equipment categories are defined in Table 2.

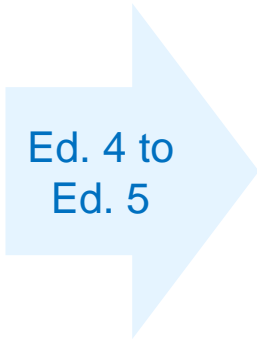
^d See 9.2 d).

^e Categories D and E. After the first sample has been taken, the user, after consultation with the manufacturer and/or laboratory, may decide to lengthen the sampling period.

^f Group 1 tests shall be performed after filling or refilling the transformer, prior to energizing.

^g These tests may be done periodically but less frequently than routine tests. The frequency will depend upon the type of oil, age and equipment. First (benchmark) measurements should be carried out in new or refurbished equipment prior to energization.

^h These are very special tests that need be carried out only under special circumstances.



- Power transformers and reactors: A (>170 kV), B (72.5 kV – 170 kV) and C (≤72.5 kV)
- Instrument and protection transformers: D (>170 kV) and E (≤170 kV)
- Tap-changers: F
- Circuit breakers and switchgear: G (>72.5 kV) and H (≤72.5 kV)
- Oil filled and OIP bushings: K (>170 kV) and L (≤170 kV)

Table 4 – Recommended frequency of testing ^a

Property ^b	Equipment category ^{c i}									
	A	B	C ^d	D ^e	E ^e	F	G	H	K ^e	L ^e
Group 1 (routine tests) ^f – years	1-2	1-4	1-12	1-2	2-6	2-6	2-6	2-12	3-12	3-12
Group 2 (complementary tests)	^g									
Group 3 (special investigative tests)	^h									
Group 3 (passivator content)	6 months or less, depending on the rate of decrease and the absolute value.									

^a These proposed periods refer to a normal routine maintenance programme and for the tests detailed in this document. Should one or more of the measured properties indicate that the oil is in a "Fair" or "Poor" condition or if an abnormal ageing trend is observed, these periods should be shortened according to the importance of the equipment. These periods can also be shortened in the case of oils contaminated with PCBs to minimize any potential environmental impact caused by malfunctioning equipment.

^b Groups 1, 2 and 3 are defined in Clause 3 and as a footnote to Table 2.

^c Equipment categories are defined in Table 1.

^d See 9.2 d).

^e Categories D, E, K and L. After the first sample has been taken, the user, after consultation with either the manufacturer or laboratory, or both, can decide to lengthen the sampling period.

^f Group 1 tests shall be performed after filling or refilling the transformer, prior to energizing.

^g These tests can be done periodically but less frequently than routine tests. The frequency will depend upon the type of oil, age, and equipment. First (benchmark) measurements should be carried out in new or refurbished equipment prior to energization.

^h These are very special tests that need be carried out only under special circumstances.

ⁱ For traction transformers, sampling can be distance based rather than time based.

- Asset owners should set their frequencies based on a thorough **risk assessment** considering their **own unique requirements** and **service conditions** as well as the **equipment manufacturer's maintenance guidance**.
- Users with equipment under **special environmental or operating stresses**, or **nominal system voltage of ≥400 kV** should carry out an evaluation as per the guidance in the text and **set sample frequency periods and limit values in accordance with their internal risk assessment and maintenance policy**; this can result in more frequent testing or onerous limits than the guidance provided.

Application and Interpretation of Tests

Table 5 – Application and interpretation of tests (1 of 4)

Property	Category ^a	Recommended action limits			Recommended action ^{b, c}	Notes
		Good	Fair	Poor		
Colour and appearance	All	Clear and without visible contamination	Dark and/or turbid		As dictated by other tests	Dark colour is a symptom of chemical contamination or ageing. Turbidity is a symptom of high water content
Breakdown voltage (kV)	O, A, D	> 60	50 to 60	< 50	Good: Continue normal sampling.	
	B, E	> 50	40 to 50	< 40	Fair: More frequent sampling. Check other parameters, e.g. water, particle content and perhaps DDF/resistivity and acidity.	
	C	> 40	30 to 40	< 30		
	F	< 30 kV for OLTC in star-point application. < 40 kV for OLTC in delta or line-end application			Poor: Recondition the oil (see 11.2) or, alternatively, if more economical because other tests indicate severe ageing, replace (see Clause 12) or reclaim (see 11.3) the oil combined with subsequent drying procedures	
	G			< 30		

Ed. 4



Ed. 5

Table 5 – Transformers and reactors – Application and interpretation of tests

Water content (mg/kg at transformer operating temperature)

Property	Category ^a	Conditions, limits and recommended actions ^{b, c}				Notes
			Condition: Good	Condition: Fair	Condition: Poor	
Colour	A, B, C	Limits >>	< 2	2 to 6	> 6	Typically, no action should be taken based on colour. Change, specifically rapid change in colour can indicate ageing and should be investigated utilising other tests. Some oils can be dark in colour but be in good condition therefore colour should not be used as an indicator of health.
		Actions >>	No action required, continue normal sampling.	As dictated by other tests.	As dictated by other tests.	
Appearance	A, B, C	Limits >>	Clear, free from sediment and suspended matter.		Either dull or turbid or both	Dull appearance can be a symptom of chemical contamination. Turbidity is a symptom of high water content or indication of material incompatibility or severe contamination from non-soluble materials.
		Actions >>	No action required, continue normal sampling.		As dictated by other tests.	
Breakdown voltage (kV)	A	Limits >>	> 60	50 to 60	< 50	High sampling temperatures (>50 °C) can lead to poor results when evaluated at ambient temperature in the laboratory. In these cases, repeat samples should be taken at lower temperatures. Alternatively, users can refer to Annex C for guidance on normalization of water content and how it can influence breakdown voltage.
	B	Limits >>	> 50	40 to 50	< 40	
	C	Limits >>	> 40	30 to 40	< 30	
		Actions >>	No action required, continue normal sampling.	More frequent sampling. Check other parameters, e.g. water, particle content.	Check the source of water or particulate contamination, resample. If high water content is confirmed, consider drying the solid insulation or filtering for removal and identification of particles.	

- Clearer layout for application and interpretation of tests, with limits and associated actions shown closely.
- More guidance now included in notes for each parameter.
- Separate tables for different equipment categories:
 - Table 5 – transformers and reactors
 - Table 6 – tap-changers
 - Table 7 – Instrument and protection transformers
 - Table 8 – Circuit breakers and switchgear
 - Table 9 – Oil filled and OIP bushings
- Tables provide a form of guidance on limits and condition classification. Local knowledge, users' industrial experience or manufacturer guidance can take precedence.

Application and Interpretation of Tests (Continued)

For completion, these are all the parts within Table 5, applicable to power transformers and reactors

Table 5 – Transformers and reactors – Application and interpretation of tests

Property	Category ^a	Conditions, limits and recommended actions ^{b, c}			Notes	
		Limits >>	Condition: Good	Condition: Fair		Condition: Poor
Colour	A, B, C	Limits >> Actions >>	< 2 No action required, continue normal sampling.	2 to 6 As dictated by other tests.	> 6 As dictated by other tests.	Typically, no action should be taken based on colour. Change, specifically rapid change in colour can indicate ageing and should be investigated utilising other tests. Some oils can be dark in colour but be in good condition therefore colour should not be used as an indicator of health.
Appearance	A, B, C	Limits >> Actions >>	Clear, free from sediment and suspended matter. No action required, continue normal sampling.		Either dull or turbid or both As dictated by other tests.	Dull appearance can be a symptom of chemical contamination. Turbidity is a symptom of high water content or indication of material incompatibility or severe contamination from non-soluble materials.
Breakdown voltage (kV)	A B C	Limits >> Limits >> Limits >> Actions >>	> 60 > 50 > 40 No action required, continue normal sampling.	50 to 60 40 to 50 30 to 40 More frequent sampling. Check other parameters, e.g. water, particle content.	< 50 < 40 < 30 Check the source of water or particulate contamination, resample. If high water content is confirmed, consider drying the solid insulation or filtering for removal and identification of particles.	High sampling temperatures (>50 °C) can lead to poor results when evaluated at ambient temperature in the laboratory. In these cases, repeat samples should be taken at lower temperatures. Alternatively, users can refer to Annex C for guidance on normalization of water content and how it can influence breakdown voltage.
Flash point						inhibited oil that reached fair values has possibly lost its oxidation protection. then be made at which point to reclaim the oil (see 14.4) or, alternatively, if more economical, replace the oil (see Clause 12).
PCBs						inhibition to original base line level based on local experience. Where acidity is > 0,08 mg _{KOH} /g _{oil} or IFT < 28 mN/m, re-inhibition is not effective. Consider reclaiming (see 14.4) or change the oil (see Clause 12).
						Where precipitable sludge is detected, reclaim oil (see 14.4). Alternatively, if more economical, replace the oil (see Clause 12).
						When BDV, acidity and DDF values are near the limits.
						See "

^a Category of eq
^b Ensure sampling
^c No action should the trend of the

^d Acidity values are typical for uninhibited oils. Inhibited oils with "Good" inhibitor content would have lower acidity values which are not expected to reach the "Poor" condition.
^e If the oil test for corrosivity is positive and DBDS is present, follow the recommendations of CIGRÉ Brochures 378:2009 [11] and 625:2015 [12] for the appropriate mitigation actions.



Application and Interpretation of Tests (Continued)

Table 6 – Tap-changers – Application and interpretation of tests

Property	Category ^a	Conditions, limits and recommended actions ^{b, c}			Notes	
			Condition: Good	Condition: Fair		Condition: Poor
Breakdown voltage (kV)	F star point (Y)	Limits >>	≥ 30 kV		If OLTC configuration is not known, then delta or line end guidance should be applied.	
	F delta (Δ) or line-end	Limits >>	≥ 40 kV			
		Actions >>	No action required, continue normal sampling.			
Water content (mg/kg at transformer operating temperature)	F star point (Y)	Limits >>	< 15 mg/kg	15-40 mg/kg	> 40 mg/kg	The value of water content shall be regarded together with the value for breakdown voltage. The value of breakdown voltage is of overriding importance.
	F delta (Δ) or line-end	Limits >>	< 15 mg/kg	15-30 mg/kg	> 30 mg/kg	
		Actions >>	No action required, continue normal sampling.	No action required, continue normal sampling. For vacuum tap-changers, consider more frequent sampling.	Check source of water. Non-vacuum type – Initiate maintenance including oil replacement. Vacuum type – Recondition or replace the oil.	

^a Category of equipment (see Table 1).
^b Ensure sampling was properly done, sampling valve was properly cleaned before sampling (Clause 6) and transportation and storage periods in the laboratory were short.
^c No action should be taken on the basis of one result and one property. All results shall be confirmed by a repeat sample especially if the result appears abnormal compared to the trend of the previous results obtained.

9.4.3 Tap-changers

See Table 6 and Table 5 for guidance. Table 6 provides guidance for parameters specific to vacuum and non-vacuum on-load tap-changers (OLTCs). For vacuum type OLTCs and de-energized tap-changers (DETCs), further guidance on relevant parameters not detailed in Table 6 can be found in Table 5. Values might be different for different types of OLTCs, the manufacturers limits (where available) will prevail.

For vacuum type OLTCs, no regular time or condition-based oil replacement is generally required, and oil ageing should be similar to the oil in the transformer main tank. Therefore, monitoring of acidity, inhibitor content and passivator content is appropriate, as for transformers.

All OLTCs will present a certain amount of sediment in their oil compartment, due to normal abrasive wear. Non-vacuum models can show significant amounts of sediment and sludge, due to contact erosion and oil deterioration which are produced during their normal service life, therefore limit values for colour, appearance, dielectric dissipation factor, resistivity, sediment and sludge cannot be provided.

Vacuum type OLTCs should maintain a high level of oil quality during their whole service life, only particles from mechanical wear should be present. Non-vacuum type OLTCs can present high amounts of particles due to normal contact and mechanical wear; additionally, normal arc breaking activity can produce high levels of carbon within the oil.

Application and Interpretation of Tests (Continued)

Table 7 – Instrument and protection transformers – Application and interpretation of tests

Property	Category ^a	Conditions, limits and recommended actions ^{b, c}				Notes
			Condition: Good	Condition: Fair	Condition: Poor	
Water content (mg/kg at transformer operating temperature)	D	Limits >>	< 20	20 to 30	> 30	The value of water content shall always be assessed together with the value for breakdown voltage.
	E	Limits >>	< 30	30 to 40	> 40	
		Actions >>	No action required, continue normal sampling.	More frequent sampling. Check other parameters, e.g. breakdown voltage, particle content and perhaps DDF or resistivity and acidity.	Check the source of water, resample. Check seals and gaskets, if values are confirmed as above the limits then carry out a risk assessment to confirm if transformer can remain in service.	
Dielectric dissipation factor at 40 Hz to 60 Hz at 90 °C	D	Limits >>	< 0,01	0,01 to 0,10	> 0,10	
	E	Limits >>	< 0,10	0,10 to 0,30	> 0,30	
		Actions >>	No action required, continue normal sampling.	More frequent sampling. Check other parameters.	If values are confirmed as above the limits, then carry out a risk assessment to confirm if transformer can remain in service.	

^a Category of equipment (see Table 1).
^b Ensure sampling was properly done, sampling valve was properly cleaned before sampling (Clause 6) and transportation and storage periods in the laboratory were short.
^c No action should be taken on the basis of one result and one property. All results shall be confirmed by a repeat sample especially if the result appears abnormal compared to the trend of the previous results obtained.

9.4.4 Instrument and protection transformers

See Table 7 and Table 5 for guidance. Table 7 provides guidance for parameters specific to instrument and protection transformers. For guidance on parameters not detailed in Table 7, refer to appropriate category in Table 5.

Normally the amount of oil in instrument transformers is limited, therefore it is not usual to carry out routine sampling.

Where sampling is carried out, the effect on the oil level and pressure should be taken into consideration.

Application and Interpretation of Tests (Continued)

Table 8 – Circuit breakers and switchgear – Application and interpretation of tests

Property	Category ^a	Conditions, limits and recommended actions ^{b, c}				Notes
			Condition: Good	Condition: Fair	Condition: Poor	
Breakdown voltage (kV)	G	Limits >>	> 50	30 to 50	< 30	
	H	Limits >>	> 40	30 to 40	< 30	
			No action required, continue normal sampling.	More frequent sampling. Check other parameters, e.g. water, particle content.	For these switching equipment types, check the source of water or particulate contamination. Resample, if high water content is confirmed, change the oil and repair as required to prevent further occurrence.	
Water content (mg/kg)	G	Limits >>	< 20	20 to 40	> 40	The value of water content shall always be assessed together with the value for breakdown voltage.
	H	Limits >>	< 30	30 to 45	> 45	
		Actions >>	No action required, continue normal sampling.	More frequent sampling. Check other parameters, e.g. water, particle content and perhaps DDF or resistivity and acidity.	For these switching equipment types, check the source of water. Resample, if high water content is confirmed, change the oil and repair as required to prevent further occurrence.	For these switching equipment types, the values of breakdown voltage are of overriding importance.
Acidity ^d (mg _{KOH} /g _{oil})	G, H	Limits >>	< 0,10	0,10 to 0,2	> 0,2	
		Actions >>	No action required, continue normal sampling.	More frequent sampling. Check the presence of sediment and sludge. An inhibited oil that reached fair values has possibly lost its oxidation protection.	Starting from a value of 0,2 and if other tests indicate severe ageing, consider replacing the oil (see Clause 12).	

^a Category of equipment (see Table 1).

^b Ensure sampling was properly done, sampling valve was properly cleaned before sampling (Clause 6) and transportation and storage periods in the laboratory were short.

^c No action should be taken on the basis of one result and one property. All results shall be confirmed by a repeat sample especially if the result appears abnormal compared to the trend of the previous results obtained.

^d Acidity values are typical for uninhibited oils. Inhibited oils with "Good" inhibitor content would have lower acidity values which are not expected to reach the "Poor" condition.

9.4.5 Circuit breakers and switchgear

See Table 8 and Table 5 for guidance. Table 8 provides guidance for parameters specific to circuit breakers and switchgear.

For other parameters not detailed in Table 8, refer to Table 5 Category C for guidance.

Based on knowledge and experience with their specific plant, asset owners operating large fleets can decide to apply different limit values to those detailed in Table 8 and Table 5, or they can opt to routinely change the oil in the equipment as they have determined that it is more economical than managing an oil testing regime, especially at distribution voltages.

Application and Interpretation of Tests (Continued)

Table 9 – Oil filled and OIP bushings – Application and interpretation of tests

Property	Category ^a	Conditions, limits and recommended actions ^{b, c}				Notes
			Condition: Good	Condition: Fair	Condition: Poor	
Breakdown voltage (kV)	K	Limits >>	> 60	40 to 60	< 40	Consider electrical tests, capacitance and power factor to verify bushing condition. Frequent sampling of bushings is generally not recommended see 9.4.6.
	L	Limits >>	> 50	30 to 50	< 30	
		Actions >>	No action required, continue normal sampling.	Check other parameters, e.g. water, particle content. Resample only if deemed required.	Check the source of water or particulate contamination. Resample. Based on all tests carry out risk assessment and remove bushing from service if required.	
Water content (mg/kg)	K	Limits >>	< 10	10 to 20	> 20	Consider electrical tests, capacitance and power factor to verify bushing condition.
	L	Limits >>	< 10	10 to 30	> 30	
		Actions >>	No action required, continue normal sampling.	Check other parameters, e.g. breakdown voltage, particle content and perhaps DDF or resistivity and acidity. Resample only if deemed required.	Check the source of water, resample. Based on all tests carry out risk assessment and remove bushing from service if required.	
Dielectric dissipation factor at 40 Hz to 80 Hz at 90 °C	K	Limits >>	< 0,01	0,01 to 0,10	> 0,10	Consider electrical tests, capacitance and power factor to verify bushing condition.
	L	Limits >>	< 0,10	0,10 to 0,30	> 0,30	
		Actions >>	No action required, continue normal sampling.	Check other parameters. Resample only if deemed required.	If other tests indicate severe ageing, contact the manufacturer.	

^a Category of equipment (see Table 1).
^b Ensure sampling was properly done, sampling valve was properly cleaned before sampling (Clause 6) and transportation and storage periods in the laboratory were short.
^c No action should be taken on the basis of one result and one property. All results shall be confirmed by a repeat sample especially if the result appears abnormal compared to the trend of the previous results obtained.

9.4.6 Oil filled and OIP bushings

See Table 9 and Table 5 for guidance. Table 9 provides guidance for parameters specific to oil filled and oil impregnated bushings (OIP). For guidance on parameters not detailed in Table 9, refer to the appropriate category in Table 5.

Oil sampling is typically performed if other bushing diagnostic methods indicate a problem or have provided an inconclusive result.

Normally the amount of oil in bushings is limited, therefore it is not usual to carry out routine sampling. Users should refer to an approved sampling method before undertaking any sampling works. Where sampling is carried out, the effect on the oil level and pressure should be taken into consideration. Due to the low volumes of oil in bushings, topping up can be required following the taking of samples. Oil sampling from bushings without an oil level gauge is not recommended.

Where oil samples are taken for analysis, tests are typically limited to DGA and water content only.

Bushings flooded with the same oil as in the main tank of the transformer are not covered in Table 9, refer to the appropriate category in Table 5 for guidance.

Application and Interpretation of Tests (Continued)

Expansion of guidance on test parameters. Some notable mentions:

- Colour: Values now provided. Still, colour should not be used as an indicator as some oils can be dark but be in good condition.
- Appearance: Turbidity indicates high water content, material incompatibility or contamination from non-soluble materials.
- Breakdown Voltage (BDV): High sampling temperature (>50 °C) can lead to poor results when evaluated at ambient temperature in the laboratory. Repeat samples at lower temperature recommended.
- Water Content: In the case of “Poor” condition due to high water content in the oil, online monitoring with relative saturation (RS) measurements is recommended. Guidance on RS limits in Annex B.
- Inhibitor Content: Clarification for originally inhibited oils and applicable to reclaimed uninhibited oils that have had inhibitor added.
- Interfacial Tension (IFT): Notes added on its use as a routine test for inhibited oil, but typically not a routine test for uninhibited oil. IFT usefulness during the early life is also mentioned.
- Corrosive Sulphur and Potentially Corrosive Sulphur: Text included more information on corrosive sulphur compounds and potentially corrosive compounds. The need for measuring DBDS in the “Poor” condition.
- Particles: Annex on particles now removed. Text highlights the importance of the type of particles (i.e. iron, aluminium, silver sulphide, fibres, carbon etc.) This can provide more info on the wear status or possible mechanical defects than particle counting.
- Polychlorinated Biphenyls (PCBs): Limits to be subject to local regulations.

Corrosive Sulphur

- Sulphur is always present in mineral insulating oils and some sulphur compounds can be corrosive to metal surfaces.
- Need for differentiating between:
 - **Corrosive sulphur compounds:** elemental sulphur and mercaptans
 - **Potentially corrosive compounds:** disulphides, including DBDS, sulphides (rarely)
 - DBDS had been widely added to mineral insulating oils as an antioxidant between 1989 and 2006.
- Two methods for assessment of corrosive sulphur in oil:
 - These are **IEC 62535** and **DIN 51353**.
 - Both tests shall give a negative result to report an oil as non-corrosive.

IEC 62535:

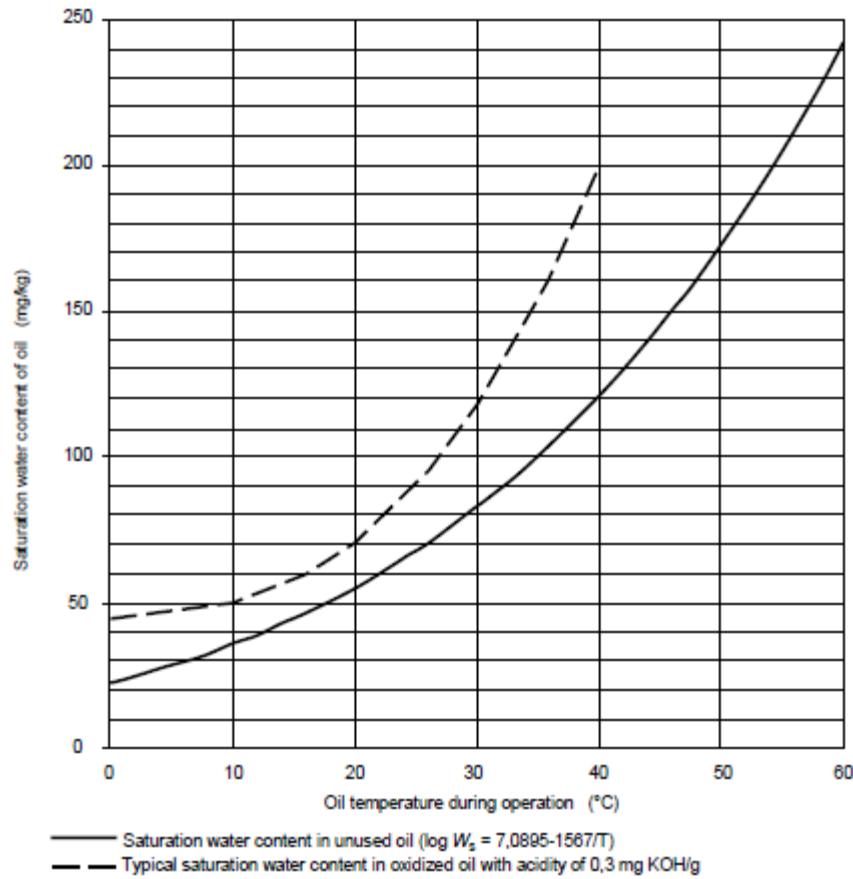
- Gives information on the oil's **corrosivity against copper** and the oil's **tendency to deposit copper sulphide on paper**.
- It shows **positive results with corrosive sulphur** but has been found to detect potentially corrosive sulphur.

DIN 51353:

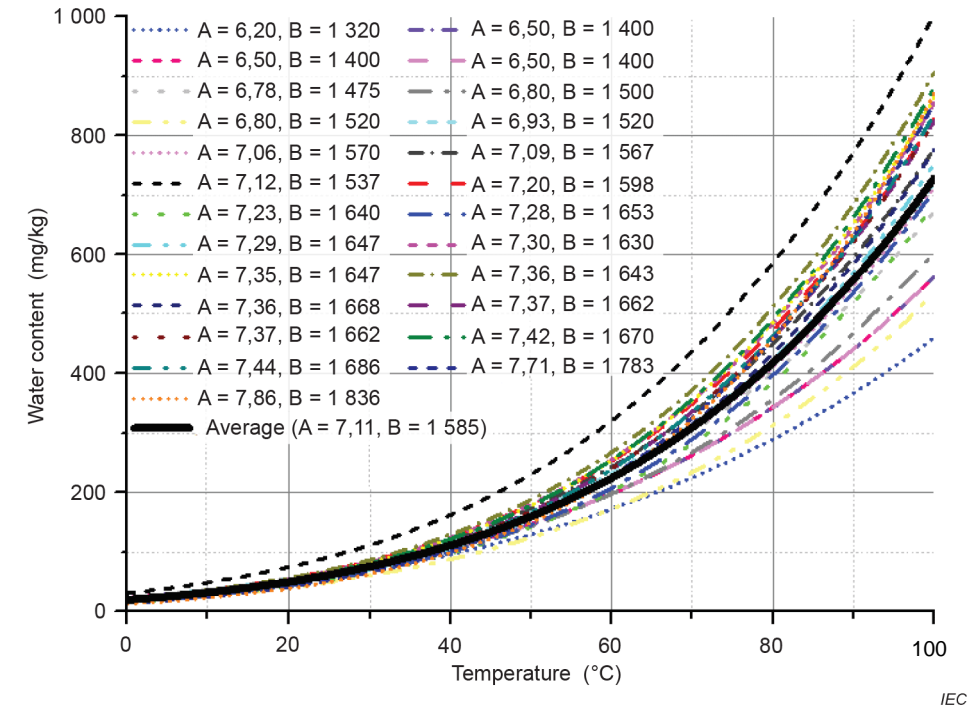
- Suitable for **silver corrosion assessment only**.
- It is **extremely sensitive** and selective to **detect corrosive sulphur** substances such as highly reactive mercaptans and elemental sulphur, but **it is insensitive to DBDS**.

- **Removal of corrosive sulphur** using Potassium Polyethylene Glycolate (**KPEG**) now also mentioned in Ed. 5.
 - Usually **also improve the parameters of the oil linked to the presence of polar compounds**, such as DDF, IFT and acidity.
 - **Can remove DBDS even at lower temperatures** (80-100 °C) compared to those needed for the efficient removal of PCBs.
 - Simultaneous removal of PCBs and DBDS is also possible.

Water Solubility



Ed. 4 to Ed. 5

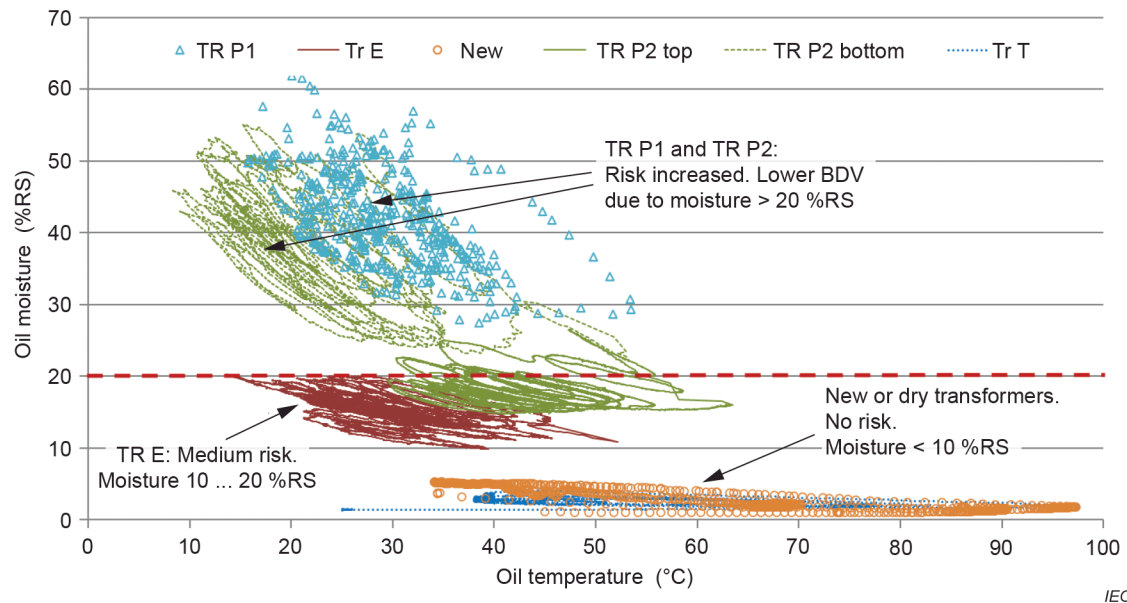


Water solubility curves for unused mineral oil as adapted from literature

- As oils become very oxidized with increasing amounts of polar ageing by-products, their water solubility characteristics, which are also dependent on the type of the oil, also increase.
- The solubility of water in very aged oils can be much higher than that in unused oils (figure on the right shows a variety of water solubility curves for unused oils – significant variations due to oil types).

Relative Saturation (RS)

- Note that water content in oil (W_{abs}) is directly proportional to the RS (in %) up to the saturation level (S): $W_{abs} = RS / 100 \times S$.
- With greater use of online sensor, [guidance now provided in Ed. 5 on how to interpret Relative Saturation \(RS\)](#).
- [Hysteresis loops of RS also included, with three indicative examples.](#)



Low Risk Transformers

- Dry transformers, with <10% RS
- Flat hysteresis loop
- Not at risk of reduced dielectric strength of oil
- Little water on paper surface for dynamic water exchange

Medium Risk Transformers

- Fit for service, but with 10% - 20% RS
- With elevated moisture in comparison to new transformer
- Can be at risk of reduced dielectric strength of oil due to moisture, particularly during cold start or after high loading

High Risk Transformers

- Moist transformers, with >20% RS
- The oils have continuously significantly reduced dielectric strength
- Broad hysteresis loop, likely to have considerable water on paper surface for dynamic exchange of water between paper and oil
- Can be at risk of dielectric breakdown due to moisture immediately after high loading or during cold start

Informative Annexes Related to Water Content

Annex B (informative)

General guideline for moisture %RS for continuous online monitoring

Table B.1 – Moisture %RS, continuous online monitoring, general guideline

Property	Category ^a	Limits >> Actions >>	Recommended action limits			Notes
			Good	Fair	Poor	
Moisture (%RS when measured online at transformer operating temperature) **	All		<10	10 – 20	>20	The follow-up period shall be long enough under normal operating transformer conditions, at least one month. Broad hysteresis curve indicates potentially wet insulation. Flat hysteresis is indication of dry insulation.

^a Category of equipment (see Table 1).
^{**} The sensor being used shall have good sensitivity at very dry conditions and supplied with calibration at close to 0 %RS. The sensor shall have no temperature dependency i.e. be temperature compensated over the whole operating range. The sensor location should be in representative and flowing oil [5].

Now in Ed.5, guideline on interpreting online monitoring relative saturation (RS) results can be found in Annex B.

Annex C (informative)

Normalizing water in oil for comparison and trending (historical practice)

C.1 General

Changes in a transformers operating temperature will result in water migration between the oil and any cellulose insulation. Therefore, normalisation for comparison and trending purposes is applied by some asset owners. The tools presented in this annex for interpreting the results are applicable only in the presence of cellulosic insulation in the equipment. Typically, this will be the active parts of power transformers and reactors. The basic idea is to normalize the measured water content of an oil sample from its sampling temperature always to the same reference temperature. Results of normalized water content should be used for moisture trending purposes to evaluate the need for additional tests or corrective actions. Additionally, normalization helps in evaluating the quality of sample taking, as normalized results should normally be similar from one year to the next.

When the normalized water content shows an increasing trend over a longer period (months), other tests as described in Table 5 are recommended to assess the moisture content of the insulation system.

The following guidance can be applied to obtain reliable results:

- Sampling temperature ≥ 35 °C
- Variation in operation temperature ± 10 °C (max ± 15 °C) within the last 12-24 h before sampling
- Accurate reading of oil temperature (always use the same measuring point)
- Oil not treated during last 90 days
- Unit in operation for at least one week after energizing

C.2 Sampling temperature at or above 35 °C

For a more realistic interpretation of water content and for trending purposes, the analytical result of water content of the oil at a given sampling temperature needs to be normalized to a defined standard temperature. For practical reasons, the defined temperature is set at 20 °C. But normalization should only take place when the operating temperature is at or above 35 °C at the time of sampling; as below 35 °C, the rate of diffusion of water is too slow to achieve a state close to equilibrium in operational equipment within a reasonable time.

Normalized water content is expressed by Formula (C.1), which utilizes the normalization formula expressed by Formula (C.2) that is also shown in Figure C.1.

$$w_n = w_m \times f \tag{C.1}$$

$$f = 2,24 \exp^{-(-0,047x)} \tag{C.2}$$

Where w_n is the normalized water content, w_m is the measured water content at the time of sampling, f is the normalization factor and T_s is the transformer oil sampling temperature in Celsius.

When using the formula at temperatures below 35 °C, care should be taken with regards interpretation of the results. This is because at lower temperatures such as between 20 °C and 35 °C, the uncertainty is increased significantly due to the difficulty of achieving equilibrium.

The transformer oil sampling temperature for normalization should always be measured at the same location. Otherwise, comparison with previous results is not possible. Always using the top oil temperature can be the easiest solution.

NOTE 1 Normalized values are valid only for comparing results obtained at different oil temperatures. Actual values of water in oil at sampling points are the measured values, not the corrected ones.

NOTE 2 Some studies like CIGRÉ TB 738 [19] or TB 779 [18] show slightly different factors in the formula.

NOTE 3 These coefficients can change in the cases of severely aged oil caused by a change in partition of water in the paper and oil system.

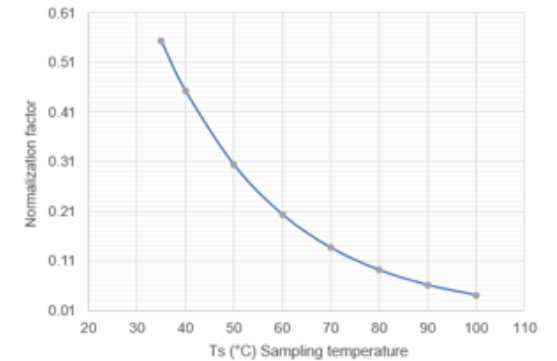


Figure C.1 – Normalization factors according to Formula (C.2)

EXAMPLE

Measured water content	10 mg/kg
Sampling temperature	40 °C
Normalization factor (from Formula (C.1))	0,45
Normalized water content (10 × 0,45)	4,5 mg/kg

Now in Ed.5, the assessment of normalized water content is further explained and clarified in Annex C.

Oil Treatment

Expansion of guidance on oil treatment. Some notable mentions:

- In addition to [contamination by PCBs](#), [cross contamination by other insulating liquids \(esters, silicones\)](#) should be avoided too.
- [Bounce-back effect explained](#), i.e. if there are still significant ageing products and contaminants in the solid insulation, these can diffuse or dissolve into the oil within a short period.
 - [Recommendation provided to avoid a significant bounce-back](#), through sufficient reclamation circulations, maintaining a high enough oil temperature (e.g. on-line operation) and follow-up sampling after a few months following the treatment.
- [Case-by-case consideration with expert consultation](#) is suggested, in addition to reference to original manufacturer's instructions.
- Classification of treatment processes expanded to cover:
 - [Off-line \(de-energized\) vs on-line \(energized\)](#)
 - [Batch mode vs continuous mode](#)
- Reconditioning section expanded, including guidance on:
 - Efficiency of reconditioning in the presence of free water (possibility of adopting draining instead).
 - Conservative conditions for heat and vacuum to [prevent undue loss of lighter liquid fractions \(and not just additives\)](#).
 - [Temperature limits and need for special care when using electrical heaters](#) to prevent overheating and burning.
 - Reconditioning equipment, [such as beta ratio related to filter efficiency and control of foaming during vacuum dehydration](#).
 - Application to electrical equipment, such as filling procedures and dealing with sealed units.
- Reclaiming section expanded (more on reclaiming in the following slide), including guidance on:
 - [Single use sorbents and reactivating sorbents \(including reactivation steps\)](#).
 - Special note on corrosive sulphur contamination (formed mainly in the reactivation process).

Oil Treatment (Continued)

- A new normative annex now included in Ed. 5 ([Annex A: Criteria for Reclamation and Treatments](#)).
- Recommendation: a [written agreement between asset owner and the service provider](#) regarding the [measurable parameters and target values](#) of the oil after reclamation is completed. [Guidelines can be based on:](#)
 - Table 3 (Limits for oils after filling in new equipment prior to first energisation)
 - Table 5 (Transformers and reactors – application and interpretation of tests)



Table A.1 – Parameters where limits should be agreed upon

Parameter	Recommended Usage	Comments
Acidity (mg KOH/g)	Agreed maximum target value	
Dielectric Dissipation Factor (DDF)	Agreed maximum target value	
Interfacial Tension (IFT)	Agreed minimum target value	
Inhibitor Content	Agreed minimum and maximum after inhibitor addition	See Clause A.3
Corrosive Sulphur	All reclamations: DIN 51353 (Silver Corrosion) should have "corrosive sulphur absent". If the purpose of the treatment is to remove potentially corrosive sulphur, then requirements for either potentially corrosive sulphur or DBDS content, or both, should be agreed upon.	See 14.4.3
PCBs content	Measure and report for reference in general cases. If the purposes of the reclamation are to remove PCBs, then requirements for total PCBs content should be agreed upon.	Local regulations can apply. PCBs content should never be increased by a reclamation process, within the uncertainty of the method.

Table A.2 – Parameters where limits should not necessarily be set but should be measured for baseline and trending

Parameter	Recommended Usage	Comments
Colour	Measure and report for reference.	
Breakdown Voltage	Measure and report for reference. In cases where batch mode treatments are done, limits should be agreed prior to filling the electrical equipment.	BDV is a property that can rapidly change in the oil depending also on the temperature dependent water equilibrium between oil and solid insulation. It should be measured just after the treatment to ensure that no moisture ingress occurred, but it can change quite rapidly when the unit is returned to service, see 7.4.
Water	Measure and report for reference. In cases where batch mode treatments are done, limits should be agreed prior to filling the electrical equipment.	Water content is a property that can rapidly change in the oil depending also on the temperature dependent water equilibrium between oil and solid insulation. It should be measured just after the treatment to ensure that no moisture ingress occurred, but it can change quite rapidly when the unit is returned to service, see 7.5.

Other Notable Mentions

- Sampling of Oil
 - [Guidance on ODAF and OFAF transformers now provided](#), i.e. samples taken with pumps running.
- Handling and Storage
 - Instead of just referring to drums, [guidance has now expanded to both drums and containers](#).
- Material Compatibility
 - [A new informative annex \(Annex D\) now included](#).
 - For oils in service, a problem with compatibility can arise in cases where replacement of one or more of the component.
 - Electrical properties can be negatively influenced by dissolution of the solid components.
 - Solid materials used in winding insulation or in gaskets can suffer dimensional changes (swelling, shrinking) too.
 - [Realistic, long duration tests are recommended in all cases](#) but especially for High Voltage application.
 - At the end of the test, the relevant properties of the constituents should be measured:
 - For oil, e.g.: Colour, DDF, BDV, water content, acidity, interfacial tension, dissolved gases, etc.
 - For solid materials, e.g.: tensile strength, dimension, weight, elastic modulus, etc.
 - [A blank test using the same ageing conditions but without solid material shall be carried-out for reference](#). The acceptance limits should be expressed, where possible, in terms of variation from the blank values (oil) or the initial value (solid).
- Contamination of Oils with Silicone
 - [A new informative annex \(Annex F\) now included](#).
 - Mineral insulating oils contaminated with silicone, phthalates or other surface-active chemicals or oils can cause undesired [slow de-aeration or excessive foaming in oil when trying to degas the transformer](#).
 - This makes it difficult or impossible to fully degas the mineral insulating oils.
 - [Oil change or reclamation can be a solution](#).

Summary of Technical Changes

- This new edition represents a major revision of the fourth edition, bringing this document **in line with the latest developments in oil condition monitoring**.
- **New interpretation tables** have been created, containing limits for oil parameters **specific to plant type** with suggested corrective actions in the tables and new test methods.
- **The action limits for all oil tests have been revised** and changes made where necessary to enable users to use current methodology and comply with requirements and regulations affecting safety and environmental aspects.
- **Category O has been removed** and is now **incorporated within Category A**.
- **Online moisture interpretation** is now incorporated.
- More **guidance on oil treatment (including reclamation criteria)** is now available.
- More **guidance regarding corrosive sulphur** is now available.
- In addition, this document **incorporates changes introduced in associated standards** (e.g. IEC 60296:2020) since the fourth edition (2013) was published.



*Mineral insulating oils in electrical
equipment – Supervision and
maintenance guidance
(IEC 60422)*

David Walker – SP Energy Networks, UK
(Tee) ShengJi Tee – SP Energy Networks, UK

1 February 2024

Thank You