United Nations
Environment Programme

PCB Transformers and Capacitors

From Management to Reclassification and Disposal

First Issue
May 2002

PREPARED BY UNEP CHEMICALS

IOMC

INTER-ORGANIZATION PROGRAMME FOR THE SOUND MANAGEMENT OF CHEMICALS
A cooperative agreement among UNEP, ILO, FAO, WHO, UNIDO, UNITAR and OECD

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Copies of this report are available from:

UNEP Chemicals
11-13 chemin des Anémones
CH-1219 Châtelaine (Geneva), Switzerland
Tel.: +41 22 917 8170
Fax: +41 22 797 3460
E-Mail: chemicals@unep.ch

UNEP CHEMICALS

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PREFACE

This publication on management, reclassification and disposal of PCB transformers and capacitors is UNEP's fourth concerning polychlorinated biphenyls (PCBs). PCBs are persistent organic pollutants (POPs), i.e. chemical substances that are persistent, bioaccumulate and adversely affect human health and the environment. They can be transported long distances and have been detected in the furthest corners of the globe, including places far from where they were manufactured and used.

While manufacture of PCBs has reportedly ceased, the potential or actual release of PCBs into the environment has not, since significant quantities of existing PCBs continue in use or in storage. Electrical transformers and capacitors are one such major source of PCBs. The likely extended period of continuing use and the persistence of PCBs once released into the environment together mean that PCBs could pose a threat for decades to come. While most of the 12 chemicals covered by the Stockholm Convention are subject to an immediate ban, in the case of PCBs existing equipment may be maintained in a way that prevents leaks until 2025 (while PCB-free replacements are being introduced).

The present publication aims to provide practical assistance to those responsible for PCB-containing transformers and capacitors, as countries work towards safe management and eventual disposal of this equipment. Guidance is provided on the main issues encountered in the total management of PCB transformers and oils, including their reclassification and taking out of service, but does not replace professional management manuals, which are of course more comprehensive and to which electrical equipment operators should refer. UNEP welcomes information or suggestions that could be incorporated into future revisions of this and its earlier PCB publications.

1 INTRODUCTION

Most transformers and capacitors use a dielectric fluid based on polychlorinated biphenyls (PCBs). These products, although having fire-resistant and other properties required for use in electrical equipment, present some major disadvantages. These disadvantages are linked to the toxic nature of PCBs and their potential contamination with or transformation into dibenzo furans. Negative biological effects have been coming to light over many years and are now well established. Unfortunately PCBs have already been in widespread use for about 40 years in transformers and capacitors, and it is now necessary to put forward practical solutions for eliminating PCBs wherever they may occur.

PCBs, along with certain pesticides, such as DDT, and the industrial and incineration by-products dioxins and furans, are covered by the *Stockholm Convention on Persistent Organic Pollutants* (POPs*)*. The Convention addresses the production, use, import, export, release of by-products, stockpile management and disposal of an initial 12 POPs.

Under the terms of the Convention, Parties are to prohibit and/or take the legal and administrative measures necessary to eliminate the production and use of PCBs. Due to the still widespread reliance on PCB-containing equipment, notably certain electrical transformers and capacitors, an exception is made to allow continued use of such equipment until 2025, within the policy framework set out in the Convention. (The principal relevant section is reproduced in Annex A of the present publication.) Parties are expected to make determined efforts to identify and label the equipment and remove it from use.

The first problem that countries with PCB transformers still in operation have to face is how to *locate* and *identify* this equipment. A decision will then have to be taken as to when, and how, the contaminated equipment will be *managed*, *reclassified* and eventually *eliminated*. It is the purpose of this publication to assist those persons responsible for such equipment to take the appropriate measures and decisions enabling their country to comply with the provisions of the Stockholm Convention.

This publication presents the background to the use of PCBs in electrical equipment, in particular transformers and capacitors, and describes how such equipment must be managed during its lifetime, and disposed of by environmentally sound procedures at the end of its authorised lifetime. In particular it deals with the question of the reclassification of equipment as non-PCB equipment (retro-filling), thus avoiding the complete (and costly) destruction of transformers before the end of their useful life-time.

The final steps of the decontamination process may involve the generation of hazardous residues of various types. It is important to remember that any such materials will have to be dealt with in strict accordance with the regulations on trans-boundary movements of hazardous waste laid down by the Basel Convention[1] and the import/export restrictions set out in the Stockholm and Rotterdam[2] Conventions.

1 The Basel Convention on Control of Transboundary Movements of Hazardous Wastes and their Disposal was adopted in 1989 and entered into force in 1992.

2 The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade was adopted in 1998 and will enter into force after 50 ratifications.

2 BACKGROUND INFORMATION

The earlier UNEP Chemicals publications on PCBs listed below are relevant, to a greater or lesser degree, to the subject of the present guide. The reader will be able to find in these publications much complementary background information about PCBs, PCB-containing equipment, and PCB destruction technologies.

- Guidelines for Identification of PCBs and Materials Containing PCBs
  (First Issue August 1999)

- Inventory of World-Wide PCB Destruction Capacity
  (First Issue December 1998)

- Survey of currently Available Non-Incineration PCB Destruction Technologies
  (First Issue August 2000)

A typical transformer. Note manufacturer's identification plate and warning labels.

3 PROPERTIES OF PCBs

The synthesis of PCBs was first described in 1881 and commercial production began in the late 1920s. Applications of PCBs in some products ceased in the mid 1970s, but they continued to be used in transformers, capacitors, heat exchangers and hydraulic equipment. It has been estimated that 1 million tonnes of PCBs have been produced throughout the world since 1930. Unfortunately, a considerable proportion has entered the environment. There is concern about the long-term effects of these compounds.

PCBs are a family of organic chemicals consisting of two benzene rings linked by a carbon-carbon bond. Chlorine atoms are substituted on any or all of the ten remaining available sites. The number and position of these chlorine atoms determines the classification and properties of the different molecules. There are 209 possible congeners[3] of PCBs. The volatility of the different molecules varies with the degree of chlorination. In general, congeners with a low chlorine content are free flowing liquids, becoming more viscous and less volatile as the chlorine content increases. Commercial preparations usually contain a mixture of congeners and are categorised by the chlorine content. Around 130 congeners have been identified in commercial mixtures. It may be noted that, besides electrical transformers and capacitors, PCBs have also been used for a great variety of other applications: varnishes, waxes, synthetic resins, epoxy and marine paints, coatings, cutting oils, heat transfer fluids, cutting oils, hydraulic fluids, etc. In these other cases, it is not of course possible to recover the PCBs and efforts can be made only to prevent the use of PCBs in such applications in the future.

PCBs are among the most stable organic chemicals known. Their low dielectric constant and high boiling point make them ideal for use as dielectric fluids in electrical capacitors and transformers. In summary, PCBs have:

- low dielectric constant;
- low volatility;
- good fire resistance;
- low water solubility;
- high solubility in organic solvents; and
- good ageing properties, with no deterioration in service.

3 That is to say there are 209 possible ways of arranging between one and ten chlorine atoms around the biphenyl structure (rings).

However, the disadvantages of PCB fluids are now seen as considerable, since they are:

- non-biodegradable;
- persistent in the environment;
- able to accumulate in fatty tissues in the body; and
- suspected of being carcinogenic

The effects of PCBs on humans can be serious:

- leading to failure of kidneys and other human organs;
- producing headaches, sickness, etc., if inhaled; and
- causing chlor-acne if absorbed through the skin.

4 ELECTRICAL EQUIPMENT AND PCBS

PCB oils were initially proposed as dielectric fluids for use in electrical equipment such as transformers, capacitors, circuit-breakers, voltage regulators, etc. because of their excellent dielectric properties and also because of their very low flammability. A PCB oil can absorb rapid changes in electric fields with very little heating up, i.e. with very little loss of energy. Also, PCBs have a low flash point and no fire point, meaning that they are stable in changing temperatures. They only burn if placed in contact with an open flame.

When PCBs do burn, for example if a transformer or capacitor is present in a factory or domestic fire, very toxic chemicals are formed. These are in particular dibenzofurans whose deleterious effects on health have been well demonstrated. Apart from the danger of PCBs producing furans in the case of fires, PCBs themselves are dangerous substances because of their great stability, and their oleophilic nature, meaning that they are easily absorbed by the fatty tissues of humans and animals. PCB concentrations can then build up in the body, for example in the fat, the liver etc., and these molecules are very difficult to eliminate.

Equipment such as transformers, capacitors and to a lesser extent heat-exchangers and hydraulic equipment may contain PCBs or fluids with varying levels of PCB contamination. For example, PCBs may be found in hermetically sealed capacitors ranging in size from those fitted to fluorescent lights, containing a few grams of PCB to high voltage units containing up to 60 kg of PCB liquid. Capacitors are maintenance free but may leak at welds. Capacitors contain the lower chlorinated congeners of PCBs, which are therefore more volatile.

PCBs were gradually phased out for applications in electrical equipment from the early 1980s, depending on the country. In the absence of further information, it may be assumed that equipment manufactured before 1986 may contain PCBs. A very large number of transformers exist today which still contain PCBs, and the challenges are first to identify such equipment, and then to select the most appropriate steps to eliminate the PCBs they contain.

5 DESCRIPTION OF TRANSFORMERS AND CAPACITORS

The main objective of this publication is to provide guidance for persons involved in the management of electrical equipment. A distinction can be made however in this present context between transformers and capacitors. Both these types of equipment can contain PCBs. However, only *transformers* can be treated so as to remove the PCBs they might contain, and be prepared for re-use. *Capacitors* must generally be destroyed to eliminate the PCBs they might hold, although some technologies allow recovery of some metals before destruction.

5.1 TRANSFORMERS

Transformers are devices that can increase or decrease the voltage level of an electrical current. Electrical energy is produced in power stations that burn various fuels (oil, coal, gas, etc.) and transform these into electrical energy. This energy is in the form of high voltage electricity that is then distributed to the end-users (factories, homes, mines, railways, schools, etc.), which may be close to or far from the producing power station.

The transfer of this electrical energy is made much more advantageously if the voltage is maintained at a high level. This is because energy losses during transportation in cables, held on pylons or placed underground, are much lower at these higher voltages. Commonly seen electrical power cables carry electricity at voltages of several thousand kilovolts.

The voltage must be decreased before use, so as to correspond to industrial requirements of possibly a few thousand volts, or to domestic requirements of a few hundred volts. This decrease, the voltage reduction, is achieved using transformers. Every transformer which can commonly be seen, in electrical sub-stations, in streets, in the countryside, on poles, etc., has the role of bringing about a reduction in the voltage.

These transformers must be adapted to the task to which they are assigned. This means that they can be very large, if dealing with high voltages and currents, or relatively small if placed in the last step in the supply chain to serve a single house or user with electricity at, say, 400 volts. Transformers therefore vary greatly in their design and size. They nevertheless have the same basic design which is that of a magnetic metallic core around which are wound two sets of conducting (copper) wires. It is the ratio in the number of wires, in the two separate coils, which decides the ratio of the input to the output voltage.

This structure is placed in a metallic container, and is supported in this container usually by wooden struts (which have insulating properties). The two electrical circuits are equipped with inlet electrodes allowing electrical connections to the outside. These electrodes are isolated from the metallic casing by ceramic insulators.

Lastly, and more importantly, the empty space inside the transformer casing must be filled with a fluid which will prevent short-circuits and sparking. A transformer, in its final stages of manufacture, is thus filled with an appropriate dielectric fluid, which has often been PCB-base oil mixtures. The transformer may be sealed, or in some cases fitted with a "breathing device" which allows changes in the volume of the oil to occur (due to temperature fluctuations).

In summary, and this is relevant for considering later de-commissioning, a transformer is made up of:

- an outer iron casing;
- a magnetic steel core (flat platelets assembled together);
- copper coils, which are covered by an insulating layer of either a resin or paper;
- variously shaped wood struts (these are porous and can absorb the dielectric oil); and
- the dielectric oil.

There are variations in the type of structures of transformers and some other metals can sometimes also be found, for example aluminium.

The design of the transformer takes into account the fact that its operation leads to the production of heat and that this heat must be evacuated to avoid heating up the whole transformer. This would lead to a decrease in the electrical efficiency of the equipment, and possibly increase risks of overheating with subsequent fire danger.

5.2 CAPACITORS

Capacitors have in common with transformers the characteristic of possibly containing PCBs. However, their nature is different in that they are always sealed structures. The question of maintenance is thus not a major issue, as long as the capacitor remains in good condition and does not leak. However, at the end of their life-time they represent the same potential danger as transformers; also of course they are used in similar conditions as transformers. It is for these reasons that capacitors are also included in some chapters of this publication.

Capacitors are devices that can accumulate and hold an electrical charge. The main structure of a capacitor consists of electrical conducting surfaces (thin metallic foils) separated by a dielectric, i.e. non-conducting, material. These surfaces are coils of metallic foil. There are two electrically separated foil coils, each fitted with contacts leading out of the capacitor. The dielectric material is usually a dielectric fluid which or may not contain PCBs.

Three main types of capacitors exist. For more details, including the operation of capacitors, the reader is referred to the UNEP handbook cited above, Guidelines for Identification of PCBs and Materials Containing PCBs.

6 MANAGEMENT OF PCB TRANSFORMERS

6.1 IDENTIFICATION OF PCB TRANSFORMERS

A problem in drawing up guidelines for the identification of PCB transformers is that large numbers of different types of transformers have been designed and sold, and are now used across the world. No complete compendium of this equipment exists (but see UNEP's Guidelines for Identification of PCBs and Materials Containing PCBs). It is only possible therefore to give general guidance from which readers may draw some information relevant to their particular situation, and to the particular types of equipment with which they need to manage.

Early PCB-filled transformers were constructed much as a conventionally oil-filled unit would be. However, later designs were developed as totally or hermetically sealed units without drainage valves and access facilities. The rationale for this was that since PCBs have the reputation of being very stable fluids, they would not degrade as do normal oils, and the transformers could thus be sealed for life. Experience has shown that this is not the case.

Unfortunately there is no absolute method of externally identifying a PCB-type transformer. However, apart from the manufacturer's original nameplate (if still present and readable), there are some construction details that can greatly help in this task.

6.1.1 MANUFACTURERS' ORIGINAL IDENTIFICATION PLATES

Many transformer manufacturers fit identification plates to the transformers in addition to the main nameplate. These identification plates usually state that the transformer contains PYROCLOR, ASKAREL, etc., and that special handling precautions are therefore required.

A transformer generally contains a dielectric fluid that is only partially a PCB, since PCBs can be viscous. The mixture can thus include a mineral oil or another chlorinated organic liquid that is not a PCB. For example, trichlorobenzene or tetrachlorethylene can be used. These products are fluid and therefore reduce the viscosity of the transformer oil. This facilitates the flow of the liquid through the cooling ducts of the transformers, and thus increases cooling efficiency.

PCB dielectric fluids can be a blend a polychlorinated biphenyl and, for example, trichlorobenzene (TCB). The purpose of the TCB is to reduce the viscosity of the PCB to enable the fluid to circulate freely through the cooling ducts in the coils. The trade names given to PCB type transformer dielectric fluids are generally well publicised, but the following list of the most common fluids may be useful:

APIROLIO	(Italy)
AROCLOR	(U.K., U.S.A.)
ASBESTOL	(U.S.A)
ASKAREL	(U.K., U.S.A.)
BAKOLA 131	(U.S.A.)
CHLOREXTOL	(U.S.A.)
CLOPHEN	(Germany)
DELOR	(Czechoslovakia)
DK	(Italy)
DIACLOR	(U.S.A.)
DYKANOL	(U.S.A.)
ELEMEX	(U.S.A.)
FENCLOR	(Italy)
HYDOL	(U.S.A.)
INTERTEEN	(U.S.A.)
KANECLOR	(Japan)
NOFLAMOL	(U.S.A.)
PHENOCLOR	(France)
PYRALENE	(France)
PYRANOL	(U.S.A.)
PYROCLOR	(U.K.)
SAFT-KUHL	(U.S.A.)
SOVOL	(U.S.S.R.)
SOVTOL	(U.S.S.R.)

Careful examination of the technical specification on the transformer name plate or manufacturer's original drawing can assist in the identification of PCB transformers. Two points to look for are:

a) Type of cooling.

- Any of the following or their abbreviations indicates a fluid other than transformer oil:
- Liquid Natural Cooling (LN)
- Liquid Natural Air Natural Cooling (LNAN)
- Synthetic Natural Cooling (SN)

In principle these transformers do not contain PCB oils.

A name-plate showing ON or ONAN applies to “Oil Natural” or “Oil Natural Air Natural" cooling.

b) Density of transformer fluid.

An examination can be made of the weight of the contained cooling liquid as shown on the nameplate and this can be related to the volume of the transformer in gallons or litres. The specific gravity of chlorinated organic liquids is much higher than that of a hydrocarbon: in the region of 1.5, whereas oil is less than 1.0.

If a drain valve or sample valve is available, an easy test would be to take a sample of the fluid and establish its specific gravity. A value in the region of 1.5 would show that the oil contains PCBs.

A simple field-test is to add a few drops of the coolant into a test tube or flask filled with water. A PCB based coolant will rapidly sink to the bottom whilst a conventional oil or silicone will float on top of the water.

6.1.2 TRANSFORMER DESIGN

The design of a transformer can give a good indication as to the presence of PCB oils. Many PCB-containing transformers were at one time hermetically sealed. There are great variations between transformers from different manufacturers, but there are some typical common features:

- lids welded to the tank in later transformers;
- drain and sample valves not usually fitted;

- pressure relief valves often fitted; and

- disconnecting link boxes often fitted to allow cable testing without requiring access to the transformer unit.

In addition to such sealed transformers, which generally used PCB oils, there are transformers fitted with two types of connection to the outside:

a) *Drain and sample valves*. Such valves have been found more and more to be useful even in the case of a sealed transformer, where it was earlier thought unnecessary to take routine fluid samples. Pressure valves can also be present to take into account abnormal increases in pressure.

b) *Expansion chamber*. If transformers are subject to strong temperature changes, or if the dielectric fluid has a rather high coefficient of thermal expansion, it is necessary to have an expansion chamber. Such structures, which appear as a sort of "hat" at the top of the transformer, are not related to the presence or absence of PCBs.

6.2 IDENTIFICATION OF PCB OILS

It is important to identify accurately PCB fluids in capacitors and transformers. What is ideally required is a simple test that can be carried out rapidly, after sampling from the suspected transformer.

There are no rapid tests that can be used for the identification of PCBs. The analysis of these substances is generally done in a laboratory using various types of chromatography:

- packed column gas chromatography;

- thin layer liquid chromatography; and

- high performance liquid chromatography (HPLC).

Such analytical tests are indispensable if precise dosages of PCBs are required. However, quantitative tests are generally not required in the first stage of identification of the contents of a transformer. There are fortunately two types of methods that can give a rapid, if not necessarily accurate indication of PCB presence and/or content:

a) *Density test*. Because of their content of chlorine, which is a fairly heavy atom, PCB oils generally have quite high densities. This allows them to be distinguished in particular from mineral oils. The latter are usually lighter than water. PCB oils on the other hand can have a specific gravity of up to 1.5. This means that a PCB oil will always sink to the bottom of a mixture with water, while mineral oils will tend to float on the top.

b) *Chlorine test*. Fortunately, the presence of chlorine can be detected by simple chemical tests. There are "test strips" that are sensitive to the presence of chlorine. Also, when a chlorine-containing compound is burnt in the presence of copper, it will give a green flame. This is because the chlorine forms small amounts of copper chloride at the copper surface, and this substance volatilises to give a characteristic green flame.

After carrying out these simple tests, it may be required to confirm that the chlorine present is in fact due to the presence of PCBs, and not to that of another chlorine-containing substance. This can be done by chromatographic analysis, as described above.

These two simple tests will indicate therefore the presence of chlorine[4], such as exists in PCBs. The tests will give the same results with chlorinated mineral oils. These are used in transformers (see above) but do not present the same hazards as PCBs; they are nevertheless being withdrawn from use in electrical equipment. Non-chlorinated transformer oils will not give positive results with the above tests.

More information about analytic testing, and available analytic test equipment, is given in the UNEP <u>Guidelines for the Identification of PCBs and Materials Containing PCBs</u>.

6.3 MAINTENANCE OF PCB TRANSFORMERS

The overall maintenance of a transformer will be carried out in accordance with standard practices as described by the manufacturer and in the corresponding handbooks of the electrical industry. Presented here is an overview and guidelines on key aspects of transformer maintenance. At issue are the possible risks which might arise from the operation of transformers containing PCB oils. That is to say:

- risks arising from leaks of PCB oils;
- risks from fire; and
- risks appearing at the end of the working life of the equipment, when it has to be reclassified.

Maintenance in this context means, firstly, the regular on-going examinations and tests that could lead to the detection of an insufficiency in any aspect of the transformer performance. Secondly, maintenance is the taking of appropriate steps to remedy the defects identified.

The simplest and cheapest test that can be applied to a transformer in operation, or in store, is a visual examination. This will be complemented by periodic testing of the electrical performance, and by chemical tests, i.e. tests on the dielectric fluid itself, when possible.

4 Any type of chlorine and even table salt will give a positive result.

6.4 LEAKS FROM TRANSFORMERS

When a leak or seepage has been detected on a transformer, it is necessary to establish the cause of the leak to prepare remedial action.

Most common is leaks at seals and gaskets. Here there may exist some possibilities of carrying out effective reparations without affecting the main body of the transformer.

A more serious situation occurs when the leakage or seepage is due to a defect in the metallic structure of the transformer. It is necessary to examine the outside surface of the transformer regularly to ensure that any problem is detected at the earliest possible moment. Such leaks, due to a breakdown of the metallic casing of the transformer, can be due to several causes.

a) First of all, ***mechanical and accidental damage*** to the transformer casing can be the seat of a leak. Even if this is not the case, the damage may render the casing more liable to attack by acidity in the oil, by weakening it and increasing the chances of corrosion, and then leakage.

b) Secondly, a ***slow degradation of the oil***, described below, will make it more corrosive. This acidity may then cause internal corrosion at the weaker parts of the transformer, even if it is apparently in satisfactory condition. These weaker parts are the transformer cooling fins that are manufactured by bending, forming and possibly welding. These operations can cause stresses, and weakening of the structure, leading to more likelihood of corrosion.

Apart from repairing the leak, if possible, it is necessary in all cases to take effective action in respect of the oil that has been released. This means collecting all the contaminated materials, including gloves and clothing used in carrying out repair work, and placing these in appropriate receptacles for elimination.

6.5 PERFORMANCE EVALUATION

Transformers must be periodically checked to detect any changes which may be the first signs of a degradation in the performance of the transformer, and therefore of possible risks arising. The process of checking on various parameters will include the following characteristics:

a) *Electrical performance*. This is a direct evaluation of performance and will be carried out in accordance with the manufacturers' specifications. Generally, decreasing performance will be seen as changes in the input/output characteristics. These observations are thus essentially electrical.

b) *Level of oil in transformer*. Certain transformers will have direct or indirect devices allowing the oil level to be controlled. A decrease in oil level may be compensated for in certain cases by topping up with a similar dielectric oil.

c) *Changes in oil characteristics*. This control involves having access to the transformer oil. If this is possible, it is necessary to carry out certain measurements on the oil to ascertain whether the physical and electrical properties have not undergone deleterious changes. The various tests (*electrical* and *chemical*) that must be carried out on the oil are described below.

6.5.1 ELECTRICAL TESTS

The *dielectric test* is important to measure the oil's continuing efficiency. The test, carried out with recognised and authorised test equipment, measures the voltage at which the dielectric breaks down.

The *power factor test* is an indication of the loss in dielectric power of the oil.

Any shortcoming in these properties will be an indication that the oil has undergone some sort of chemical degradation. These chemical changes will be due to a number of factors related to the design of the transformer and the manner in which it has been used.

6.5.2 CHEMICAL TESTS

As already indicated, a transformer is a complex structure that can vary quite considerably from one manufacturer to another. All, however, include a system of cooling fins, implying complex shapes, and many welds. The cooling system is designed to allow the heat that is generated in the oil during its electrical functioning, to be evacuated through the cooling fins. This overall system means that several causes of degradation can develop:

pin-hole leaks in the welds leading to influx of moisture and/or air

excessive variations in the temperature of the oil, because of ambient temperatures changes, insufficient circulation leading to over heating, etc.

influx of air and moisture through seals and gaskets, etc.

The result of these incidents is essentially to allow air (oxygen) and water to interact with the PCB oil leading to chemical degradation of the oil. This chemical degradation can be detected and measured as follows:

a) The *acidity* of the oil will be the sign that oxidation of the oil has occurred, because of the presence of air (possibly under the effect of electrical fields and temperature). The acidity is measured as the number of milligrams of KOH (potassium hydroxide) required to neutralize one gram of oil. A new oil would have an acid value of less than 0.05 mg. A transformer oil is considered to be unusable if this value rises above 4 mg. The effect of acidity will of course be to favour corrosion of the metallic parts of the transformer, in particular the cooling fins which are thinner, and thus more sensitive to corrosion than the main casing of the transformer.

b) The *interfacial* test measures the surface tension between the oil and a non-miscible liquid such as water. As the organic, hydrophobic, transformer oil starts to degrade under the effect of oxygen or water, it becomes slightly less hydrophobic, and therefore the wetting angle with water changes. This test can therefore foresee subsequent decreases that will occur in electrical performance of the oil.

7 HEALTH AND SAFETY

Health and safety whilst handling PCB containing materials are of prime importance. The following chapter is not a rigorous presentation of measures to be taken in that context. Rather it is a series of guidelines that should encourage the operator to refer to more complete instructions and recommendations made by his local health authorities.

7.1 HANDLING PCB CONTAMINATED LIQUIDS AND EQUIPMENT

7.1.1 HEALTH PRECAUTIONS

Operatives handling PCB liquid and contaminated materials must take the following precautions:

a) Ensure *adequate ventilation* in the working area. Portable fans at ground level should be used in enclosed substations.

b) Wear full protective clothing, i. e.

- one-piece chemical resistant suit;
- chemical resistant gloves;
- boots, or disposable covers for shoes;
- fully approved face breathing mask, with a positive air flow from remote air compressor or bottles; and
- a full face mask with Type "CC' replacement canister can be used for low lever exposure.

The symptoms of PCB exposure are chloracne, eye irritation, drowsiness, headaches and a sore throat.

Under no circumstances must any operatives or observers smoke in the area where PCB is being handled.

Acceptable threshold limit values (TLV's) are usually not fixed by legislation. However we can cite here, for example, the levels recommended by the United Kingdom Heath and Safety Executive:

- for 42% chlorine content (e.g. Aroclor 1242): long term exposure: 1 mg/ m^3

- for 54% chlorine content (e.g. Aroclor 1254): long term exposure: 0.5 mg/m^3

In Germany the former Federal Health Office recommended the following:

- Tolerable Daily Intake (TDI): 1 mg per kg body weight per day

- Action to be taken if level exceeds 3,000 mg per m^3 of air

- Target: keep level below 30 mg per m^3 of air

Should any spillage of PCBs occur, this must be contained with absorbent materials, which would be placed in steel drums for subsequent approved disposal. Operatives dealing with spills must take the following first-aid precautions:

- if PCBs come into contact with eyes, immediately irrigate eyes with water for at least 15 minutes and obtain medical attention.

- if PCBs come into contact with skin, immediately remove any contaminated clothing and wash affected skin with soap and water.

- if swallowed, wash out mouth several times with clean water, drink water, and obtain medical attention.

- if inhaled, move to a fresh air zone and obtain medical attention.

7.1.2 PERSONAL PROTECTIVE EQUIPMENT (PPE)

Since the main danger from PCBs is skin absorption, careful consideration must be given to the choice of protective clothing including overalls, boots or overshoes, gloves and eye protection. PCBs will penetrate most materials, but certain materials including natural rubber are particularly permeable to PCBs and are thus unsuitable for use as protective garments. Chemical resistant fluorinated rubbers or elastomers are more suitable and laminated materials offer the best protection against PCBs.

No material is completely impervious to PCBs and therefore it is necessary to make certain that arrangements are in place to regularly change all PPE. The equipment supplier will normally provide details on the rate at which PCBs permeate protective equipment, this information will be useful in estimating, for each task, the time it takes for PCBs to penetrate through the protective equipment. This is known as the breakthrough time. This will depend on the frequency and duration of contact of the protective equipment with PCBs and may vary from one task to the next. The supplier should be able to provide typical breakthrough times for the different applications and say whether there is a need to reduce this time to allow for other factors such as abrasion.

If rubber boots are used, the boots need to be regularly discarded, and the foot protection reinforced by the use of disposable overshoes to be worn either inside or outside the boot.

For laboratory work, laboratory coats and suitable disposable gloves are necessary for protection against skin contact. If there is a danger of dust or fume formation (for example by heating) then the use of a fume cupboard is recommended. It will be necessary to treat all potentially contaminated protective equipment as PCB waste and dispose of it accordingly.

7.1.3 VENTILATION

Adequate ventilation will help ensure that levels of PCB vapour or aerosol do not build up. For purpose-built premises, ventilation can be an integral part of the design. For non-purpose-built premises or on temporary sites good general ventilation should be adequate as long as air is supplied at a higher level than it is extracted, thus ensuring a down-draught. PCB vapours and aerosols are likely to be heavier than air and more easily controlled by this method. Where mechanical ventilation is necessary it will be necessary to ensure that the air is extracted by air handling equipment with suitable filtration. To prevent environmental contamination, these filters may need to be of the two-stage variety: a fabric or electrostatic filter will remove aerosol and an activated carbon filter will remove vapour.

7.1.4 RESPIRATORY PROTECTIVE EQUIPMENT (RPE)

Respiratory protective equipment may be required, in particular if:

work areas are poorly ventilated;

work involves the less chlorinated, more volatile PCB congeners; or

work is liable to lead to aerosol formation, and if temperatures are abnormally high.

RPE must be selected which will give adequate protection for workers. This must be fully approved equipment. If workers use non-disposable RPE regularly in a dirty area, they need to be aware that their RPE may become contaminated with PCBs that can be transferred to their face. This contamination can arise from absorption and passage of PCBs through the mask's material, or more likely, from contamination from the inside of the mask due to handling and poor storage during periods of non-use. It must be ensured that workers are aware of these possibilities, and that they are informed about how to minimise these risks by regular cleaning and maintenance of their RPE. It is to be noted that disposable respirators are now being developed.

Workers wearing protective clothing while handling a PCB transformer.

7.2 ENVIRONMENTAL MONITORING

In working areas where PCBs are being handled, it is necessary to monitor the levels of chlorinated solvents. In practice, such chlorinated solvents will not be the PCBs themselves, which are only very slightly volatile at room temperature. Rather they will be other similar solvents often used in conjunction with PCBs: chlorinated hydrocarbons, which do have a characteristic smell. These would preferably be monitored automatically and continuously, fixing an alarm level at, say, 20 ppm (parts per million) of a chlorinated solvent in the workshop atmosphere.

It is also possible to use a cheaper, manual system to carry out spot checks. Such devices are testing tubes that change colour in the presence of a chlorinated vapour. Samples of air are drawn through the device at a given flow-rate.

The measurement of PCBs in ambient air is technically possible but a fastidious process, having to be carried out in two steps: sampling, followed by analysis in an appropriately equipped laboratory.

7.3 LEAKS AND SPILLS

7.3.1 EMERGENCIES

In the unlikely event of an accident, spill or leakage during shipment, certain emergency response measures must be taken immediately. Steps must be taken first of all to avoid unauthorised persons from approaching the area.

If liquid PCBs are leaking from a vehicle or from damaged or spilled containers, the drivers and/or safety personnel should attempt to control the spread of liquids. Spilled material should be prevented from entering sewers, streams or other bodies of water if at all possible. As soon as is practical to do so, the driver's supervisor or responsible official at the utility should be notified. The vehicle should not be left unattended until the spill is cleaned up.

If the operator of the vehicle is incapacitated, the emergency services must rely on the shipping papers to identify the type of quantities of hazardous material being transported. The shipping papers must be kept on the driver's seat or in the driver's side door container. In any accident, a timely and proper response can prevent a minor accident and spill from becoming a major catastrophe.

Transportation of PCBs is one of the highest risk areas for potential spills or leaks. Most problems occur during loading or unloading of the vehicle. Loading areas should have adequate spill response materials and spill prevention measures should be taken and spill control and clean-up materials should be available, should they be needed. Any subsequent movement of the contaminated wastes shall be made in strict accordance with the provisions of the Basel Convention on hazardous waste movements.

7.3.2 LEAKS FROM TRANSFORMERS

In the event of a PCB liquid spill from a transformer or capacitor, the following steps are to be taken.

1) A crew should *respond immediately* upon notification that a PCB spill has occurred.

2) All clean-up personnel handling PCBs and/or engaged in the actual clean-up are to wear *personal protective clothing and equipment* to prevent PCB contamination of clothing on skin.

3) It is extremely important that any *PCB fluid must be prevented from reaching storm drains, sewers, drainage ditches, or any other place where water is flowing*. The crew is to exercise every available option open to them to contain the PCB spill, including temporary diversion or bunding (use of retaining walls). In addition, the crew should anticipate and prevent water from flowing into the contaminated area from sources such as nearby sprinkler systems and/or street gutter runoff. Every reasonable effort should be made to stop or retard the flow of PCBs and contain that which has been discharged, using such manpower, equipment and material as is on site or immediately available.

4) If the PCB spill does reach flowing water, storm sewers or any inaccessible area, the first employee arriving at the spill area should initiate notification procedures immediately, and also initiate measures to *prevent any additional spill material from reaching water or lands*.

5) *Barricades* should be placed around the contaminated areas to prevent pedestrians and vehicles from entering until the spill material is cleaned up and removed.

6) In most cases, *oil absorptive material* is a useful clean-up tool. If used, it should be spread on the contaminated area and should be left in place for at least one hour, or as long as necessary to ensure that all PCB fluids have been absorbed.

7) After the spilled fluids have been absorbed, the absorptive material, along with any contaminated soils, should be placed in the *steel containers* provided for that specific disposal purpose. If conditions are such that PCB penetration cannot be determined, then at least 15 cm of soil depth should be removed.

8) All surfaces exposed to the spilled fluid should be *decontaminated with swabs* containing an efficient solvent, such as trichlorethane.

9) *Any contaminated steel structures, wood racks, cable trays (all types) etc*., should also be washed down with solvent. All equipment on these structures that may be contaminated by a PCB spill, but will not be removed, must also be similarly cleaned. Caution will be used with the solvent to prevent further contamination of equipment, vehicles etc. in the spill area.

10) *All types of structures, building, private vehicles* etc. that may be contaminated are to be washed down with solvent (taking care that the solvent does not damage the vehicle varnish). All necessary measures must be taken to prevent solvent and PCB from entering into any sewer or drainage system.

11) *All contaminated items, including tools, clothing, boots, and other equipment*, must either be thoroughly cleaned with solvent where practical, or disposed of in the steel containers provided specifically for disposal purposes.

12) *All drums* should be clearly identified and stored or loaded onto a vehicle. Drums must be carefully secured to avoid further spills.

13) The *vehicle carrying the drums* must also be labelled in accordance with transportation procedures.

14) The *containers* are to be taken directly to a licensed PCB storage area for subsequent shipment to a disposal point.

15) At large spills in densely populated areas, the *spill area will be continuously manned* until the spilled PCB oil and all clean-up materials have been removed from the site, secured in drums, or otherwise neutralised.

16) *If contact occurs between the skin and PCBs* a waterless hand cleaner should be used on the oil, the cleaner being disposed of in an appropriate container. If eye contact occurs, the eye should be thoroughly washed with water and specialise advice sought.

17) *Spills into water* require special consideration.

8 RECLASSIFICATION OF TRANSFORMERS

When it has been decided that the condition of a transformer is no longer compatible with the requirements of environmentally sound management (as may be set down in legislation), it is necessary to examine the different options that are available for treating the problem. There can be two basic reasons for reclassification of a transformer:

a) The transformer is found to have a PCB content which is above those levels which are acceptable in the local or regional regulatory situation. However the equipment is still in a satisfactory electrical and mechanical condition justifying it's continued use. In such cases, *retrofilling* of the transformer may be an option.

b) The transformer has been found to no longer comply with the specifications related to its use, for example due to poor electrical performance, poor mechanical condition or leaks. In these cases the transformer must be *replaced* by a new unit, and must also be *eliminated* by methods permitted by the relevant legislation.

Note: It has been found in many countries that there are two different reasons why a transformer may contain PCBs. The first is that the transformer was designed and built to be used with a PCB oil. These are the cases that have been considered up until now in this publication. However, experience has shown that many transformers sold, or labelled, as non-PCB transformers can in fact contain PCBs. This is because many transformers using conventional oil have been cross-contaminated by PCBs. In Europe, this figure may be as high as 45 per cent. The reason is that the facilities used many years ago for filling transformers were often employed both for PCB oils, and for other, non-PCB oils. Cross-contamination thus occurred and a transformer marked as a conventional oil transformer may contain well above 0.005 per cent (50 ppm) of PCBs, which is the ultimate threshold specified in Annex A of the Stockholm Convention. In such cases retrofilling is a practical method of reducing PCB levels to below 0.005 per cent.

9 RETROFILLING OF TRANSFORMERS

Retrofilling of a transformer means emptying the equipment of its dielectric fluid, and replacing this with a new non-PCB oil. As has already been mentioned, this operation can be quite long, since the inside of a transformer is complex. A more serious problem is related to the fact that the transformer usually contains wooden and possibly paper components. These materials are porous and retain the contaminated oil. It is thus not possible, in a relatively short time, to remove all the PCB oil. The result is that when a new, clean oil is placed in the transformer, there is a gradual leaching out of residual PCBs from the porous components. Over a period of weeks, or longer, the measured PCB level in the new transformer oil can slowly rise again, perhaps to above the levels which are legally permitted.

The time required for the leaching action to be finished, thus stopping any release of PCBs into the transformer oil depends on the size and structure of the equipment. In some cases it may be necessary to carry out several retrofilling operations, and this over several months.

It is possible in certain cases to retrofill a transformer whilst it is under load. This is usually done in cases where the equipment is inaccessible, for example on off-shore platforms.

A decision about the viability of doing a retrofilling operation will take into consideration local factors. These are basically the cost of carrying out the retrofilling operation, including disposal costs for the contaminated materials, to be set against the cost of buying a new transformer, if the original one is discarded. One will also take into consideration the legislation in force concerning the allowable level for PCBs in transformers. This would probably be about 0.005 per cent (50 ppm), as in most countries today. Parties to the Stockholm Convention will be obliged to eliminate the use of PCBs in equipment such as transformers and capacitors by 2025. They will also be required to make determined efforts designed to lead to environmentally sound waste management of liquids containing PCBs and equipment contaminated with PCBs (PCB content above 0.005 per cent) as soon as possible and no later than 2028. See Convention extract reproduced in Annex A of this publication.

9.1 RETROFILLING DECISION CHECK-LIST

A large number of factors will have to be taken into consideration before a decision can be made on retrofilling:

1) *What is the age of the equipment*? A transformer generally has an effective life of about 30 years. Does the remaining expected life-time justify retrofill? (Phase-out targets stipulated by the Stockholm Convention should also be taken into consideration.)

2) *What is the condition of the transformer*? Is the electrical performance of the transformer still satisfactory? What about signs of leaking, condition of seals, appearance of rust, etc.?

3) *What will be the effective shutdown time for the equipment*? If the transformer is taken

out of operation, what will be the impact on the stopping the electrical supply it was providing?

4) What is the potential impact on downstream users if the operation is stopped?

5) *Will there be positive results in terms of public perceptions if the transformer is decontaminated*? The fact that PCBs are no longer being used will have a marked positive effect on any persons or populations living near the transformer site.

6) *Is technology readily available for the retrofilling operation*? Is it available close to the transformer or must the unit be transported to the retrofilling site?

7) *Are suitable replacement fluids available, in view of the transformer's characteristics*? Electrical oils are not completely interchangeable. The transformer will have been designed to use a particular oil, and a similar non-PCB oil must be selected, or adjustments may have to be made in the design of the transformer.

8) Will retrofilling really reduce the PCB content of the oil, taking into account back-diffusion of PCBs from porous components of the transformer? As explained elsewhere, the complete removal of PCBs from the interior of a transformer may be a long process. This time requirement may be an important factor which will have to be taken into account.

8) *How will the waste transformer oil be eliminated*? Retrofilling implies removal of the PCB oil, and its decontamination. Such decontamination technology may be set up near the transformer itself. If not, and if the oil must be taken to an elimination site, the conditions of transport of such a hazardous material must be done in accordance with the provisions of the Basel Convention for such hazardous waste movements.

9) *How will other wastes generated by the retrofilling (clothing, sawdust, rags, etc.) be eliminated*? Such hazardous wastes, although not produced in large quantities, can represent a real elimination problem. Technologies described in the UNEP publications cited above, and applicable to well-defined cases (equipment, oils) are not suitable for decontamination or elimination of such products. It may be found that incineration is the only solution available. If shipment to an external high-temperature incinerator is planned, again the provisions laid down by the Basel Convention will have to be respected.

10) *What will be the total cost, taking into account all the above factors*? The economic aspects of carrying out a retrofilling operation must of course be calculated, and this will be done as a function of local conditions. The important point however is to be aware of *all* the costs factors which retrofilling involves.

9.2 REQUIRED CHARACTERISTICS OF PCB REPLACEMENT OILS

PCB replacement oils are used in two different contexts:

a) for the *filling of new transformers* (here the transformer can be designed to take into account the key characteristics of the oil: specific gravity, viscosity, and coefficient of thermal expansion in particular); and

b) for the *retrofilling of old transformers* (here the selected oil must take into account the design of the transformer, to make sure that it can operate with the physical properties of the new oil, mentioned above).

This publication considers the second case, where the transformer characteristics are known, and the replacement oil's characteristics must be chosen to accommodate these parameters. The selection of a replacement oil for retrofilling will therefore be made taking into consideration the following parameters:

1) *Electrical characteristics*. In principle these do not present any problems. The dielectric constant, breakdown point, etc. are chosen as a function of what is required by the conditions of use of the transformer;

2) *Fire-resistance properties*. It must be remembered that PCB oils were introduced many years ago when the danger of fires in electrical installations were seen as being of great importance. Since PCBs were seen as being eminently fire-resistant, and also very good electrically, their use became widespread. However, they were used in many environments where fire-resistance was not an over-riding factor; in a way, oils were therefore "over-qualified" for the uses for which they were required;

3) *Density*. The density of a replacement oil might be a problem if much higher than the original one. However, PCBs have high specific gravities, and thus the change to a lower density oil should not cause mechanical problems in the transformer.

4) *Coefficient of thermal expansion*. This property is of great importance. Transformers are not only required to work in different climatic conditions, but the operation of the transformer itself leads to electrical energy losses which appear as heat. Marked temperature changes may thus occur. It is essential therefore that the transformer be designed to accept volume changes resulting from changes in temperature.

5) *Viscosity*. A transformer is designed firstly to allow electrical field changes with the minimum of electrical losses, and secondly to cool the oil which is absorbing the energy losses and producing heat. This heat is removed by circulating the oil through cooling fins that are an essential part of the transformer design. The movement of the liquid through small channels is more efficient for lower oil viscosities. The temperature dependence of the oil viscosity is also

of importance.

6) *Flash point and flammability*. Although the flash and fire points of the replacement PCB oils will not approach those of the PCB oils, they should be as low as possible.

7) *Combustion by-products*. This may not be a determining factor for oil selection, but the behaviour of the oil upon combustion must be known. To take extreme examples, it can be said in general that a hydrocarbon oil will burn to harmless by-products, such as water, carbon dioxide, etc., if it burns in ideal conditions (although black smoke will be produced in the case of shortage of oxygen). On the other hand, a silicone oil will produce silica, and therefore dense white smoke. It can be noted that PCBs are fire resistant because of the presence of chlorine, an element which hinders combustion and which is often used in fire retardants.

8) *Environmental considerations*. An oil called upon to replace PCB oils must of course not present the same disadvantages as PCBs with respect to the environment. It will therefore be non-toxic. The main characteristic which is looked for is biodegradability: the ability of the oil, if spilt, to be decomposed slowly in the environment, by natural effects, in particular micro-organisms and sunlight. In addition, the combustion products should present no special danger from the toxicity point of view.

9.3 OTHER CONSIDERATIONS

Replacement oils offered on the market today are all of course suitable for use in electrical equipment. They may however not be suitable for a particular use, e.g. for a transformer being used in certain conditions. The reason is that transformers have a variety of designs, and that these designs call for a transformer oil with the appropriate properties.

A transformer can be either hermetically sealed, or be of the "breathing" type; this means a transformer which is not completely sealed and which may also be fitted with an expansion chamber to take into account variations in density, and therefore of volume, as a function of temperature.

In the case of transformers that can accommodate temperature changes, and this is seen by the expansion chamber placed outside the transformer (above it), it is possible to use an oil which has a relatively high coefficient of thermal expansion. The temperature changes will in these cases be absorbed by the transformer design.

However in the case of a sealed transformer, it is imperative that the replacement oil have the same thermal expansion coefficient as the original oil, to avoid the generation of high internal pressures as the temperature rises.

9.4 CONTROL MEASURES FOR RETROFILLING

9.4.1 HANDLING OF PCB-CONTAINING TRANSFORMERS

Transformers are best drained on-site before transportation to the specialist retrofilling facility. The PCB fluid needs to be transferred to metal drums of appropriate quality for transportation to their elimination destination. It is recommended that absorbent material be made readily available so as to facilitate dealing with any spillage that may occur. To reduce potential exposure to the fluid, it is necessary to avoid all manual operations such as decanting. Mechanical pumping of fluids is better. It will be necessary of course to wear personal protective clothing (PPE) during these procedures to prevent skin absorption. During draining there will be a need to prevent splashing and any spillage. Precautions will also need to be taken to avoid and prevent the spread of any leaks or overflow. Respiratory protective equipment will be necessary if ventilation is poor.

9.4.2 PROVISION OF FACILITIES FOR HANDLING AND DISMANTLING EQUIPMENT CONTAINING PCBS

It is recommended that the central facility be divided into clean and dirty work areas, separated by a changing facility. Clean and changing areas should have smooth impermeable surfaces. Transformers and capacitors should only be dismantled in the dirty area. This dirty area should be a discrete area, preferably a separate room. The work benches of the dirty area need to be covered with a smooth impervious material and be fitted with lip edges to retain any spills. The floors of the dirty area need to be constructed of, or covered by, a smooth impervious material, and have a low retaining wall (bund) to contain spillage. The bunded area should not be connected to any public drainage system. A large enough opening will needed to bring transformers and capacitors into the dirty area. To reduce potential back-contamination this needs to be screened by plastic strips (or other suitable means).

Over time, the floor of the dirty area is likely to become contaminated with PCBs, especially if the concrete is cracked or damaged. Depending on the extent of work done, the flooring may need to be removed at intervals, or possibly just when the area is no longer used for work with PCBs. The floor life may be extended by using wooden or fibreboard mats when dismantling large transformers. In addition to physically protecting the floor, these mats will also absorb small spills or drips of PCB. Contaminated flooring and mats will need to be treated as PCB waste. Personnel access to the working surfaces should only be by way of a changing area. It is recommended that the dismantling facility include the following:

- an entry to the clean side;
- shower/toilet area;
- a dirty side, where PPE may be put on; and

- an exit to the work area.

There may need to be an area set aside for mid-shift and other breaks. This area would have restricted access. No one wearing contaminated PPE would be allowed in. In the shower/toilet area, individual lockers must be provided to allow storage of clean clothing.

9.4.3 PRECAUTIONS REQUIRED WHEN CUTTING PCB-CONTAINING EQUIPMENT

When sealed *transformers* are dismantled (to allow access to the core) there is the possibility that PCB vapour, fumes or aerosols may be generated. Work practices should be adopted to minimize the generation of these. For example, as the temperature increases, so will the vapour pressure of the PCB and hence its ability to form a vapour. This effect can be very pronounced at higher temperatures. The vapour pressure of Aroclor 1260 increases ten-fold between 300°C and 600°C and that of Aroclor 1248 increases a hundred-fold between 0°C and 500°C. There is also some evidence that under certain conditions, temperatures of between 200°C and 450°C can produce slow formation of furans and that with higher temperatures, between 450°C and 700°C dibenzofuran generation is possible. Because of this, it is clear that any sort of flame cutting or welding process should be avoided if it is reasonably practicable to do so. The heat from the flame will not only vaporise PCBs on the surface of the piece being cut, but will spread to adjacent parts and increase the volatilisation of nearby PCBs.

Capacitors need to be punctured and drained (if they contain liquids) in a way that minimises the production of aerosols or vapour. If this is an automated process, testing will confirm that any aerosol or vapour is confined to areas around the process where there are unlikely to be any personnel. *If* this process is performed manually then local exhaust ventilation may be required.

Mechanical cutting of equipment is the preferred option, but it should be remembered that it can generate localised heat or cause aerosol formation. These effects are most pronounced when cutting speeds are high. It is therefore recommended that when mechanical cutting is used, cutting speeds are reduced to as low as possible consistent with effective use.

9.4.4 EMPTYING OF PCB TRANSFORMERS

It must be appreciated that even when great care is taken to remove as much of the original oil from the transformer tank as possible and after allowing a period of two hours for the transformer to "drip" off some surface oil from the windings, there will still be contaminated oil trapped within the core and coils. In the case of distribution transformers it is generally found that there is a 10 per cent retention in the core and coils and that the PCB contamination reaches equilibrium with the new oil after a period of 90 days on load cycles. Thus if the original oil was found to be contaminated to a level of 500 ppm a retrofill of new oil will stabilise at 50 ppm of PCB after 90 days.

9.4.5 PRECAUTIONS NEEDED FOR FLUSHING EQUIPMENT TO REMOVE PCBS

If the transformers have been washed through with solvent, possible exposure to these solvents must be considered, and appropriate measures taken. Reduction of exposure may be accomplished by increased ventilation at the work station or by a system of work which reduces the need for operator presence when the flushing takes place. The use of PPE should be regarded as the method of last resort, to protect against residual risk only.

9.4.6 HANDLING PCB-CONTAINING CAPACITORS

Capacitors are best removed from the site of origin as whole units and placed in metal containers that can be sealed to await transportation to a licensed storage site or an authorised elimination plant. Leaking units require specialised handling. It is recommended that all leaks be absorbed with sawdust, sand or earth and the units and the contaminated absorbing material, be stored in metal containers ready for disposal. As capacitors are likely to contain more volatile congeners, large spills or spills in confined spaces may require respiratory protection, as well as skin protection measures.

10 ALTERNATIVE FLUIDS FOR RETROFILLING

There are many dielectric oils that can be employed for refilling transformers. It must be said that the product chosen may depend on, apart from the oil's characteristics, local and regional practice. For example, silicone oils are used in some countries, and not others, even if all these countries have the same environmental and industrial legislation. The following are examples of different classes of replacement fluids that may be considered:

10.1 MINERAL OILS

These are in fact "conventional" oils that can be, and have been, used in transformers. The basic difference with the subsequently used PCB oils is of course their greater flammability. However, a closer analysis of the fire risks in certain transformer applications may make it acceptable to use such a higher flammability fluid.

Certain transformers, because of the way in which they operate and the place in which they are located, can accept a higher fire risk, for example in out-of-door uses. Thus conventional hydrocarbon oils can be considered as replacements for PCB oils in well-analysed situations. The decision will be a matter of trading off advantages and disadvantages from the environmental, fire risk, economic, and legislative points of view.

Many such conventional oils are available from major oil companies, and also from some smaller, specialised companies.

10.2 SILICONE FLUIDS

These fluids contain no chlorine; they are organo-silicon compounds. They are used in the manufacture of new transformers in Europe and the United States. Their properties lead however to certain consequences for practical use in the case of retrofilling:

1) Silicone fluids are particularly sensitive to water and it is important to handle them accordingly. The maximum water content is 50 ppm.

2) The transformer must be completely sealed because of this sensitivity to water.

3) The lower electrical performance means that a de-rating factor of about 7 per cent should be applied to the transformer after conversion, i.e. it is necessary to operate the transformer at a lower rating.

4) The coefficient of thermal expansion is greater than that of the original PCB oil, and this requires modifications to be made to the tank to enable the transformer oil to expand without damaging the transformer casing.

5) A silicone oil contaminated with PCB is more difficult to dispose of than the original PCB. This is because during incineration, silica (a silicon oxide powder) is formed around the

burners causing problems in the gas scrubbing plant.

6) Tapping switches fitted to the transformer may require changing. When they are used in new transformers, the transformer design can take care of these different properties compared to PCB oils. However, when used as a replacement for PCB oils in an existing transformer, it will be necessary to modify the transformer to take account of these different properties, in particular concerning the thermal expansion coefficient. This means that silicone are more difficult, and thus more expensive to use as replacement fluids.

It should be noted that under no circumstances should normal transformer oil be mixed with silicone oils, and vice versa; the two fluids are not compatible.

10.3 SYNTHETIC ESTER MATERIALS

These are well-established replacements with good properties. The fluid has marked technical advantages over many others, namely:

- no de-rating factor after conversion
- good electrical properties; and
- suitability for up-grading oil transformers to become classified as less flammable.

The disadvantage of synthetic ester oils is their higher price.

Various other oils have been proposed, for example some chlorinated hydrocarbons. Whilst not being PCBs, such oils contain chlorine and are thus used less and less. There are also natural oils manufactured from biomass sources.

Some key properties of these types of replacement oils are presented in Table 1. Table 2 shows the specifications of replacement oils set out by three Standards Commissions. (Slight variations among them will be observed.)

A selection of data sheets of some commercially available PCB replacement oils on the marker will be found in Annex B. The selection is of course not exhaustive, and other products will be found to be available. The sheets do show, however, that the properties of the replacement oils can vary considerably, and that a choice will have to be made as a function of the operational characteristics of the transformer that is to be retrofilled.

Table 1: Basic properties of replacement oils

	Mineral oil	Silicone oil	High mol. Wt. Hydro-carbon	Synthetic ester	Natural ester
Dielectric break-down (Kv)	45	40	52	43	56
Viscosity (cSt) 40^0 C 100^0 C	 9.2 2.3	 39 17	 113 12	 29 5.6	 33 8
Flash point (^{0}C)	147	300	276	270	324
Fire point (^{0}C)	165	343	312	306	360
Specific heat	0.39	0.36	0.45	0.45	0.50
Pour point (^{0}C)	- 50	- 55	- 21	- 50	- 21
Specific gravity	0.87	0.96	0.87	0.97	0.92
Biological oxygen demand (ppm)	6	0	6	24	250

Table 2: Replacement oil specifications of three Standards Commissions

Characteristics	IEC 296 (Class II)	ASTM D 3487	BS 148/84
Density at 20°C	< 0.895	0.91	< 0.895
Viscosity at 40°C mm^2/s	< 11.0	< 12.0	< 11.0
Viscosity at – 30°C mm^2/s	< 1800		< 1800
Pour point °C	< –45	< – 40	< – 45
Flash point PM °C	> 130		> 130
Flash point COC °C		> 145	

Neutralisation value Mg KOH/g	< 0.03	< 0.03	< 0.03
Antioxidant content for Uninhibited oils %	not detectable	0.08	Not detectable
Water content %	< 0.003 % for bulk < 0.004 % for drums	< 0.0035 %	< 0.003 % for bulk < 0.004 % for drums
Interfacial tension nM/m	> 40	> 40	-
Breakdown voltage as delivered kV	> 30	-	> 30
Treated kV	> 50	>70	-
Dielectric dissipation factor at 90°C	0.005	0.003 (at 100°C)	0.005
Oxidation stability	no comparable requirement		

* The comparisons are between the following national or international standards.

IEC: International Electrotechnical Commission
ASTM: American Society for Testing Materials
BS: British Standard

11 ELIMINATION AND/OR REPLACEMENT OF PCB TRANSFORMERS

Although not within the scope of this publication, a few comments can be made here about the elimination and replacement of PCB transformers. More details about available technologies for the elimination of transformers can be found are described in UNEP's publication, Survey of Currently Available Non-Incineration PCB Destruction Technologies, cited above.

It should be remembered that all transportation of hazardous wastes containing PCBs are covered by the Basel Convention, to which reference should be made for further guidance on the shipping of such wastes.

11.1 TRANSFORMER ELIMINATION

If a transformer is found to have a PCB content resulting in it having to be a classified as a "PCB transformer" and if retrofilling has been rejected as a viable option for dealing with it, the problem has to be faced as to how to eliminate this equipment.

The main problem related to transformer elimination is that of knowing what technologies are available for this purpose. In Europe and the United States, for example, the problem is relatively easy since there is a choice of methods. In these countries incineration is mostly used, although this is combined with some sort of pre-treatment allowing recovery of some or most of the metallic components. Incineration is widely used but can be more expensive than other, less drastic techniques. Amongst these may be cited the complete dismantling of the transformer, with separation into similar metals, decontamination of these metals, and recycling as appropriate.

The contained oil will be either incinerated, or treated with a solvent to extract the PCB. This PCB concentrate will be sent to a chemical company for conversion to hydrochloric acid. Decontamination of the transformer oil by chemical methods is little used in developed countries, because of the prevalence of incineration. Oils are easy to transport in drums, and their incineration is easier, and thus cheaper, than for equipment such as transformers and capacitors.

For other countries, with no easy access to incineration, one of the technologies described in the UNEP publication mentioned above will be applicable.

11.2 TRANSFORMER REPLACEMENT

It may be noted that new transformers can now either conform to conventional designs, and still use a dielectric, non-PCB fluid, or be of completely new design.

In the former case, as with retrofilling, the transformer is still based on the use of a fluid which has the appropriate dielectric properties, and which also acts as the coolant, circulating through cooling fins. Examples of such dielectric replacement oils are described in chapter 10 above.

In the second case, new technology means that transformers can be quite different, internally, to conventional transformers. Such transformers are generally dry, that is to say they contain no liquid dielectric:

a) *Cast resin transformers* have a core that is a solidified resin around the electrical wiring. The main problem here is to prevent changes in temperature bringing about stresses leading to cracks. Such problems appear now to have been overcome. The resin should of course be fire-resistant with appropriate non-chlorine additives therefore to reduce the effects of any fire.

b) *Gas filled transformers* have been developed which contain a gas such as sulphur hexafluoride under pressure to act as the dielectric fluid and cooling vector. It is beyond the scope of this publication to present detailed information about replacement transformers. Such information will be obtainable from well-known suppliers of such equipment in each region or country.

12 SOURCES OF FURTHER INFORMATION

This publication is intended to give an overview of the problems related to the management of PCB-containing electrical equipment. More detailed information on the different aspects of such management is available from other sources, in particular on Internet web-sites. Examples of these sources are given below. They cover both professional electrical equipment associations, and individual supply and service companies. This list is not exhaustive and does not indicate any preference for the cited organisation or company.

12.1 GENERAL MAINTENANCE

Information about the maintenance of transformers can be found on many sites on Internet; the following are cited here:

- http://www.atd.siemens.de
- http://www.electricityforum.com
- http://www.swgr.com
- http://www.members.aol.com
- http://www.winder.uk
- http://www.sunohio.com
- http://www.abb.com
- http://cix.co.uk

12.2 RETROFILLING

Covered by some of the above sites, and also:

- http://www.er.doe.gov
- http://www.cgli.com
- http://dynex.com
- http://cogentregs.com

- http://www.nttworldwide.com
- http://www.mcdean.com

12.3 BOOKS

Many books deal with this subject. A selection is:

- Electrical power transformers and power equipment, Fairmount Press (www.pearsonptg.com)
- Transformers and motors, G Schultz
- Transformer oil handbook, from Nynas (see fiches)

The website http://www.usbr.gov/power/dat contains chapters of a book on transformers, including their maintenance.

Lists of relevant books can be found on the website http://www.processassociates.com

12.4 GENERAL INFORMATION ON PCBS AND LEGISLATION

- http://www.defra.gov.uk
  Overview of UK legislation and available documents.
- http://www.epa.gov
  US regulations concerning reclassification of PCB transformers.
- http://dla.mil
  Overview of TSCA regulations as applicable to PCBs.
- http://www.rcctt-lac.org.uy
  Guidelines on PCB and similar wastes.
- http://www.ec.gc.ca
  Relevant Canadian legislation.

The websites of UNEP Chemicals and the Basel Convention contain detailed information on all aspects of PCBs:

- http://www.chem.unep.ch
  UNEP Chemicals have also issued a CD-ROM covering all their activities, which may be obtained by sending an e-mail to: chemicals@unep.ch

- http://www.basel.int
  The sub-section "publications" gives access to information on all aspects of the management, transport and elimination of hazardous wastes.

ANNEX A : EXTRACT FROM THE STOCKHOLM CONVENTION CONCERNING PCBS

See also, for example, Articles 3, 5 and 6, and Annex C of the Convention. The full text and further information on the Convention may be found at www.pops.int

STOCKHOLM CONVENTION ANNEX A

Part II

Polychlorinated biphenyls

Each Party shall:

(a) With regard to the elimination of the use of polychlorinated biphenyls in equipment (e.g. transformers, capacitors or other receptacles containing liquid stocks) by 2025, subject to review by the Conference of the Parties, take action in accordance with the following priorities:

(i) Make determined efforts to identify, label and remove from use equipment containing greater than 10 per cent polychlorinated biphenyls and volumes greater than 5 litres;

(ii) Make determined efforts to identify, label and remove from use equipment containing greater than 0.05 per cent polychlorinated biphenyls and volumes greater than 5 litres;

(iii) Endeavour to identify and remove from use equipment containing greater than 0.005 per cent polychlorinated biphenyls and volumes greater than 0.05 litres;

(b) Consistent with the priorities in subparagraph (a), promote the following measures to reduce exposures and risk to control the use of polychlorinated biphenyls:

(i) Use only in intact and non-leaking equipment and only in areas where the risk from environmental release can be minimised and quickly remedied;

(ii) Not use in equipment in areas associated with the production or processing of food or feed;

(iii) When used in populated areas, including schools and hospitals, all reasonable measures to protect from electrical failure which could result in a fire, and regular inspection of equipment for leaks;

(c) Notwithstanding paragraph 2 of Article 3, ensure that equipment containing polychlorinated biphenyls, as described in subparagraph (a), shall not be exported or imported except for the purpose of environmentally sound waste management;

(d) Except for maintenance and servicing operations, not allow recovery for the purpose of reuse in other equipment of liquids with polychlorinated biphenyls content above 0.005 per cent;

(e) Make determined efforts designed to lead to environmentally sound waste management of liquids containing polychlorinated biphenyls and equipment contaminated with polychlorinated biphenyls having a polychlorinated biphenyls content above 0.005 per cent, in accordance with paragraph 1 of Article 6, as soon as possible but no later than 2028, subject to review by the Conference of the Parties;

(f) In lieu of note (ii) in Part I of this Annex, endeavour to identify other articles containing more than 0.005 per cent polychlorinated biphenyls (e.g. cable-sheaths, cured caulk and painted objects) and manage them in accordance with paragraph 1 of Article 6;

(g) Provide a report every five years on progress in eliminating polychlorinated biphenyls and submit it to the Conference of the Parties pursuant to Article 15;

(h) The reports described in subparagraph (g) shall, as appropriate, be considered by the Conference of the Parties in its reviews relating to polychlorinated biphenyls. The Conference of the Parties shall review progress towards elimination of polychlorinated biphenyls at five year intervals or other period, as appropriate, taking into account such reports.

ANNEX B : EXAMPLES OF PCB REPLACEMENT OILS

The following fiches have been prepared from information obtained from various transformer oil manufacturers. The list is not exhaustive but shows the properties of the various PCB-free oils on the market. The data shows that oil properties can vary considerably, and this is to enable a suitable oil to be selected for retrofilling, as a function of the transformer's design and operational characteristics, as explained earlier.

Although every effort has been made to obtain representative information about these PCB-replacement oils, UNEP Chemicals cannot be held responsible for any errors or omissions in the data presented. Neither does it endorse or certify any product or process cited in the document. UNEP Chemicals is willing to up-date this information in future editions of this publication and therefore invites companies to provide useful further information on this subject.

Company	**ABB Power T & D Co. Inc**
	Raleigh North Carolina 27502 United States
Name of product	BIOTEMP®
Chemical family	vegetable based oleic oil

General properties		
	test method (all ASTM)	BIOTEMP®
Physical state		liquid
Colour	D1500	0.5
Specific gravity at 15°C		0.91
Flash point °C	D92	300
Fire point °C	D92	320
Pour point °C	D97	-15 to -25
Viscosity, cp 0°C 40°C 100°C	 D445 D445 D445	 300 45 10
Biodegradability		97%

Electrical properties		
Dielectric breakdown voltage kV at 60 Hz a) disc electrode b) VDE electrode	D877 D1816	45 74
Dissipation factor (power point) at 60 Hz, % 25°C 100°C	D924 D924	0.025 1.0
Chemical properties		
Corrosive sulphur	D1275	non-corrosive
Neutralisation value mg KOH/g	D794	0.06
Gassing tendency	D2300b	1µlitre/min

Company		**Agip Petroli**	
		via Laurentina, 449 00144 Roma Italy	
Name of product		Agip ITE 320 and 360	
Chemical family		mineral oil	
General properties			
	Test method IEC	AGIP ITE 320-320L	AGIP ITE 360-360L
Physical state		liquid	liquid
Aniline point °C		66	78
Density at 20°C, kg/l	ASTM D 1298	0.880	0.890
Flash point °C	ASTM D 92	145	152
Fire point °C	ASTM D 92	170	180
Pour point °C	ASTM D 97	– 48	– 33
Kinematic viscosity mm^2/s			
– 30 °C	ASTM D 445	1220	
– 15 °C	ASTM D 445		254
40 °C	ASTM D 445	9.3	14.03
100 °C	ASTM D 445	2.67	3.32
Interfacial tension, dynes-cm	ASTM D 971	45.5	47.3
Biodegradability	OECD 301 B	6% after 28 days	
Electrical properties			

Dielectric breakdown voltage kV at 50 Hz	IEC 156	60	60
Dissipation factor (power point) at 90°C, 50 Hz, %(after IEC 296 treatment)	IEC 247	0.001	0.001
Chemical properties			
Corrosive sulphur	ASTM D 1275	non-corrosive	
Neutralisation (acid no.) mg KOH/g	IEC 296		
Oxidation stability	IEC 74	0.1	0.1
Sludge % wt		0.02	0.02
Induction time, h		12.4	12.4
Oxidation inhibitor		none	none
Water, max. ppm		30	30

Company	**Dow Corning**	
	Midland Michigan United States	
Name of product	561® Transformer Fluid	
Chemical family	polydimethyl-siloxane polymer	
General properties		
	test method	561® Transformer Fluid
Specific gravity at 25°C	ASTM 1298	0.957 - 0.964
Flash point °C	ASTM D 92	268
Fire point °C	ASTM D 92	371
Pour point °C	ASTM D 97	– 50
Viscosity 0°C 25°C 40° C 100°C	ASTM D 445;D2161	81-92 47.5 35-39 15-17
Interfacial tension, dynes-cm	ASTM D 971	20.8
Moisture content	ASTM D 1533	50 max
Specific heat cal/g/°C 25°C	ASTM D 2766	0.360
Coefficient of expansion cc/cc/°C	ASTM D 1903	0.00104

Thermal conductivity cal/(sec.cm^2.°C)/cm	ASTM D 2717	0.00036
Electrical properties		
Dielectric strength 25°C kV at 60 Hz	ASTM 877	35
Dissipation factor 25°C 100°C	ASTM D 924	 0.0001 0.0015
Dielectric constant, 25°C	ASTM D 924	2.7
Volume resistivity ω-cm 25°C	ASTM D 1169	1 X 10^{14}
Main products on combustion: plus solid products:	Hydrogen, water, CO, CO_2, CH_n SiO_2, C	

Company	**Ergon Inc.**
	Vicksburg Massachusetts 39181 United States
Name of product	HYVOLT II
Chemical family	Hydrotreated light naphthenic distillate

General properties

	test method (all ASTM)	HYVOLT II
Aspect		clear and bright
Colour	D 1500	0.5 max
Specific gravity at 25°C	D 4052	0.889
Flash point °C	D 92	149
Aniline point °C	D 611	70.4
Pour point °C	D 97	– 55
Viscosity, cSt 40°C 100°C	 D 445 D 445	 9.8 2.4

Electrical properties		
Dielectric breakdown kV at 60 Hz	D 877	40
Power factor %, 25 °C 100 °C	D 924 D 924	0.005 0.084
Chemical properties		
Corrosive sulphur	D 1275	non-corrosive
Interfacial tension 25 °C, dynes/cm	D 971	51
Neutralisation no. mg KOH/g	D 974	< 0.01
Water content Karl Fisher, ppm	D 1533	14
Oxidation stability 72 hrs % sludge by mass acid no. KOH mg/g 164 hrs % sludge by mass acid no. KOH mg/g	D 2440	 0.1 max. 0.3 max. 0.2 max. 0.4 max.

Company	**Lubricants USA Fina**
	Plano Texas 75075 United States
Name of product	DIEKAN 410 (other grades available)
Chemical family	Inhibited naphthenic mineral oil

General properties

	test method (all ASTM)	DIEKAN 410
Physical state		liquid
Colour	D 1500	0.5
Specific gravity	D 1298	0.8959
Flash point °C	D 92	300
Fire point °C	D 92	149
Pour point °C	D 97	- 62
Viscosity, cSt 40°C 100°C	 D 445 D 445	 10.9 2.54

Electrical properties		
Dielectric strength kV	D 877	40
Dielectric breakdown 60 Hz disc electrodes	D 877	38
Power factor %, 25 °C 100 °C	D 924 D 924	0.002 0.070
Chemical properties		
Corrosive sulphur	D 1275	no corrosion
Neutralisation no. mg KOH/g	D 794	0.014
Gassing tendency µl/min Procedure A Procedure B	D 2300	15 30
Oxidation stability 72 hrs % sludge acid number	D 2240	0.1 0.1
Water content ppm	D 1533	21
Aniline point °C	D 611	74

Company	**M & I Materials**
	PO Box 136 Manchester M60 1AN Great Britain
Name of product	MIDEL® 7131
Chemical family	pentaerythritol fatty acid ester

General properties

	Requirements of IEC 1099 norm	MIDEL® 7131
Colour (hu units)	< 200	125
Density at 20 °C, kg/l	< 1	0.97
Flash point °C	> 250	275
Fire point °C	> 300	322
Pour point °C	< - 45	- 48
Kinematic Viscosity, mm^2/s 40°C - 20°C	 < 35 < 3000	 30 1700
Biodegradability	(EEC 79/831 method)	83% after 28 days

Electrical properties		
Breakdown voltage, kV	> 45	80
Dielectric dissipation factor at 90°C, 50 Hz	< 0.03	0.004
DC resistivity at 90°C, G ω-m	> 2	9
Chemical properties		
Neutralisation value, mg KOH/g	< 0.03	0.02
Oxidation stability sludge % wt acidity, mg KOH/g	< 0.01 < 0.3	0 0.01
Induction time, h		12.4
Water content, mg/kg	< 200	50

Company	**Nippon Petrochemicals Co., Ltd**
	1-3-1 Uchisaiwai-cho Chiyoda-ku, Tokyo 100-8530 Japan
Name of product	PXE (Phenyl xylyl ethane) (other types available)
Chemical family	synthetic hydrocarbon oil

General properties

	Test method	PXE
Colour (hu units)	JIS K 2580	+30
Aniline point	JIS K 2256	15
Density at 15 °C, kg/l	JIS C 2101	0.988
Flash point °C	JIS C 2101	152
Fire point °C	JIS K 2265	170
Pour point °C	JIS C 2101	- 47.5
Viscosity kinematics, mm^2/s 40°C 100°C	 JIS K 2283 JIS K 2283	 5.2 1.6
Biodegradability	MITI method	good degradability

Electrical properties		
Dielectric breakdown voltage, kV at 50 Hz	JIS C 2101	70 min.
Dissipation factor at 80°C, 60 Hz %	JIS C 2101	0.002
Dielectric constant at 80°C	JIS C 2101	2.51
Volume resistivity at 80°C, Ω cm	JIS C 2101	$1.5x10^{15}$
Chemical properties		
Corrosive sulphur	JIS C 2101	no corrosion
Neutralisation (acid no.), mg KOH/g	JIS C 2101	0.00
Oxidation inhibitor		none
Water, max. ppm		50

Company	**Nynas Naphthenics AB**
	PO Box 10701 121 29 Stockholm Sweden
Name of product	Nytro 10GBN, 10BN, 10GBX (others also available)
Chemical family	napthenic oil

General properties

	Test method	Nytro 10GBN (uninhibited)	Nytro 10BN (uninhibited)	Nytro 10GBX (inhibited)
Density at 20 °C, g/dm^3	ISO12185	0.886	0.882	0.886
Flash point °C	ISO2719	148	144	148
Fire point °C				
Pour point °C	ISO3016	- 57	- 57	- 57
Viscosity kinematics, cp -30° C 40°C	ISO3104 ISO3104	1180 8.9	870 8.0	1180 8.9
Interfacial tension, dynes/cm	ISO6295	49	44	49

Electrical properties				
Dielectric breakdown voltage before treatment Kv after treatment Kv	IEC 156 IEC 296	40-60 > 70	40-60 > 70	40-60 > 70
Dissipation factor (power point) at 90°C	IEC 247	< 0.001	< 0.001	< 0.001
Chemical properties				
Neutralisation value, mg KOH/g	IEC 296	< 0.01	< 0.01	< 0.01
Oxidation stability a) 100°C, 164 h neutralisation value mg KOH/g sludge wt % b) 120°C, 164 h total acidity, mg KOH/g sludge wt % c) 120°C, induction h	IEC1125A IEC1125C IEC1125B	 0.15 0.02 0.26 0.08	 0.09 < 0.02 - -	181
Corrosive sulphur	ISO 5662	non-corrosive	idem	idem
Water content mg/kg	IEC 814	< 20	< 20	< 20
Aromatic content %	IEC 590	14	10	14

Company	**Shell** (many offices across the world)		
Name of product	Diala D, M (other grades available)		
Chemical family	naphtenic oil		
General properties			
	Test method	Diala D	Diala M
Purity, aspect	DIN 57370	clear, no particles	clear, no particles
Density at 15°C, kg/m^3	DIN 51757	877	889
Flash point°C	DIN EN 22719	138	141
Pour point °C	ISO 3016	< - 60	< - 45
Kinematic viscosity mm^2/s 40 °C mm2/s - 30 °C mm2/s	 DIN 51562-1 DIN 51562-1	 9 780	 10.2 1700
Electrical properties			
Dielectric breakdown voltage Kv	DIN EN 60156	> 60	> 50
Dissipation factor (power point) at 90°C	DIN 57370	0.001	0.002

Chemical properties			
Corrosive sulphur	DIN 51353	non-corrosive	non-corrosive
Neutralisation (acid no.) mg KOH/g oil	DIN 51558-2	< 0.03	< 0.03
Saponification index Baader 140 h/110°C mg KOH/g		0.2	0.48
Oxidation stability acid no. after 164 h (mg KOH/g oil)	IEC 1125 A	0.05	0.20
Sludge content %		0.04	0.04
Toxicity class OFSP T no.		free/617200	free/617200

ANNEX C : LIST OF ACRONYMS AND ABBREVIATIONS

DDT	Dichlorodiphenyl trichlorethane
HPLC	High performance liquid chromatography
LN	Liquid Natural Cooling
LNA	Liquid Natural Air Cooling
ppm	parts per million
PCBs	Polychlorinated Biphenyls
POPs	Persistent Organic Pollutants
PPE	Personal Protection Equipment
RPE	Respiratory Protective Equipment
SN	Synthetic Natural Cooling
TCB	Trichlorobenzene
TDI	Tolerable Daily Intake
TLV	Threshold Limit Values
TSCA	Toxic Substances Control Act (United States)
UNEP	United Nations Environment Programme