SHELL DIALA TRANSFORMER OIL HANDBOOK

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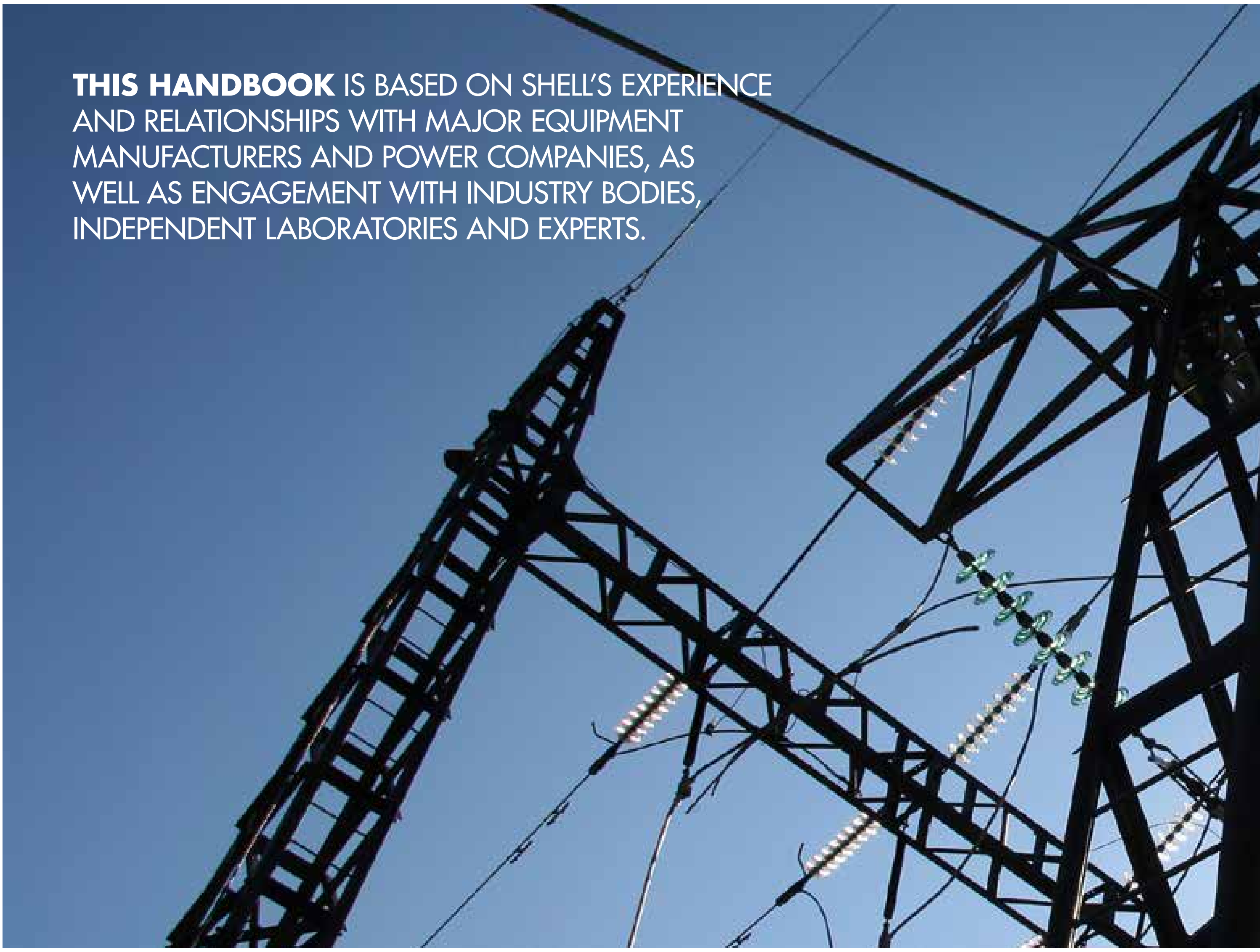

THIS HANDBOOK IS BASED ON SHELL'S EXPERIENCE AND RELATIONSHIPS WITH MAJOR EQUIPMENT MANUFACTURERS AND POWER COMPANIES, AS WELL AS ENGAGEMENT WITH INDUSTRY BODIES, INDEPENDENT LABORATORIES AND EXPERTS.

This Shell handbook provides information and guidance for works and utility company engineers responsible for the maintenance, operation and performance of transformers. It does not replace instructions issued by equipment manufacturers, rather it adds to them by providing further information about the transformer oil. This handbook is based on Shell's experience and relationships with major equipment manufacturers and power companies, as well as engagement with industry bodies, independent laboratories and experts.

SECTION 2 / SELECTING AN INSULATING OIL

The functions of transformer oil are to provide electrical insulation, protect critical components and transfer heat generated by the transformer core to the external heat exchangers to keep the equipment cool.

In addition, equipment manufacturers have other expectations for transformer oil, for example, it should be compatible with the materials used in construction, have long-term ageing stability and be capable of providing information through oil condition monitoring tests and dissolved gas analysis.

(i) TRANSFORMER OIL TYPES

Transformer oils are classified according to their base materials. This handbook covers mineral-oil-based transformer oils, which are produced from hydrocarbons. Other oil types, for instance, those made from ester-based, silicone and synthetic aromatic components, are not within the scope of this guide.

Transformer oil consists of base oil plus, in some cases, additives (Figure 1). Typical additives include antioxidants (inhibitors), metal passivators and pour point depressants.

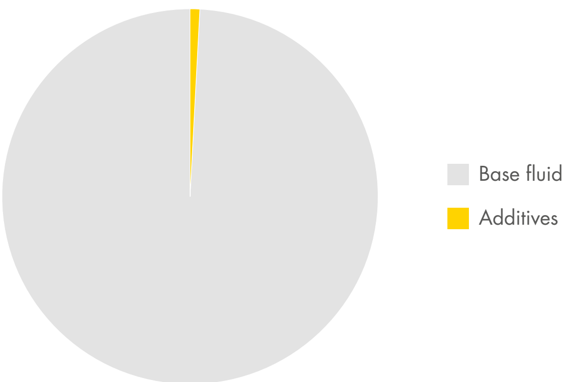


FIGURE 1: The composition of transformer oil

Mineral-based oils

Mineral-based oils are often then further differentiated as naphthenic or paraffinic oils. This distinction is based on the proportions of the different types of hydrocarbon molecule in the oil (Table 1).

Most conventional mineral base oils contain all molecule types and are thus mixtures or blends.

As a guide, transformer oils can be classified as shown in Table 2.

LETTER	TYPE OF OIL
P	Paraffinic
N	Naphthenic
A	Aromatic

TABLE 1: Mineral oil designation

CLASSIFICATION		PARAFFINIC CONTENT
Naphthenic	More paraffinic ↓	Paraffinic content below 50%
Paraffinic		Paraffinic content 56% and above

TABLE 2: Mineral oil classification

Normally, the composition of transformer base oils is measured using a technique called Fourier transform infrared spectroscopy (FTIR), as described in ASTM D2140. It gives an approximate percentage breakdown of the component parts of paraffinic and naphthenic oils.

A typical example of an oil classed as paraffinic using FTIR contains

CP = 67%; CN = 32%; CA = 1%.

A typical example of an oil classed as naphthenic using FTIR contains

CP = 47%; CN = 49%; CA = 4%.

Mineral-based oils are mainly produced by traditional refining of crude oil. This process relies on the quality and composition of the crude oil; different crude oils from different parts of the world have different compositions and contain different levels of impurities such as sulphur, oxygen or nitrogen. These variations can affect the quality and consistency of the transformer oils produced from them. However, there are now new methods capable of producing hydrocarbon mineral-oil-type products such as-gas-to-liquids (GTL) technology in which mineral oils are produced from natural gas using methane as the first building block. GTL-based transformer oils are classed as isoparaffinic; the carbon molecules are similar to those found in traditional paraffinic oils but have more branching, which results in improved low-temperature properties.

Inhibited or uninhibited transformer oils

Inhibited oils contain inhibitors known as antioxidants that prevent or slow down oxidation and thus improve the oxidation stability of the oil. They prolong oil life and consequently reduce paper degradation in the transformer.

Inhibitors work in a sacrificial manner; they sacrifice themselves by reacting with oxygen in the oil to form inactive molecules. This reduces the rate at which oxidation of the base oil occurs, which, consequently, prevents the formation of corrosive acids and high-molecular-weight sludge.

The first transformer oils were uninhibited and contained natural sulphur compounds with some natural antioxidant properties. Today, there are both uninhibited, trace-inhibited and inhibited oils. Some regions such as North America and China only use inhibited oils whereas other regions in Asia and in Europe may use a mixture.

The most common inhibitor in transformer oils is di-tert-butyl-p-cresol (DBPC), also known as butylated hydroxytoluene (BHT), which may be used at up to 0.08% for trace inhibition or at 0.08–0.40% for inhibited oils. Uninhibited oils do not contain any artificial antioxidants.

Table 3 shows that the oxidation test for uninhibited oils (U) lasts only 164 h compared with 500 h for inhibited oils (I). This clearly demonstrates the longer resistance of inhibited oils to oxidation. For high-voltage applications, oil according to IEC 60296 Section 7.1 should be chosen.

Some manufacturers may produce oils containing additives such as passivators in addition to inhibitors to improve performance, especially if corrosive sulphur is suspected. These additives need to be declared.

OXIDATION PERFORMANCE RANKING	LIMIT IEC 60296 (U)	LIMIT IEC 60296 (I)	LIMIT IEC 60296, SECTION 7.1
	Uninhibited	Inhibited (standard)	Mainly inhibited (higher oxidation stability and low sulphur)
Oxidation test according to IEC 61125C			
Test duration, h	164	500	500
Total acidity,[a] mg KOH/g	≤1.2	≤1.2	≤0.3
Sludge level,[a] wt%	≤0.8	≤0.8	≤0.05
Dielectric dissipation factor at 90°C[a]	≤0.5	≤0.5	≤0.05
Sulphur content, %	No general requirement	Maximum 0.05	

[a]In some countries, more stringent limits and/or additional requirements may be requested.

TABLE 3: The IEC 60296 specification limits clearly show that uninhibited oils are expected to degrade more quickly than inhibited oils

(ii) TRANSFORMER OIL STANDARDS AND SPECIFICATIONS

Transformer oils are normally produced in accordance with international standards. These standards may be supplemented or replaced by standards published by the transformer manufacturer or the utility company.

International standards are set by the IEC (International Electrotechnical Commission) and ASTM, which is a US-based international technical standards organisation for the construction, manufacturing and transportation industries.

The major international standards for unused mineral transformer oils are IEC 60296 and ASTM D3487. They cover the properties of the oil and their significance, specifications, sampling and testing methods for inhibited and uninhibited oils.

In order to insulate, cool and protect, a transformer oil must possess good electrical insulation properties. In addition, because efficient heat transfer depends on good circulation, the oil should have a low viscosity so that it can flow through the transformer, even at low temperatures. The significance of some of the key properties are summarised in Table 4.

PROPERTY	ASTM D3487	IEC 60296
Viscosity at 100°C, mm²/s	≤3	–
Viscosity at 40°C, mm²/s	≤12	≤12
Viscosity at 0°C, mm²/s	≤76	–
Viscosity at –30°C, mm²/s	–	≤1,800

TABLE 5: Specified standards for viscosity at set temperatures

Cooling

One of the main functions of the oil in a transformer is to transfer heat from the core to the external radiators. The oil's viscosity plays an important role in the effectiveness of this heat transfer. The lower the viscosity, the easier the oil can be pumped or can circulate freely throughout the transformer for improved heat transfer and better cooling.

At low temperatures, oils are more viscous. This is a critical factor at low operating temperatures when poor or no circulation of the oil can cause overheating at the hot spots in the transformer. The oil's pour point indicates the temperature at which it ceases to flow. This is a maximum of –40°C for most specifications (Table 5).

COOLING	ELECTRICAL INSULATION	LIFE TIME	MATERIAL COMPATIBILITY	HEALTH, SAFETY AND THE ENVIRONMENT	OTHER
▪ Viscosity ▪ Pour point	▪ Breakdown voltage ▪ Dielectric dissipation factor ▪ Impulse breakdown ▪ Resistivity ▪ Water content	▪ Oxidation stability ▪ Inhibitor content ▪ Sulphur content	▪ Chemical composition	▪ Flash point ▪ Health, safety and environment classification	▪ Density ▪ Interfacial tension ▪ Gassing tendency

TABLE 4: Summary of property requirements

Electrical insulation

For a transformer to function, the main electrical windings need to be electrically isolated from one another. This insulation is achieved using cellulose paper that is wrapped around the windings and impregnated with the transformer oil. The insulating performance of the oil is affected by its inherent physical characteristics, water content and cleanliness in terms of particulate contamination. The insulation effectiveness of the oil is assessed using parameters such as

- breakdown voltage
- dielectric dissipation factor
- impulse breakdown
- resistivity.

During the life of a transformer, the oil will degrade through normal oxidation processes, which can lead to an increase in water content and the formation of sludge (or deposits) and acids. These can reduce the insulating properties of the oil and increase the rate of degradation of the insulating material. Consequently, a structured oil condition monitoring programme is always recommended for transformer oils.

Lifetime

The lifetime of a transformer is governed by the life of the oil and of the insulating paper. Water, oxygen and oil ageing by-products, including acids and sludge, can reduce the life of the paper, the oil and, ultimately, the transformer.

Acids may attack some of the materials used in transformer construction, including metal components and the insulating paper. Sludge coats the windings and interferes with heat transfer by restricting oil and heat flow.

Keeping the production of acid and sludge as low as possible is critical to the performance of the oil and the protection of the transformer. Therefore, it is vital to use refined oils that provide high oxidation stability.

INTERFACIAL TENSION	
Fresh oil typical value, nM/m	>40
First warning, mN/m	<25

TABLE 6: Interfacial tension of transformer oils

Material compatibility

Transformers are complex in design and contain many different materials, including paper, board, seals and coatings such as paint, so it is important that the oil does not adversely react with any of these.

In most transformers, it is the degradation of the insulating paper that determines when a transformer needs replacing. Experience has shown that doubling of the water content in the oil halves the working life of the insulation paper. Similarly, an increase in the average operating temperature of just 8°C has the same effect. So, the cooling and protecting properties of the insulating oil are vital to extending a transformer's working lifetime.

Health, safety and the environment

From the safety perspective, it is important to look for oil with a high flash point. The flash point is the lowest temperature at which the oil vaporises and can be ignited with a flame.

For safety reasons, IEC 60296 specifies a minimum flash point of 135°C to prevent the risk of fire and accidental ignition.

Transformer oils should also be free of environmental toxins such as polychlorinated biphenyls and carcinogens such as polychlorinated alkanes.

Other

Interfacial tension is a measure of the tension at the interface between oil and water. Transformer oil should have a certain interfacial tension to prove that it is high quality, clean and free of impurities. A high interfacial tension shows that the level of contamination of the oil is low, but the interfacial tension will decrease with time, so it is a useful indication of oil condition (Table 6).

Decreases in interfacial tension may also indicate compatibility problems between the oil and one of the transformer materials, for example, the varnish or the gasket material, or of contamination when filling with oil.

The density of the transformer oil is determined by its type. In general, isoparaffinic oils have a lower density than naphthenic grades and can lead to lower overall transformer weights.

Technical data sheets

The technical data sheets showing the performance specifications for all Shell oils can be accessed online at www.epc.shell.com.

The performance of a transformer oil can be severely compromised by contamination with particles, chemicals and moisture.

Small amounts of contaminants can lower the oil's electrical strength and larger amounts can affect its insulating ability and lead to damage to the transformer. It is, therefore, important at all times during transit, storage and service to keep the oil clean.

(i) STORAGE

Dedicated tankers, tanks and equipment should be used to avoid contamination. Nitrogen-blanketed tankers and tanks are preferable for keeping the oil dry.

Drums containing transformer oil are best stored under cover so that they are not exposed to the weather and temperature variations. Changes in temperature may cause the drums to "breathe" and draw dirt and moisture into the oil (Figure 2). This is particularly likely for upright drums with bungs at the top when the top of the drum is exposed to water.

The risk of this contamination can be avoided by

- storing the drums on their sides or, if this is not possible, upside down so that the bungs are at the bottom (Figure 3)
- raising the drums off the ground on, for example, wooden pallets.

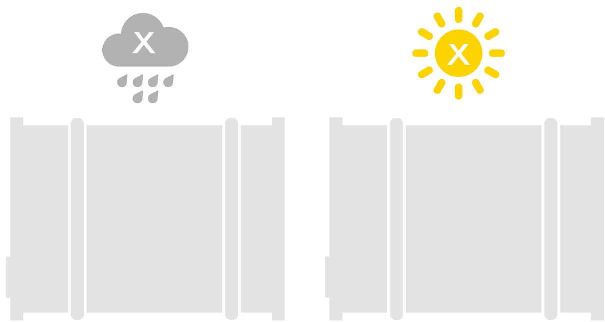


FIGURE 3: Storage position: unexposed to weather, drums on side and raised off the ground

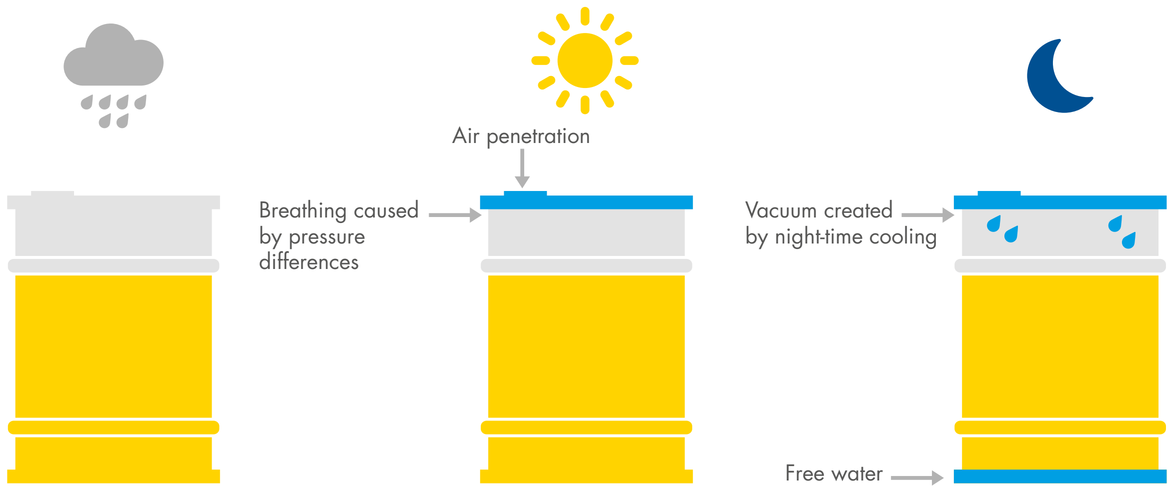


FIGURE 2: How oil becomes contaminated when stored outside

If indoor storage is unavailable, an open-sided shed or shelter should be used and the drums should be regularly inspected for leaks and the obliteration of identification and hazard marks. Local regulations and standards should always be adhered to.

Before use, it is advisable to move the drums from storage and allow them to stand upright (bung up) under suitable cover for about 12 h before they are opened. This will ensure that the drums are at ambient temperature and thus prevent air, which may contain dust or moisture, being drawn in when they are opened.

Before a drum is opened, remove any loose dirt and dust from around the bung with a rag or brush. When the bung is removed, it should be placed with the inner part upwards in a clean dry place.

(ii) OIL HANDLING: HEALTH, SAFETY AND THE ENVIRONMENT

Health and safety

Manufacturers produce material safety data sheets (MSDS) for their oils that provide detailed information on physical and chemical properties, toxicology, disposal, health and safety.

Always refer to the product's MSDS to determine the potential risks and hazards associated with the handling and use of transformer oils.

Personal protective equipment used when handling oil should meet recommended national standards: check with your suppliers. Protective eyewear is recommended.

Gloves approved to relevant standards (for example, in Europe: EN 374; in the USA: F739) and made from PVC, neoprene or nitrile rubber may provide suitable chemical protection when handling oil. Always seek advice from glove suppliers. After using gloves, hands should be washed and dried thoroughly. The application of an unperfumed moisturiser is recommended.

Transformer oils typically have a normal petrochemical odour and do not require the use of specific breathing equipment.

It is important to observe good personal hygiene measures such as washing hands after handling the material and before eating, drinking and/or smoking. Routinely wash work clothing and protective equipment to remove contaminants. Discard contaminated clothing and footwear that cannot be cleaned.

For more information or the answer any enquiries about Shell MSDS, please email lubricantsds@shell.com.

Environmental management

Unused mineral transformer oil received from a refiner will not be classified as an environmental hazard. Modern oils do contain major constituents that are expected to be inherently biodegradable, but they also still contain components that may persist in the environment.

All oil purchased and disposed of must be logged using an on-site oil management book. The book must be kept up to date to meet international standards. Any spillages or leaks also need measuring and recording.

In the case of an accidental leak or spillage, it is necessary to use appropriate containment to avoid environmental contamination and to prevent accidents. Prevent spillages from spreading or entering drains, ditches or rivers by using sand, earth or other appropriate barriers.

Reclaim the liquid oil by scooping it into a container and soak up any residue using clay, sand or other suitable materials.

Dispose of both the contaminated oil and the absorbent, including soil or sand, properly and in accordance with local and national laws.

Local authorities should be advised if significant spillages cannot be contained.

When transformer maintenance or breakdown occurs:

- drain the oil before starting work where necessary
- retain the drained oil in sealed containers ready for disposal or recycling
- classify and dispose of the waste oil safely, as this is the responsibility of the end-user
- check with local authorities if the oil needs sending for incineration or to refining or treatment plants for recycling
- comply with local area and regional laws and regulations.

Used oil may contain harmful impurities that have accumulated during use and older transformers may contain oil that contains polychlorinated biphenyls, the concentration of which will depend on use. They may present risks to health and the environment on disposal. All used oil is generally classified as special or hazardous waste, depending on the state of the oil and its polychlorinated biphenyl content.

(i) FILLING A TRANSFORMER FOR THE FIRST TIME

Smaller transformers normally arrive from the manufacturer already filled, but larger transformers are delivered without oil and therefore require filling on-site. If this is the case, always follow the procedures outlined by the transformer manufacturer.

The following guidelines are designed for use in conjunction with the manufacturer's instructions.

Oil preparation

Drums of oil should be allowed to stand before use for about 12 h until they are at ambient temperature. Their contents should then be tested for electric strength by measuring the breakdown voltage using an on-site portable oil tester, if available.

Contaminants and water content affect the dielectric properties and strength of the oil. Therefore, if the oil's electric strength is below the specified minimum, it should be dried using purification methods such as vacuum dehydration or gas sparging. It should also then be filtered.

Shell offers two levels of water content in its transformer oils: a standard product and a more highly dehydrated one that goes through an extended drying period before shipment. For more information, please contact your local Shell technical advisor.

During transportation, care needs to be taken to maintain the oil's condition: it can and will absorb moisture, especially under hot and humid conditions.

To ensure the oil is dry before filling a transformer, a further processing step is recommended immediately before filling (see filling section).

Note that all batches of Shell transformer oils are rigorously tested after manufacture and each batch has its own specific certificate of analysis.

For more information on Shell quality assurance or to recall a certificate of analysis, please contact your Shell sales representative.

Filling

When filling a transformer, always check any specific guidance from the manufacturer. Remember to

- keep all dedicated tools such as pumps and hoses clean by flushing them through under vacuum with clean insulating oil before each use with the transformer
- prevent bubbles forming when filling with a hose by making sure the hose reaches the bottom of the tank and remains submerged during filling
- take care when inserting the hose into the tank to avoid any damage to the windings
- fill larger units fitted with conservators from the bottom and then top up from the conservator until the oil reaches a depth of about 8 cm
- make sure the oil covers the windings and cooling tubes in units with no conservator
- allow the transformer to stand for at least 24 h to allow air bubbles to rise after filling with traditional oils (this "resting" time can be significantly reduced if using GTL oils, as they do not foam in the same way as traditional oils)
- open the air release vents on tank covers, cable boxes and inspection covers when doing the final top-up
- run the transformer on short circuit at low voltage for some hours after filling to minimise moisture and trapped air
- open the air vents again to fully degas the system, taking care not to introduce fresh air or moisture, and check the oil level; alternatively, fill the transformer under a half vacuum
- check the electric strength of the oil before applying the full working voltage or at least perform a crackle test on a sample from the bottom valves on the transformer and conservator (flush at least 5 L before taking the sample)
- check the insulation resistance of the windings.

(ii) REFILLS AND TOP-UPS

Refilling an old transformer

The procedure and guidelines for refilling are the same as those on the previous page for a new transformer, although care should be taken to remove as much of the old oil as possible: 85–90% is feasible.

Before starting work on any transformer, ensure that the equipment is isolated and safe to work on.

A suggested process for draining and refilling a transformer is as follows:

1. Drain the oil.
2. Leave the transformer for at least 12 h to allow the oil to drain off the windings, core and components.
3. Drain the remainder of the oil using a plastic hose to get as much oil out as possible.
4. Flush with 20% hot oil by pouring it in through the conservator and removing it from the bottom drain valve while heating to about 80°C and filtering with a processing unit.
5. Complete at least three passes.
6. Drain and dispose of the flushing oil.
7. Fill as normal but under a maximum of half vacuum to avoid damaging any bushing seals and gaskets that have not been replaced.
8. Process for at least three passes.

If planning to refill transformers containing old uninhibited oils with an inhibited oil meeting IEC 60296, check the compatibility. The oil manufacturer usually provides such details.

If an old transformer is being refilled, elastomeric and other types of sealants and gaskets should be checked to assess their condition (they should preferably be replaced). The old oil may have caused them to soften and swell significantly and/or they may have a compression set that could be disturbed, which could lead to incomplete sealing and leaks after refilling the transformer with new oil.

Take care during the refilling process to dispose of the old waste oil and any oil used for flushing properly. Check the correct disposal methods with the local authority and dispose of oil in accordance with local and national laws.

Topping up transformer oil

Transformer oil top-up is not generally required during maintenance. However, it may be necessary in some cases. As a general guide, top-up volumes should be <5% of the total volume of the transformer.

Generally, new transformer oils conforming to the same specification are miscible with each other. If in doubt, contact your transformer service company to discuss testing the oils for compatibility. No properties should get worse after the transformer is topped up as the oils are mixed. Typical mixing tests will assess foaming, oxidation, corrosive sulphur and the presence of copper passivator for different mixtures.

As with filling a new transformer, any top-up oil should be clean and dry. If this is not possible, the breakdown voltage of the oil should be checked to ensure that the resultant mixture is still suitable for service.

Most new mineral transformer oils are miscible and compatible with aged oils; however, large top-up volumes should be avoided with heavily aged oils. This is because of the risk of sludge precipitation and the resultant impact on oxidation stability. Your transformer service company can help with options such as extra filtration, but if a top-up is more than 60% of the volume, a full drain and refilling are recommended.

The new GTL inhibited oils, such as those in the Shell Diala range, can be topped up or be used to top up either uninhibited or inhibited oils in accordance with IEC 60422.

If topping up uninhibited oil with inhibited oil or vice versa, the oil should still be monitored as the original oil. It is very unlikely that a transformer will need to be topped up to such an extent that this changes.

(i) TAKING SAMPLES FROM DRUMS, TANKS AND TRANSFORMERS

It is important to have a robust sampling procedure that ensures that neither the bulk oil nor the sample becomes contaminated during sample taking. The equipment used must, therefore, be clean and treated with great care. It is important to use new or uncontaminated hoses, pumps and sample vessels. Failure to follow this guidance may lead to inaccurate data collection that means no reliable conclusions can be made.

Sampling frequency is largely dependent on the size of the transformer and its importance in the network. Annually is typical, but this frequency can be increased if necessary owing to specific concerns over a particular transformer.

Drums

When taking a sample from a drum:

- take the sample indoors when the oil is at or above ambient temperature to avoid condensation
- make sure the drums have been allowed to rest, bungs up and undisturbed for 12 h before sampling to allow moisture to settle
- take an initial sample from the middle of the drum and discard it to flush the sampling tube
- always use new sampling equipment or equipment that is dedicated to transformer oils
- take the final sample from the bottom.

Storage tanks

When taking a sample from a storage tank:

- take the sample from the bottom when impurities have been allowed to settle
- flush the test tap with oil from the tank before taking the sample
- take the sample slowly to avoid air bubbles.

Transformers

To take a contamination-free sample from a transfer, use an oil sampling kit. If the instructions in the sampler kit are followed, they should ensure that no contamination by ambient air or any introduction of dirt occurs.

Oil sampling kits usually contain

- tubing
- couplings
- connectors
- multifunctional grippers
- syringes and bottles.

The sampling procedure is normally as follows:

1. Take samples when the oil is warm and record its temperature.
2. Flush the sampling point with oil from the transformer first.
3. Collect the flushed oil in a clean container if using sample bottles or into a first syringe if using sample syringes.
4. Label all the bottles and syringes.
5. Follow the relevant documentation and protocols if sending the sample to a laboratory for testing. It is important to create a good historical record of results, as this will help to identify trends and deviations from them. If possible, use the same laboratory to achieve this, as variations between laboratories can have impacts.
6. It is important to test the sample as soon as possible, as characteristics, especially for dissolved gas analysis, can change over time.

There are also many on-site portable testing units that can be used.

For additional guidelines relating to sampling, please consult IEC 60475.

(ii) MAINTENANCE TESTS: TESTING OF INHIBITED AND UNINHIBITED TRANSFORMER OILS

Oil sampling has two purposes:

a. oil condition monitoring to assess the condition of the oil
b. dissolved gas analysis to identify if the transformer has experienced any faults.

The design of each type of test and the frequency with which the tests are carried out may differ.

Oil condition monitoring

The oil's condition and the health of the transformer itself are interdependent, so a well-structured oil condition monitoring programme enables the operator to assess the oil's condition over an extended period. This offers peace of mind and enables the operator to determine if and when an oil change or reconditioning is necessary.

Many tests can be applied to mineral insulating oils in electrical equipment. The tests in Table 7 are considered sufficient to determine whether the condition of the oil is adequate for continuing operation and to suggest the type of corrective action required, where applicable. In general, the frequency of oil condition monitoring testing should be determined according to IEC 60422. For critical transformers, this should be at least every 12 months.

Always monitor transformer oil in accordance with the specific guidance offered by the transformer manufacturer.

The oxidation (ageing) of uninhibited oils is normally monitored by measuring the formation of acidic compounds and oil soluble and insoluble sludge. An oil acidity test is generally used. Regular acidity measurements are taken and tracked to calculate the oxidation rate and therefore the safe operation of the oil in the transformer.

PROPERTY	GROUP[a]	SUB-CLAUSE	METHOD
Colour and appearance	1	5.2	ISO 2049
Breakdown voltage	1	5.3	IEC 60156
Water content	1	5.4	IEC 60814
Acidity (neutralisation value)	1	5.5	IEC 62021-1 or IEC 62021-2
Dielectric dissipation factor and resistivity	1	5.6	IEC 60247
Inhibitor content[b]	1	5.7.3	IEC 60666
Sediment sludge	2	5.8	IEC 60422, Annex C
Interfacial tension[c]	2	5.9	ASTM D971 EN 14210
Particles (count and size)[c]	2	5.10	IEC 60970
Oxidation stability[c]	3	5.7	IEC 61125
Flash point[d]	3	5.11	ISO 2719
Compatibility[d]	3	5.12	IEC 61125
Pour point[d]	3	5.13	ISO 3016
Density[d]	3	5.14	ISO 3675
Viscosity[d]	3	5.15	ISO 3104
Polychlorinated biphenyls	3	5.16	IEC 61619
Corrosive sulphur[c]	3	5.17	IEC 62535 ASTM D1275, Method B DIN 51353
Dibenzyl disulphide content	3	5.18	IEC 62697-1
Passivator content[b]	3	5.19	Annex B of IEC 60666:2010

[a]Group 1 tests are routine; Group 2 tests are complementary; Group 3 tests are special investigations
b Restricted to inhibited and/or passivated oils.
c Only necessary under special circumstances: see applicable sub-clause.
d Not essential, but can be used to establish identity

TABLE 7: Tests for in-service mineral insulating oils from IEC 60422

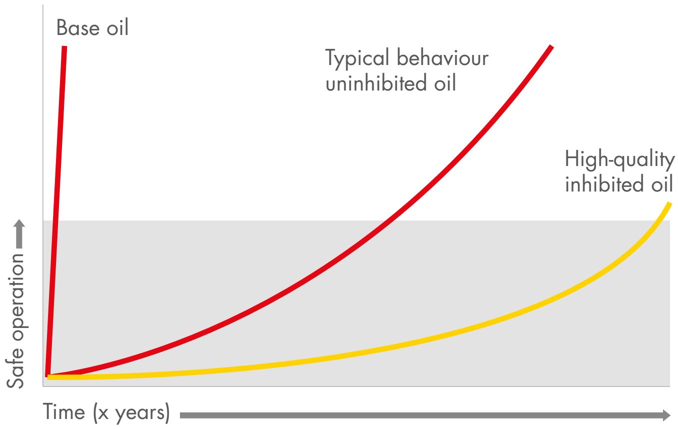


FIGURE 4: Oxidation rates of oils

Inhibited oils are also monitored using an oil acidity test but they have a different oxidation pattern compared with uninhibited oils (Figure 4). At the beginning of an oil's service life, its inhibitor (antioxidant) is consumed with little formation of oxidation products. This is referred to as the induction period.

After the antioxidant is consumed, the oxidation rate is determined mainly by the base oil's oxidation stability, so the patterns and rates of oxidation are very different, which means that the total acidity test is not as useful.

As acidity levels increase more slowly with inhibited oils, an additional measurement is useful that directly measures the amount of antioxidant in the oil. This periodic testing is not difficult or expensive. It simply measures the quantity of antioxidant left in the oil to enable prediction of the remaining oxidation protection, i.e., the oil life.

The normal method of monitoring antioxidant consumption is to measure its concentration as a percentage drop of its starting point according to IEC 60666. Once the antioxidant reaches the warning levels (see Table 8), the recommended actions must be taken.

The antioxidant content should be monitored at regular intervals, the frequency of which will depend on operational temperature and load levels. For calibrating the method, the same base oil type as the oil to be measured should be used.

PROPERTY	CATEGORY	RECOMMENDED ACTION LIMITS			RECOMMENDED ACTION
		GOOD	FAIR	POOR	
Antioxidant content	All	>60% of original value	40–60% of original value	<40% of original value	**GOOD:** No action required if not indicated by other property tests **FAIR:** where acidity <0.08 mg KOH/g and interfacial tension >28 mN/m. Consider re-inhibition to the original base line level **POOR:** Continue to use and monitor as uninhibited oil. Reclaim or change the oil
Note: If an inhibited oil has an initial level of 0.2% antioxidant, the poor alert level will be 0.08% (<40%) of its original level.					

TABLE 8: Antioxidant content levels and required actions

Dissolved gas analysis

A fault in a transformer, for instance, a partial electrical discharge, will result in the decomposition of the electrical insulation materials such as the oil or the paper. This can create specific gases that dissolve in the oil and leave a unique chemical signature. The analysis of these gases (dissolved gas analysis) is used to determine the health and functionality of the transformer, and can help the operator decide whether additional action is necessary.

Dissolved gas analysis on transformer oil is usually carried out periodically to observe trends or changes, as these are often more significant than the individual results. Interpreting the results for a particular transformer depends on the age of the unit, the loading cycle and the date of any major maintenance such as filtering (and degassing) of the oil. The IEC standard 60599 gives guidelines for the assessment of equipment condition based on the amounts of different gases present.

The equipment available includes gas chromatographs that are very accurate but too heavy and bulky for on-site use and portable units that are less accurate. Those units that comply with IEC 60567 and ASTM 3612 are often used for on-site analysis and in laboratories, and are cost-efficient, precise and easy to use.

Note that, in all cases, the sample should be analysed as soon as possible to prevent the loss of volatile gases.

The first step in evaluating dissolved gas analysis results is to consider the concentration levels of each key gas. These values are recorded at intervals so that the rate of change of the various gas concentrations can be evaluated. Any sharp increase in key gas concentration indicates a potential problem with the transformer.

The faults that the dissolved gas analysis results determine are shown in Table 9.

FAULT	EXAMPLES
Partial discharge	Discharges of cold plasma (corona) type in gas bubbles or voids with the possible formation of x-wax in the paper
Low-energy discharges	Partial discharges of the sparking type inducing pinholes or carbonising punctures in the paper Low-energy arcing inducing carbonised perforation or surface tracking of the paper or the formation of carbon particles in the oil
High-energy discharges	Discharges in paper or oil with power follow through that result in extensive damage to the paper or the formation of numerous carbon particles in the oil, metal fusion, tripping of the equipment and gas alarms
Thermal fault <300°C	Evidenced by the paper turning brownish (>200°C) or carbonised (>300°C)
Thermal fault 300 < T <700°C	Carbonisation of paper, formation of carbon particles in oil
Thermal fault >700°C	Extensive formation of carbon particles in oil, metal colouration (800°C) or metal fusion (>1,000°C)

TABLE 9: Transformer faults determined by dissolved gas analysis

The dissolved gases in transformer oils can be measured and the faults diagnosed using the following methods:

- IEEE methods (Rogers, Dornenburg and key gases methods)
- IEC ratio codes
- the Duval triangle.

The relative performance of these methods is summarised in Table 10.

One drawback of the gas ratio methods (Rogers, Dornenburg and IEC) is that some results may fall outside the ratio codes and no diagnosis can be given (unresolved diagnoses). This does not occur with the Duval triangle method.

Note that dissolved gas analysis can be used on inhibited and uninhibited oils. For critical transformers, online monitoring equipment can be installed.

	UNRESOLVED DIAGNOSES, %	WRONG DIAGNOSES, %	TOTAL, %
Key gases	0	58	58
Rogers	33	5	38
Dornenburg	26	3	29
IEC	15	8	23
Duval triangle	0	4	4

TABLE 10: Relative performance of the different dissolved gas analysis diagnostic methods

SECTION 6 / THE SHELL DIALA PORTFOLIO

Shell has been at the forefront of technology developments in transformer oils for over 50 years and during that time has constantly updated and improved its oils to meet the performance needs of its customers.

Table 11 summarises the Shell portfolio of transformer oils and how it has evolved over recent years.

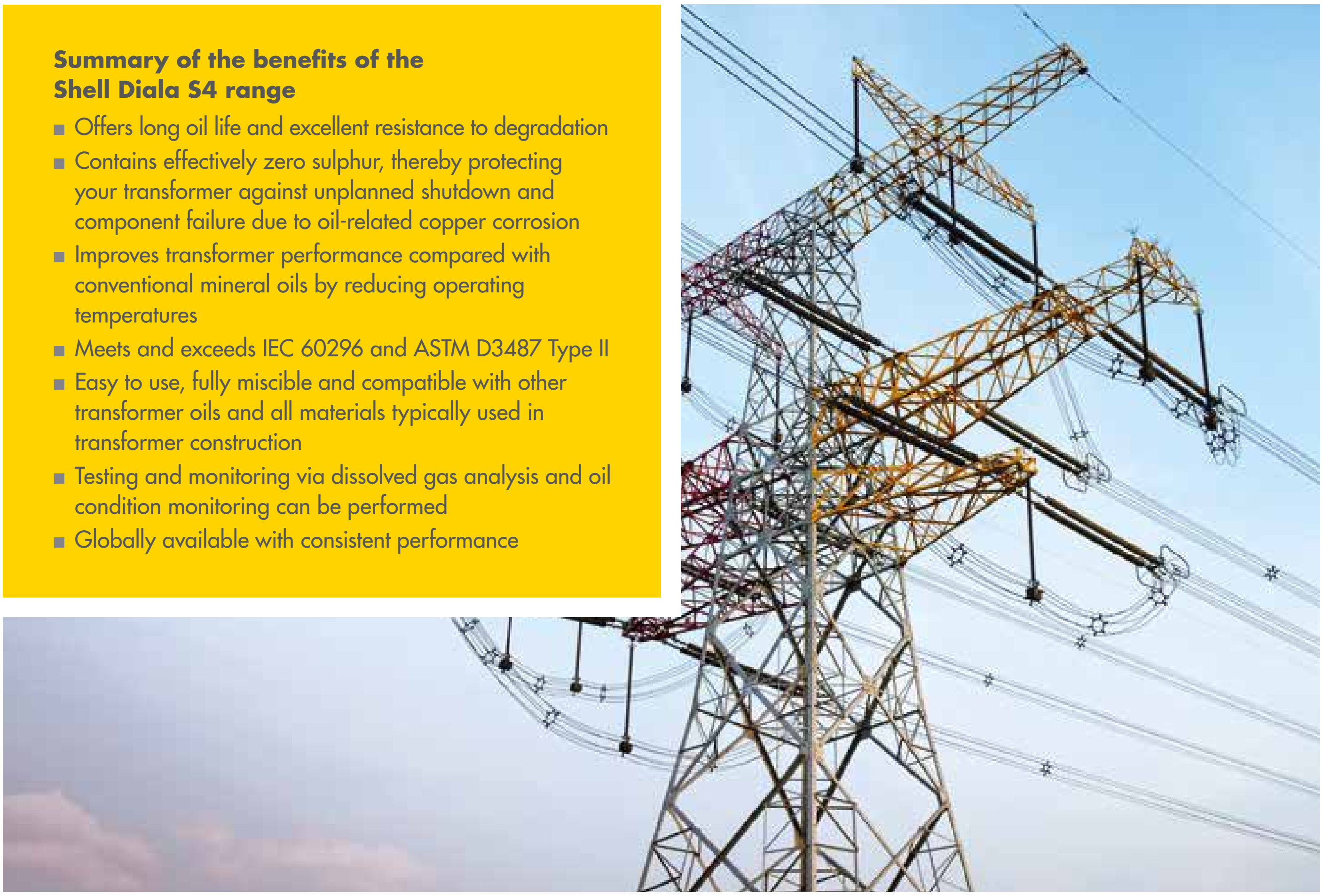
PORTFOLIO BEFORE 2005	STANDARDS	PORTFOLIO 2005–2010	STANDARDS	PORTFOLIO 2010–2016	STANDARDS	PORTFOLIO 2016–	STANDARDS
Shell Diala B	IEC 60296 – uninhibited	Shell Diala B	IEC 60296 – uninhibited	Shell Diala S2 ZU-I	IEC 60296 uninhibited		
Shell Diala D	IEC 60296 + VDE 0370 PI/ DIN 57370-1 – uninhibited	Shell Diala D	IEC 60296 + VDE 0370 PI/ DIN 57370-1 – uninhibited				
Shell Diala M	IEC 60296 – uninhibited	Shell Diala M	IEC 60296 – uninhibited				
Shell Diala S	IEC 60296 – uninhibited						
Shell Diala BX	IEC 60296 – inhibited	Shell Diala BX	IEC 60296 – inhibited	Shell Diala S3 ZX-I	IEC 60296 higher oxidation stability and low sulphur content – inhibited	Shell Diala S4 ZX-I	IEC 60296 higher oxidation stability[a] and low sulphur content – inhibited
Shell Diala DX	IEC 60296 – higher oxidation stability and low sulphur content – inhibited	Shell Diala DX	IEC 60296 – higher oxidation stability and low sulphur content – inhibited				
Shell Diala MX	IEC 60296 – inhibited						
Shell Diala GX	IEC 60296 inhibited + gas absorbing	Shell Diala GX	IEC 60296 inhibited + gas absorbing	Shell Diala S3 ZX-IG	IEC 60296 inhibited + gas absorbing	Shell Diala S4 ZX-IG	IEC 60296 – higher oxidation stability[a] and low sulphur content – inhibited + gas absorbing ASTM D3487 Type II inhibited
Shell Diala A	ASTM D3487 I – Type I – uninhibited	Shell Diala A	ASTM D3487 I – Type I – uninhibited				
Shell Diala AX	ASTM D3487 II – Type II – inhibited	Shell Diala AX	ASTM D3487 II – Type II – inhibited	Shell Diala S2 ZX-A	ASTM D3487 II – Type II – inhibited	Shell Diala S2 ZX-A	ASTM D3487 II – Type II – inhibited

[a]Shell Diala S4 ZX-I's performance has been compared with conventional mineral oils following testing by Shell and third-party laboratories. Details are available from your local Shell representative.

TABLE 11: The Shell Diala portfolio history

Summary of the benefits of the Shell Diala S4 range

- Offers long oil life and excellent resistance to degradation
- Contains effectively zero sulphur, thereby protecting your transformer against unplanned shutdown and component failure due to oil-related copper corrosion
- Improves transformer performance compared with conventional mineral oils by reducing operating temperatures
- Meets and exceeds IEC 60296 and ASTM D3487 Type II
- Easy to use, fully miscible and compatible with other transformer oils and all materials typically used in transformer construction
- Testing and monitoring via dissolved gas analysis and oil condition monitoring can be performed
- Globally available with consistent performance



Shell Diala S4 ZX-I is the latest inhibited transformer oil from Shell and a very important one, as Shell's GTL technology offers a long life, high-performance oil with effectively zero sulphur. A summary of usage guidelines for Shell transformer oils based on GTL technology is shown in Table 12.

OPERATION	GUIDELINES FOR SHELL DIALA S4 OILS
Vacuum treatment and filtration	No change compared with Shell Diala S2/S3
Oil reclamation	No change compared with Shell Diala S2/S3
Topping up with conventional oils	Up to 10% if no maintenance change proves possible without significant performance impact[a]
Filling old transformers	15% if remaining oil proves to be acceptable[a]
Oil monitoring	As described in IEC 60422
Interpretation of dissolved gas analysis	As described in IEC 60599
Concentration measurement of antioxidant	As described in IEC 60666

[a]Assuming oil is not heavily aged

TABLE 12: Usage guidelines for Shell transformer oils based on GTL technology

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For more information, please contact

Find out more by visiting

www.shell.com/lubricants

'Shell Lubricants' refers to the various Shell companies engaged in the lubricant business.