IEEE Guide for Acceptance of Silicone Insulating Fluid and Its Maintenance in Transformers

Sponsor

Insulating Fluids Subcommittee of the Transformers Committee of the IEEE Power Engineering Society

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Foreword

(This Foreword is not a part of IEEE C57.111-1989, IEEE Guide for Acceptance of Silicone Insulating Fluid and Its Maintenance in Transformers.)

This guide was prepared by the Insulating Fluids Subcommittee of the Transformers Committee of the IEEE Power Engineering Society. The purpose of the guide is to identify standards for acceptance and maintenance of silicone fluid in transformers.

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IEEE Guide for Acceptance of Silicone Insulating Fluid and Its Maintenance in Transformers

1. Introduction

1.1 Scope and Purpose

This guide recommends standard tests and evaluation procedures for silicone transformer fluid. Criteria for maintenance and methods of reconditioning of silicone fluid are described. It is not the intent of this guide to cover the subject of retrofilling transformers with silicone fluids.

The purpose of this guide is to assist the transformer operator in evaluating the silicone insulating fluids in transformers, fluid received from the manufacturer for filling transformers at the installation site, and fluid processed into such transformers. It also assists the operator in maintaining the properties of silicone fluid in operating transformers.

1.2 Applicable Documents and References

The following standard references are found in section 10, volume 10.03 of the Annual Book of ASTM Standards:[1]

[1] ASTM-D-92: Test for Flash and Fire Points by Cleveland Open Cup.

[2] ANSI/ASTM-D-97: Test for Pour Point of Petroleum Oils.[2]

[3] ANSI/ASTM-D-445: Test for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity).

[4] ANSI/ASTM-D-877: Test for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes.

[1]ASTM publications are available from the Sales Department of the American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103.
[2]ANSI publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY. ASTM publications are available from the Sales Department of the American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103.

[5] ASTM-D-923: Methods of Sampling Electrical Insulating Liquids.

[6] ASTM-D-924: Test for A-C Loss Characteristics and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids.

[7] ASTM-D-974: Test for Neturalization Number by Color-Indicator Titration.

[8] ASTM-D-1169: Test for Specific Resistance (Resistivity) of Electrical Insulating Liquids.

[9] ANSI/ASTM-D-1298: Test for Density, Relative Density (Specific Gravity), or API Gravity Petroleum and Liquid Petroleum Products by Hydrometer Method.

[10] ANSI/ASTM-D-1533: Test Method for Water in Insulating Liquids (Karl Fischer Method).

[11] ASTM-D-1807: Test for Refractive Index and Specific Optical Dispersion of Electrical Insulating Liquids.

[12] ANSI/ASTM-D-2129: Test Method for Color of Chlorinated Aromatic Hydrocarbons (Askarels).

[13] ANSI/ASTM-D-2161: Method of Conversion of Kinematic Viscosity to Saybolt Universal Viscosity or to Saybolt Furol Viscosity.

[14] ASTM-D-2225: Testing Silicone Fluids Used for Electrical Insulation.

[15] ASTM-D-3455: Test for Compatibility of Construction Material with, Electrical Insulating Oil of Petroleum Origin.

[16] ASTM-D-4059: Standard Method for Analysis of Polychlorinated Biphenyls in Mineral Insulating Oils by Gas Chromotography.

[17] ASTM-D-4559: Test Method for Volatile Matter in Silicone Fluid.

[18] ASTM-D-4652: Specification for Silicone Fluid Used for Electrical Insulation.

The following ANSI/NFPA document was used as a reference in the preparation of this guide:

[19] ANSI/NFPA 70-1987, National Electrical Code.[3]

2. Background Information

2.1 Silicone Transformer Fluid

Silicone transformer fluid is one of a family of fluids known chemically as polydimethylsiloxanes. Its structure is as follows:

$$CH_3-\begin{matrix}CH_3\\ Si\\ CH_3\end{matrix}\left[O-\begin{matrix}CH_3\\ Si\\ CH_3\end{matrix}\right]_x-O-\begin{matrix}CH_3\\ Si\\ CH_3\end{matrix}-CH_3$$

[3]NFPA documents are published by the National Fire Protection Association, Publications Sales Division, Batterymarch Park, Quincy, MA 02269. Copies are also available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

x = 0 to greater than 2000

The water clear liquid has a viscosity of 50 cSt at 25 °C and is virtually odorless.

2.2 Fluid and Equipment Reliability

The reliable performance of a silicone liquid insulation system depends upon basic fluid characteristics which affect overall electrical apparatus characteristics. Such characteristics are integral parts of the equipment design, and since this design is the responsibility of the equipment manufacturer, it is not the intent of this guide to suggest or recommend them.

However, the reliable operation of the transformer in service is also dependent upon maintaining the physical, electrical, and chemical properties of the insulating liquid. Values for these properties, which are contained in this guide, will assist the transformer owner in obtaining the desired equipment reliability and safety. Tests other than those specified in this guide will allow verification of the integrity of the total insulation system and are required in order to assure long equipment life.

2.3 Installation of Silicone Transformers

Transformer silicone dielectric fluid meets the requirements of the ANSI/NFPA 70-1987, National Electrical Code, section 450-23 [19][4] as a less flammable liquid in indoor applications when used in properly designed and installed transformers.

2.4 Test Methods and Their Significance

2.4.1 Test Methods and Standards

These methods cover the testing of silicone fluids for use as an insulating or cooling medium in transformers and reactors. These methods are generally suitable for specification, acceptance, factory control, referee testing, and research.

Although some of the methods listed here apply primarily to petroleum-based fluids, they are, with minor revisions, equally applicable to silicone fluids. (See ASTM-D-2225 [14] for revisions.)

A list of the properties and test methods are as follows:

[4]The numbers in brackets correspond to those of the references listed in 1.2.

Property Measured	**ASTM Method***
Physical:	
Color	ANSI/ASTM-D-2129 [12]
Flash point	ASTM-D-92[1]
Fire point	ASTM-D-92 [1]
Pour point	ANSI/ASTM-D-97 [2]
Refractive index	ASTM-D-1807 [11]]
Specific gravity	ANSI/ASTM-D-1298 [9]
Volatility	ASTM-D-4559 [17]
Viscosity	ANSI/ASTM-D-445 [3], ANSI/ ASTM-D- 2161[13]
Chemical:	
Neutralization number	ASTM-D-974 [7]
Water content	ANSI/ASTM-D-1533 [10]
PCB analysis	ASTM-D-4059 [16]
Electrical:	
Relative permittivity (dielectric constant)	ASTM-D-924 [6]
Dielectric breakdown voltage	ANSI/ASTM-D-877 [4]
Dissipation factor	ASTM-D-924 [6]
Specific resistivity	ASTM-D-1169 [8]
Compatibility	ASTM-D-3455 [15]

*A specification for new silicone fluid was approved by ASTM-D-27 in 1986, and this guide is using the test limits shown in this standard, ASTM-D-4652, Specification for Silicone Fluid Used for Electrical Insulation [18].

2.4.2 Significance of Physical, Chemical, and Electrical Test Methods

2.4.2.1 Color (ANSI/ASTM-D-2129)

The chief significance of color as applied to silicone fluid lies in the fact that if the fluid is colored, some degree of contamination exists that may affect the physical, chemical, and electrical properties of the fluid.

2.4.2.2 Flash and Fire Points (ASTM-D-92)

The flash and fire points of a silicone insulating fluid indicate the limit to which the material may be heated, under the specified test conditions, before the emitted vapors form a flammable mixture in air. Unusually low flash or fire points for a given product may indicate contamination.

2.4.2.3 Pour Point (ANSI/ASTM-D-97)

The pour point is important as an index of the lowest temperature to which the material may be cooled without seriously limiting the degree of circulation of the fluid. Some materials are sensitive to temperature cycling or prolonged storage at low temperatures, and their pour points do not adequately predict their low temperature flow properties.

2.4.2.4 Refractive Index (ASTM-D-1807)

The refractive index is often useful for the detection of some types of contamination and for the identification of the various types of silicone insulating fluids.

2.4.2.5 Specific Gravity (ANSI/ASTM-D-1298)

Silicone insulating fluids are usually sold on a weight basis. The values of the specific gravities must frequently be known to calculate the volume of fluid present at any given temperature.

2.4.2.6 Volatility (ASTM-D-4559)

High values may indicate contamination of the silicone with other organic materials, inadequate removal of volatile components, or contamination with a depolymerization catalyst.

2.4.2.7 Viscosity (ANSI/ASTM-D-445)

The viscosity of a silicone fluid is important when the fluid is used as an impregnant. At operating temperatures, the viscosity of a silicone fluid is a principal factor affecting heat transfer by convection flow of the fluid. The kinematic viscosity may be converted to say-bolt viscosity in accordance with the method described in ANSI/ASTM-D-2161 [13].

2.4.2.8 Neutralization Number (ASTM-D-974)

In the inspection of unused silicone fluids, the neutralization number is of importance as an index of purity. Properly refined silicone fluids are free from mineral acids and alkalines.

Since silicone fluids oxidation products are not acidic, small changes in neutralization number of used silicone fluids may indicate the solution of basic or acidic materials from the various solid materials in contact with the silicone or the deterioration of such soluble materials to form basic or acidic materials.

2.4.2.9 Water Content (ANSI/ASTM-D-1533)

Under high humidity conditions, silicone fluids can absorb moisture up to about 250 ppm (parts per million) by weight at 25 °C. High levels of water content will significantly lower the resistivity and dielectric breakdown voltage of the fluid.

2.4.2.10 AC Loss Characteristics (ASTM-D-924: Relative Permittivity (Dielectric Constant) Dissipation Factor (Power Factor)

This method covers the determination of the dissipation factor (power factor) and relative permittivity of new electrical insulating fluids as well as liquids in service or subsequent to service in transformers and other electrical apparatus.

Dissipation factor (or power factor) is a measure of the dielectric losses in an electrical insulating liquid when used in an alternating electric field and of the energy dissipated as heat. A low dissipation factor indicates low dielectric losses. Dissipation factor may be useful as a means of quality control and as an indication of changes in quality resulting from contamination and deterioration in service.

2.4.2.11 Dielectric Breakdown Voltage (ANSI.ASTM-D-2225)

The importance of the dielectric breakdown voltage of a silicone liquid is as a measure of its ability to withstand electrical stress without failure. It may also indicate the presence of contaminating materials, such as water, conducting solid particles, dissolving contaminants, or the decomposition products resulting from an electric arc. A high dielectric breakdown voltage, however, is not a certain indication of the absence of all contaminants.

2.4.2.12 Specific Resistance (Resistivity) (ASTM-D-1169)

The specific resistance of a silicone insulating fluid is a dc measurement of its electrical insulting capability in d-c apparatus. High resistivity reflects low content of free ions and ion-forming particles, and normally indicates a low concentration of conductive contaminants.

2.4.2.13 Compatibility (ASTM-D-3455)

It is very important to know how other construction materials will affect silicone liquid or the converse. Incompatibility of the silicone fluid with the materials of construction can affect the usable life of transformers and reactors.

Compatibility tests are usually made at high temperatures, and for specific time periods. They may consist of physical methods, chemical methods, electrical methods, or all types, depending upon the particular application. ASTM-D-3455 [15] may be used as a guide for conducting this testing.

2.4.2.14 PCB Analysis (ASTM-D-4059)

U.S. regulations require that electrical apparatus and electrical insulating fluids containing PCB be handled and disposed of through the use of specific safety procedures. These procedures are dependent on the PCB content of the fluid. The analytical test method used for mineral oil can also be used on silicone fluid.

3. Sampling, Testing, and Procedure for Filling Apparatus at the Installation Site

3.1 Sampling

Every effort should be made to ensure that samples are representative of the silicone fluid in the electrical equipment. It is recommended that the procedure and precautions outlined in the latest revision of ASTM-D-923 [5] be followed. When available, transformer manufacturer's instructions should be followed.

3.2 Test Values for Silicone Fluid as Received (Prior to Filling Equipments)

Silicone transformer insulating fluid received in shipping vessels must be free from excessive moisture and foreign material before filling. Prior to filling the apparatus, the new fluid should meet the ASTM specification for silicone fluids used for electrical insulation as listed in Table 1.

3.3 Filling with Silicone Fluid

The transformer manufactures provide detailed instructions for filling units. The method of fluid filling can vary because of differences in design and equipment. Some general recommendations follow: Steps should be taken to prevent the introduction of moisture into the transformer during filling. In order to avoid moisture condensation inside the transformer, the temperature inside the unit should be kept several degrees *above* the outside air temperature. It is also recommended that the silicone fluid be vacuum degassed before filling and that the transformer be filled under vacuum.

3.3.1 Vacuum Degasification of the Liquid

The fluid should be processed by filtering and degassing before being put into service in power transformers. The ideal liquid will be low in impurities to maintain good dielectric properties and will also have a low level of dissolved air and water. Liquid whose dissolved air level is well below its saturation point will take air trapped inside the transformer insulation into solution and may eliminate those potential insulation system weak spots. Vacuum filling is one way of reducing dissolved air. This technique is limited by the amount of vacuum the tank is capable of withstanding.

3.3.2 Pumping

Centrifugal and gear pumps have both been successfully used with silicone fluid.

It is imperative that, when preparing to pump silicone liquid in a dielectric application, pump suitability is confirmed. The technical department of the pump manufacturer should be contacted and the suitability of the pump to pump silicone liquid should be confirmed. Alternatively, the pump can be checked by circulating a small quantity of silicone fluid for an extended period of time and checking the pump for wear and the fluid for dielectric properties. During this evaluation, be sure to back-pressure the pump to a pressure that is similar to it will be used under in an actual field service job. Always maintain a filter between the pump and the electrical equipment being filled.

3.3.3 Filling under Vacuum

Entrapped air is a potential source of trouble in all liquid-filled transformers. Therefore, it is desirable to fill all silicone liquid transformers under vacuum. This is normally done for transformers filled in the factory, and should be done where practical when transformers are filled in the field.

NOTE — Consult the transformer manufacturer to determine the transformer tank vacuum limit and the filling procedure to be used with it. This vacuum limit must *not* be exceeded during vacuum filling or tank damage may result.

3.3.4 Filling without Vacuum

In the cases where the transformers are not filled under vacuum, do not energize the windings for at least 24 hours after the silicone liquid has been put into the tank. This is necessary to allow the air bubbles to escape.

Where practical, fill through the drain valve to keep aeration to a minimum, and vent the top of the tank to allow the air to escape. Be sure valves and pipe connections between the main tank and any silicone liquid-filled compartments are open for free circulation of gas and liquid. Otherwise, trapped air or gas may cause the silicone liquid level in some parts of the transformer to be below the safe operating level.

Tanks and compartments should be filled at ambient temperature to the point on the gauges marked “25 °C Liquid Level.” If the ambient temperature varies greatly from 25 °C (77 °F) when filled, the silicone liquid level should be checked when the average liquid temperature is 25 °C. Sufficient silicone liquid should be added to or drained from the tank to bring the liquid to the proper level. The transformer should never be operated or left standing, even out of service, without the silicone liquid level being indicated on the gauge.

4. Testing and Evaluation of Fluid in Equipment

4.1 Periodic Fluid Inspection and Testing

The physical and dielectric properties of the liquid should be maintained in order to obtain the longest possible service life and provide maximum protection for the transformer. The insulating liquid inside the transformer must be maintained at the proper level. Tests other than those specified in this guide allow verification of the integrity of the total insulation system and may be required to ensure long equipment life.

The frequency of inspecting and testing depends upon the service to which the silicone fluid is subjected and the construction of and the materials used in the apparatus. It should be noted that the more handling an insulating fluid receives, the greater the opportunity for contamination unless adequate precautions are taken.

Silicone fluid contained in electrical equipment, such as transformers and reactors should meet certain minimum standards in order to ensure satisfactory performance. It is expected that silicone contained in equipment received from the manufacturer will exhibit characteristics slightly different from those obtained from new fluid that has not been in contact with apparatus construction materials. These test values should be provided by the transformer manufacturer.

Table 1— Test Limits for Silicone Fluid as Received

Property	Limit	ASTM Test Method
Physical		
Color (max.)	15	ANSI/ASTM-D-2129
Flash point (°C min.)	300	ASTM-D-92
Fire point (°C min.)	340	ASTM-D-92
Pour point (°C max.)	-50	ANSI/ASTM-D-97
Refractive index (25 °C)	1.4010–1.4040	ASTM-D-1807
Viscosity at 0 °C, cSt	81–92	ANSI/ASTM-D-445, ANSI/ASTM-D-2161
Viscosity at 25 °C, cSt	47.5–52.5	ANSI/ASTM-D-445, ANSI/ASTM-D-2161
Viscosity at 100 °C, cSt	15–17	ANSI/ASTM-D-445, ANSI/ASTM-D-2161
Specific gravity (25 °C)	0.9570–0.9640	ANSI/ASTM-D-1298
Volatile matter (max. weight %)	0.5	ASTM-D-4559
Electrical Properties		
Dielectric breakdown (voltage at 60 Hz, kV min.)	35	ANSI/ASTM-D-877
Dissipation factor (60 Hz, 25 °C, % max.)	0.01	ASTM-D-924
Volume resistivity (25 °C)	1×10^{14}	ASTM-D-1169
Chemical		
Neutralization number (mg KOH/g max.)	0.01	ASTM-D-94
Water content (ppm max.)	50	ANSI/ASTM-D-1533

4.2 Test Limits for Silicone Fluid in New Equipment

Table 2 shows the test limits for silicone fluids received in new equipment.

Table 3 shows the test limits for service-aged silicone fluids in equipment.

4.3 Treatment of Contaminated Silicone Fluid

Table 4 provides a list of possible contamination sources and recommendations for cleaning of fluid.

The choice of method for reconditioning silicone liquids will depend upon many factors, including the type of contamination, location, and the amount of fluid to be treated.

4.3.1 Economic Factors

A review of experience and cost data obtained from many operators and users of transformers reveals a wide variation of practices and cost data involved in the reconditioning of silicone fluid. These differences are mostly attributable to the type of system, field inspection operations, and available laboratory and shop facilities. For example, an operator having a large number of small transformers installed over a large area may follow a different practice than one who has large transformers in stations that are located in a metropolitan area.

In determining whether or not reconditioning of silicone insulating liquids is economically justifiable, the following factors must be considered:

- Cost and availability of new versus reprocessed fluid
- Disposition of service-aged materials
- Total cost of process versus quality of end product
- Equipment maintenance and amortization
- Cost of the collection and storage of fluid
- Labor and transportation costs
- Laboratory costs
- Loss of fluid during reprocessing
- Risk of contamination from processing

Table 2— Test Limits for Fluid in New Transformers

Property	Acceptance Values	Unacceptable Values Indicate	ASTM Method
Minimum			
Visual	Clear, free of particles	Particulates, free water, contamination	ANSI/ASTM-D-2129
Dielectric breakdown (voltage at 60 Hz, kV min.)	30	Particulates, water	ANSI/ASTM-D-877
Additional			
Water content (ppm max.)	50	Water contamination	ANSI/ASTM-D-1533
Dissipation/power factor (60 Hz, 25°C, % max.)	0.1	Polar/ionic contamination	ASTM-D-924
Viscosity (25°C, cSt)	47.5-52.5	Fluid degradation, contamination	ANSI/ASTM-D-445
Fire point (°C, min.)	340	Contamination by volatile material	ASTM-D.92
Neutralization number (mg KOH/g max.)	0.01	Contamination	ASTM-D-974

Table 3— Test Limits for Service-Aged Silicone Fluid

Property	Acceptance Values	Unacceptable Values Indicate	ASTM Method
Minimum			
Visual	Colorless, clear, free of particles	Particulates, free water, contamination	ANSI/ASTM-D-2129
Dielectric breakdown (voltage at 60 Hz, kV min.)	25	Particulates, water	ANSI/ASTM-D-877
Additional			
Water content (ppm max.)	100	Water contamination	ANSI/ASTM-D-1533
Dissipation/power factor (60 Hz, 25 °C, % max.)	0.2	Polar/ionic contamination	ASTM-D-924
Viscosity (25 °C, cSt)	47.5-52.5	Fluid degradation, contamination	ANSI/ASTM-D-445
Fire point (°C, min.)	340	Contamination by flammable material	ASTM-D-92
Neutralization number (mg KOH/g max.)	0.2	Degradation of cellulose	ASTM-D-974

Table 4— Nature of Contamination and Reclamation*

Contamination	Fluid Appearance	Equipment	Filter Aid	Test	Comments
Water	Clear to milky white	Dehydrator	None	Water content dielectric	Separated water should be siphoned or drained
Products of Arcing					
Silicone dioxide, carbon, highly crosslinked gelatinous polymer	Clear w/particulates to grey-white, strong odor	Cartridge filter/ vacuum or filter press and vacuum	None or diatomaceo us earth	Dielectric strength, volume resistivity, dissipation factor	This method will not return liquid to original mfr. spec
Particulates	Clear with particles hazy	Cartridge filter or filter press	None or diatomaceo us earth	Dielectric strength, visual	May be removed by filtration
Discoloration due to interaction with transformer	Faint to distinct coloration	Cartridge filter or filter press	Activated carbon	Power factor, acid number, flash point, dielectric strength	May have no effect on ANSI/ASTM-D-877 performance, check with equipment mfr.
Mineral oil and low fire point contaminants of higher volatility	Clear to two phase	Highly volatile materials may be removed by heat and vacuum. Mineral oil contamination requires replacement of fluid.	None	Flash and fire points	The NEC requires that the fluid has a fire point of ≥ 300 °C.

*Consultation with the transformer manufacturer is important before any action is taken to reclaim fluid from a transformer.

4.3.2 Types of Treatment

4.3.2.1 Filtering

Filtering through a filter press or a cartridge filter is the only recommended procedure for removing particulates or solid contaminants. The same type of equipment that is used for processing mineral oil can be used; but, to prevent contamination, suitable equipment should be dedicated to silicone transformer liquid (e.g., hoses, filters, pumps, tanks, etc.).

Care must be taken to properly dry any paper to be used in the filtering operation of silicone fluid. Do not attempt to remove large amounts of separated (free) water from any dielectric liquid using a filter press or cartridge filter. Rapid wetting and saturation of the filter elements will occur and the water will then be dispersed in the fluid. In this situation, use a vacuum drying or a coalescing filter. If the filtration is to be done on a transformer, the transformer should not be taken our of service until ready to filter the fluid. This will keep the transformer coils relatively hot and dry. Processing the fluid should start immediately after deenergizing the unit. Circulate the silicone transformer liquid through the filter fitting with the dry paper liners or dry cartridges. Also, the condition of the cartridges must be carefully monitored to prevent water saturation. Filtration can be accomplished in the transformer or other container by circulating the silicone transformer liquid from the bottom to the top through a filter press or cartridge filter. Filtering can be done faster and more efficiently by passing the liquid from the transformer, through the filter and into a separate, clean, dry container and then, after cooling, back through the filter again to refill the transformer. Using this method, all of the liquid will be given two complete passes through the filter system. If additional filtering is required, the entire procedure can be repeated. Since the amount of dissolved water at saturation level increases markedly with increasing temperature, filtering at low temperatures is more effective.

Fuller's earth is a naturally occurring clay that can chemically degrade silicone liquid. For this reason, Fuller's earth is not recommended to recondition silicone liquid, nor is it recommended as a filter aid with silicone liquid.

4.3.2.2 Vacuum Degasification

The fluid should be processed by filtering and degassing to remove dissolved water, gas, and volatile contaminants. The units should then be filled under vacuum.

5. Storage, Handling, and Safety Instructions

5.1 Storage

Every precaution should be taken to protect silicone transformer liquid from exposure to high humidity and moisture contamination during its handling, storing, sampling, and testing.

Shipping drums should be stored indoors in an area especially selected for that purpose. If it is necessary to store drums or cans containing silicone transformer liquid outdoors, they should be stored in a covered area, or otherwise protected from the weather and direct contact with water. Drums should be kept sealed until the liquid is actually needed. Partially emptied drums should be tightly resealed and stored as already described above.

Bulk storage tanks should be mounted on piers above the ground, and all points should be accessible for inspection for leakage. There should be a curb on the ground around the tanks to contain any spillage or leakage.

Stainless steel is recommended as the best material for piping and storage tanks. Carbon steel is good for piping, and carbon steel with a zinc primer or an epoxy paint-on lining is also suitable for tank storage. Silicone transformer liquid has an unlimited useful life when stored under normal conditions as specified above.

5.2 Handling

It is *strongly* recommended that all apparatus used in sampling, filtering, storing, or transporting silicone transformer liquid be maintained for the exclusive use with silicone transformer liquid. It is extremely difficult to remove all traces of hydrocarbon oil or other contaminants from equipment of this type. Care must be taken to protect all such equipment from the elements and from water or moisture contamination.

5.3 Safety Instructions

Detailed safety instructions and data can be obtained from the Materials Safety Data Sheet of the silicone fluid suppliers. Although there are no special risks involved in the handling and use of silicone fluid, attention is drawn to the general need for washing exposed skin or clothing that may come in contact with the fluid.

Avoid eye contact with silicone fluid because it may cause temporary eye irritation. This effect is caused by the water repellency of the silicone liquid that produces a feeling of dryness. This is a physical and not a chemical effect, and it is similar to the eye sensation that occurs after prolonged exposure to the wind.

The potential hazards from the combustion products in the silicone fluid when exposed to a flame are described in the Materials Safety Data Sheet available from the producers of the fluid.

When silicone fluid has to be disposed of, the same precautions and regulations applicable for handling mineral oils shall be followed.

5.3.1 Minor Spills

Minor spills that can occur in the manufacture or repair of transformers and in the testing of silicone liquid can be cleaned using absorbent rags. Using a suitable solvent will facilitate cleanup. The following is a list of some of these solvents:

1) Chlorothene NV
2) Methylene chloride
3) Naphtha VM&P
4) Perchloroethylene
5) Stoddard solvent
6) Toluene
7) Turpentine
8) Xylene

5.3.2 Spills on Water

Because silicone fluids float on water, a spill can be contained by floating booms or dykes. If contaminant equipment is unavailable or impractical, the silicone can be concentrated by applying a surface-active chemical designed for this purpose around the perimeter of the spill. Such materials have a high spreading pressure (43 dyn/cm) and force the silicone (spreading pressure = 10 dyn/cm) to contract into a small, low-surface area pool. A monomolecular layer of silicone fluid contracts to cover a surface area about 10 times less when thus treated. Very little surface-active material is required (0.1 ppm). Section 311 of the U.S. Federal Clean Water Act imposes reporting requirements for silicones (considered an oil in this situation) that are spilled into navigable waters. The requirement to report is triggered by the appearance of a sheen on the water. If any sheen is noted, the U.S. Coast Guard, which is the proper national authority, must be called.

Once the silicone fluid has been concentrated, it can be removed from the water surface by the same systems that are used for petroleum spills. These include pumps, skimmers, physical absorbents, and oleophilic hydrophobic fibers that are fabricated into floating ropes.

These ropes are moved through the oil-laden water to a machine with wringer rollers and a holding tank, and back into the water. This technique is effective for crude oil spills and is equally useful for silicones.

Once collected, the fluid may be reclaimed or incinerated in a suitable burner. Silicone fluids are usually diluted to 10% or lower concentration with solvent for incineration.

5.3.3 Spills on Soil

Results of studies with silicone fluid is sandy soil show a gradual downward migration to a depth of 50 cm during a 2-year time period. No significant lateral movement of the fluid was found.

Laboratory experiments with columns of soil showed that migration rates are dependent in a complex way on the kind of soil (sandy, clay, or loam), its moisture content, and the amount of its watering. In general, dry soils seem to have a greater absorptive capacity and hold silicone fluids more tenaciously than wet soils. The soil thus appears to act as its own absorbent, and if the presence of fluid is objectionable, the soil can be removed to a landfill area and replaced with fresh soil.

Silicone fluids in spill situations behave in much the same way as motor or mineral oil of comparable viscosity. The same cleanup procedures are applicable.

5.3.4 Leaks

During regular maintenance schedule, routine checks should be made for leaks. Areas to check and repair should include valves, bushings, gauges, tap changers, welds, sample ports, manhole covers, pipe fittings, pressure relief valves, etc. If the leak does not involve a replaceable seal, welding and epoxy sealing kits are two commonly used techniques to stop leaks.

The standard epoxy sealing kits used on oil leaks will work on silicone transformers if the leak is stopped and the surface is thoroughly cleaned. Some small leaks can be stopped by peening. Some patch kits include a crayon-type stick that may stop leaks. If necessary, lower the silicone fluid level below the leak. After the leak is stopped, clean off all silicone fluid, abrade the surface to bare metal, and apply the well mixed epoxy. Do not return the silicone fluid to its normal level until the epoxy is fully cured.

Proper care must be taken to protect the integrity of the silicone dielectric if leak repair requires lowering the liquid level.

Dedicated equipment and clean, dry storage containers must be used. Testing of the liquid before returning it to its normal level is necessary. The recommendation on sampling, testing, and filling of transformers presented in this guide should be followed faithfully.