

XIAMETER™ 561 Silicone Transformer Liquid

Technical manual

DOW



The information and data contained herein are based on information we believe reliable. You should thoroughly test any application and independently conclude satisfactory performance before commercialization. Suggestions of uses should not be taken as inducements to infringe any particular patent.

Preface

We hope this technical manual will help you discover for yourself the advantages of using a transformer filled with XIAMETER™ 561 Silicone Transformer Liquid. The information on proven performance, fire safety, human and environmental safety, recyclability, and cost effectiveness all indicate that XIAMETER™ 561 Silicone Transformer Liquid offers significant benefits over other types of liquid-filled and dry-type transformers.

XIAMETER™ 561 Silicone Transformer Liquid is backed by Dow, which has a team of technical specialists around the world specifically committed to XIAMETER™ 561 Silicone Transformer Liquid. That means if you ever have a question or a problem, you'll always get an answer—and a solution.

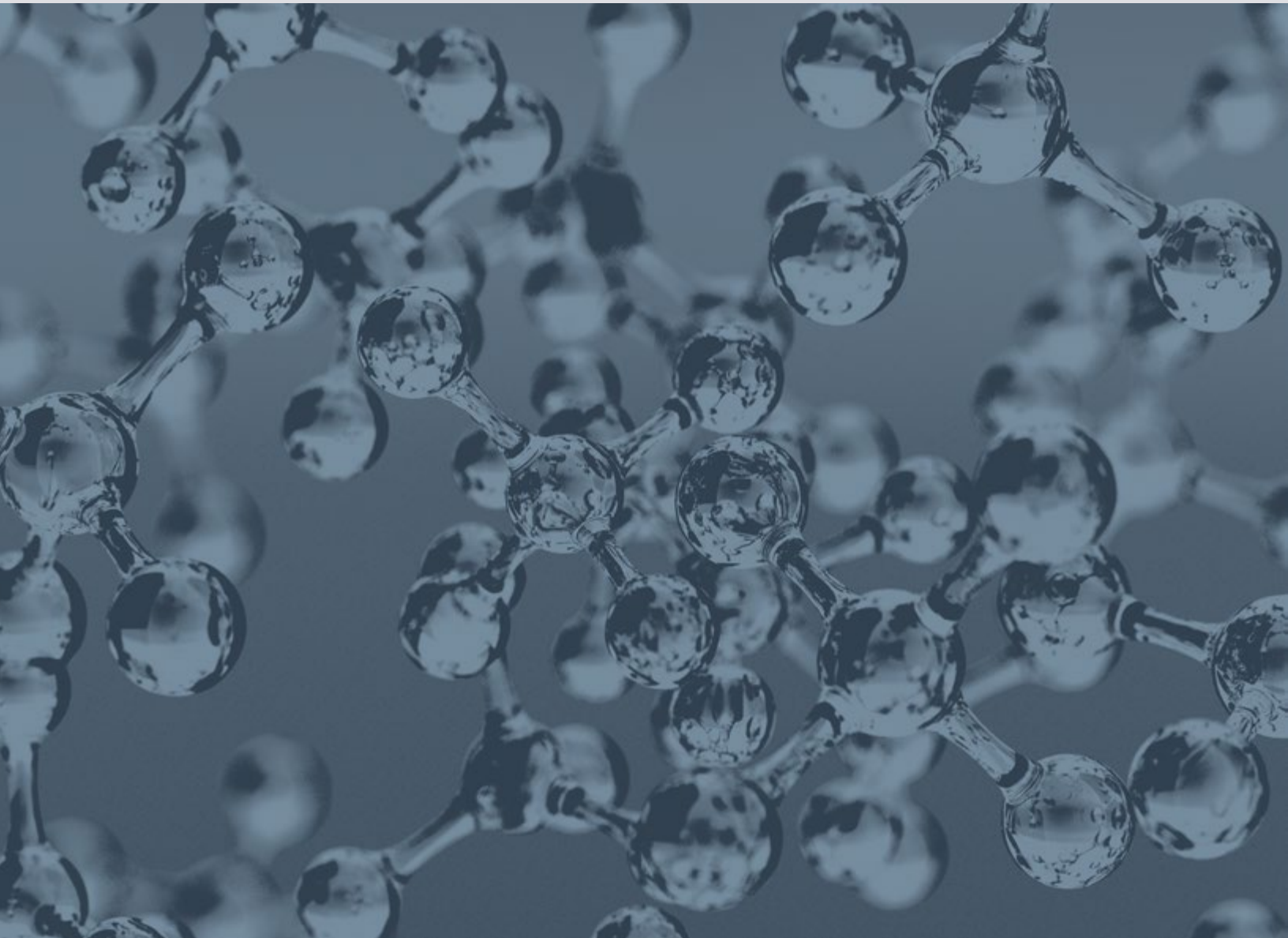
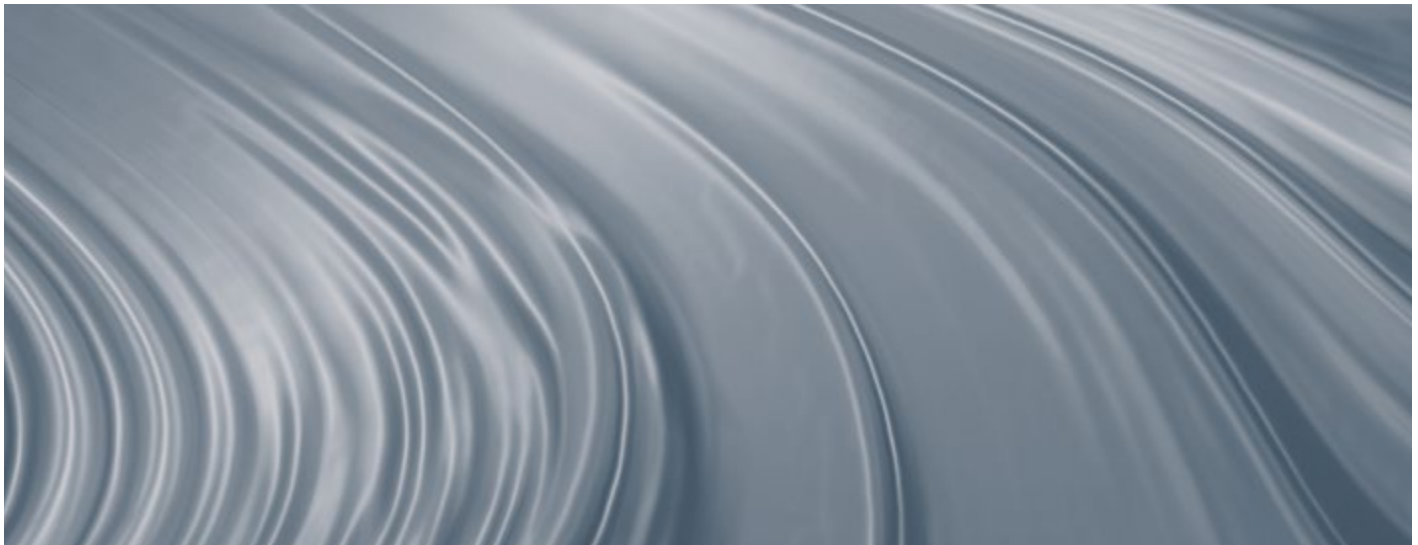


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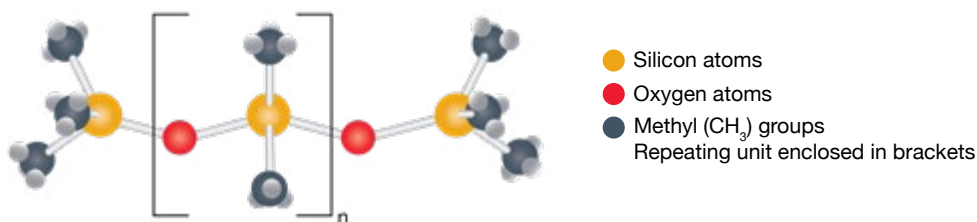
Section 1: General information

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- 1.1 What is a silicone fluid?
- 1.2 Selecting a new transformer
- 1.3 Why a liquid-filled transformer?
 - Performance without extra cost
 - Size and weight
 - Quiet
 - Predictable performance
- 1.4 Why a silicone liquid?
 - A pure synthetic material
 - Fire safety indoors or outside
 - Stability leads to long life and lasting performance
 - Widespread acceptance
- 1.5 Bibliographic resources
 - How to use these bibliographic resources
 - General properties
 - Performance and service life
 - Fire safety
 - High voltage strength
 - Water contamination
 - Environmental
 - Toxicological
 - Codes and standards

1.1 What is a silicone fluid?

Silicone fluids are a family of synthetic liquids having the molecular structure shown below, in which the groups identified as methyl groups may represent any organic group. The organic groups can be all the same or different. The value of n determines the molecular weight of the silicone fluid, which in turn determines its viscosity.



Polydimethylsiloxane (PDMS) fluids are thermally stable, chemically inert, essentially nontoxic, and water repellent. The viscosity of the commercial products varies from 0.65 to 2,500,000 centistokes (cSt). These fluids remain fluid over a wide range of temperatures, even though the value of n can vary from 0 to 2,000 or more. Other physical and electrical properties exhibit relatively small variations with temperature.

Silicone fluids are used as lubricants, mold-release agents, dielectric coolants, antifoam agents, and heat-transfer fluids. Because of their unique surface properties, low toxicity, and thermal and chemical stability, they are used in small concentrations in car polishes, paints, and cosmetics.

XIAMETER™ 561 Silicone Transformer Liquid is a 50 centistoke viscosity PDMS product, in which all the organic groups are methyl groups, CH₃. It is water-clear, nongreasy, and virtually odorless, with good insulating and dielectric properties.

1.2 Selecting a new transformer

Selecting the best transformer for a given application might seem like a difficult task, but with the right information—backed by proven applications and 20 years of testing—a difficult decision can be made easy.

There is a variety of transformer types from which to choose, including air-cooled dry-type, cast-resin, and liquid-filled transformers. Liquid-filled transformers can contain mineral oil, chlorinated hydrocarbons, high molecular weight hydrocarbons, or silicone fluid. Depending on the needs of your application, each type offers distinct advantages. But many also have drawbacks. The key is to decide which engineering and operating compromises are acceptable and estimate the long-term effects they will have on your application.

We believe the information in the following pages will help you select which type of transformer will work best for you and which should be avoided for your application.

1.3 Why a liquid-filled transformer?

Liquid-filled transformers were developed more than 90 years ago. Today, many users continue to prefer this design over dry-type transformers, especially for demanding applications such as networks and medium and large power transformers. There are several important reasons for this preference.

- Unlike solids, liquids cool as well as insulate. As a result, you can select a liquid-filled transformer that is more compact than a comparable dry-type or cast-resin type
- Liquid-filled transformers provide high efficiency and high BIL at reasonable cost. Similar electrical performance can be obtained from dry-type or cast-resin transformers—but usually only at additional cost.

Performance without extra cost

The high dielectric strength of liquid-filled transformers provides greater design flexibility. As a result you can optimize the design to meet specific load requirements and thereby reduce operating costs. For example, beginning with a liquid-filled system, you can design a small, compact core transformer that delivers a very high BIL and very low no-load losses. You can achieve a combination of operating economy, reliability, and small size that is not practical with dry-type and cast-resin transformers. Table 1.1 compares the BIL rating of dry-type transformers to liquid-filled transformers.

Liquid systems also have an advantage stemming from their superior ability to remove heat from the core and coil assembly. This results in greater overload capacity and corresponding savings in maintenance and operating costs, as well as longer insulation life. This is especially true for silicone-filled transformers

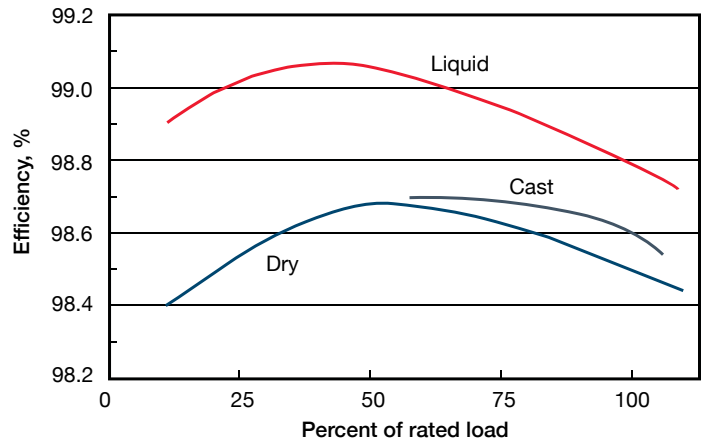
Table 1.1 — Typical temperature rise and BIL ratings for transformers

Transformer type	Average winding temperature rise	BIL rating
Liquid filled	55/65°C	95 kV
Dry	150°C	60 kV

because silicones have the highest thermal stability of all available liquids. Long-term costs resulting from energy loss in a unit can exceed the capital costs of purchasing the transformer. As a result, it is very important to evaluate the rate of loss and select the best design for your load and service conditions.

To provide for load growth or emergency loading, transformers are usually designed to handle more than the expected initial load. A loss evaluation is based on average transformer loading. Figure 1.1 shows that liquid-filled transformers are more efficient, particularly at low load levels.

Figure 1.1 — Typical efficiency for major types of transformers



Size and weight

Table 1.2 shows a dimension and weight comparison of liquid-filled, dry-type, and cast-coil transformers with different temperature rises.

Table 1.2 — Dimensions and weights of 1000 kVA, 13.8 kV-480 V transformer^a

	Liquid-filled	Conventional dry type		Cast coil
	65°C	150°C	80°C	80°C
Height	65.0 in	90.0 in	100.0 in	90.0 in
Width	58.5 in	78.0 in	84.0 in	84.0 in
Depth	74.5 in ^b	58.0 in	70.0 in	54.0 in
Total weight	6980 lb	5830 lb	8500 lb	7500 lb

^aReferences from transformer manufacturer's data

^bIncludes depth of radiators

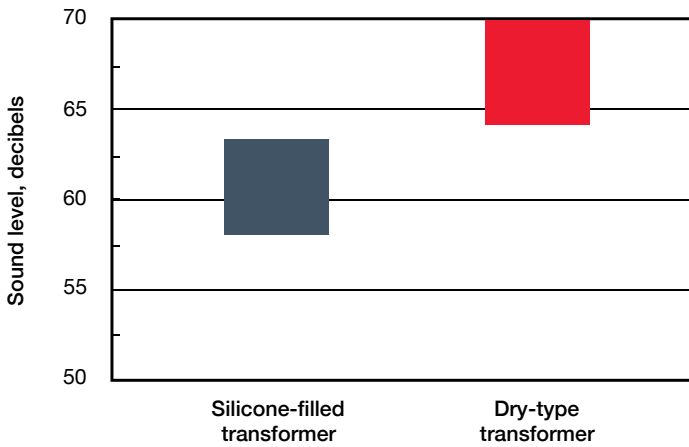
Quiet

Whether indoors or near buildings and people, loud or overbearing noise can be an environmental nuisance. Dry-type transformers, in general, aren't known to be quiet. Liquid-filled transformers, because of their insulation, are the quietest transformers available. Figure 1.2 shows maximum average sound levels.

Predictable performance

One reason liquid-filled transformers are more reliable than dry types is because they can be diagnostically tested, providing important predictive information to transformer owners. Periodic testing of water content, breakdown strength, and dissolved

Figure 1.2 – Maximum average sound levels for three-phase, substation-type transformers



gas composition can help avoid costly, unplanned outages and catastrophic failures by detecting leaks, low-level arcing, and other insulation problems before they develop into serious situations. See section 6.1 for details on diagnostic tests for silicone-filled transformers.

Liquids don't crack or form voids under extreme temperature variations, so you can expect long service life. Plus, liquid-filled transformers are sealed so they can operate in many harsh environments without special housings. They also reduce maintenance costs by eliminating the need for an inconvenience of annual shutdowns for cleaning. All in all, liquid-filled transformers are reliable and efficient suppliers of modern power requirements.

1.4 Why a silicone liquid?

Most liquid-filled transformers are filled with mineral oil. The primary drawback of mineral oil is that it can present an unacceptable fire risk when used in or near buildings. With silicone fluid, you can meet code requirements without the expense of special vaults and/or fire protection. You gain the reliability and efficiency of liquid-filled design even when the transformer must be located close to the load, indoors, or near buildings. See section 4.2 for details on code requirements.

Dow began investigating silicone fluids as potential dielectric coolants in the 1950s. The investigation resulted in the development and production of XIAMETER™ 561 Silicone Transformer Liquid, which is now widely used to provide excellent performance in liquid-filled transformers, especially where fire safety and thermal stability are required.

A pure synthetic material

XIAMETER™ 561 Silicone Transformer Liquid contains no chlorine or other halogens. It is a pure polydimethylsiloxane material that contains no additives, such as pour-point depressants or thermal stabilizers. Similar silicone fluids are used in cosmetics and as food additives. It is compatible with materials used in the construction of transformers, nonvolatile, thermally stable, and chemically inert. This compatibility and stability are instrumental in prolonging transformer life and reducing maintenance.

Fire safety indoors or outside

XIAMETER™ 561 Silicone Transformer Liquid presents a much lower fire hazard than other transformer fluids. It is difficult to ignite, but if it should ignite, it produces less heat and smoke and virtually extinguishes itself when the external source of heat is removed. XIAMETER™ 561 Silicone Transformer Liquid is Underwriters Laboratories, Inc. (UL) classified and Factory Mutual Research Corporation (FM) approved as “less flammable” per NEC 450-23. In addition, tests have shown that the toxicity of combustion by-products from XIAMETER™ 561 Silicone Transformer Liquid is lower than other commonly used insulating materials, such as high molecular weight hydrocarbons or mineral oil, as well as epoxies, phenolics, polyesters, and other dielectric materials used for transformer construction. See section 2.5 for details on fire safety.

Stability leads to long life and lasting performance

The thermal stability of silicone also improves performance while reducing the need for fluid reprocessing during use. XIAMETER™ 561 Silicone Transformer Liquid will not form sludge and/or acidic by-products, even at elevated operating temperatures. See section 3.2 for details on the thermal capabilities of silicone fluid. Figures 1.3 and 1.4 show how dissipation factor and dielectric strength change as common transformer fluids age at elevated temperatures.

Figure 1.3 – Change in dissipation factor of silicone fluid with aging compared to mineral oil.

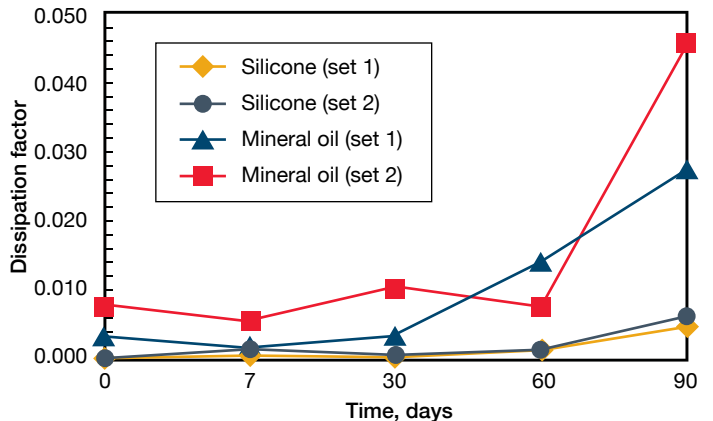
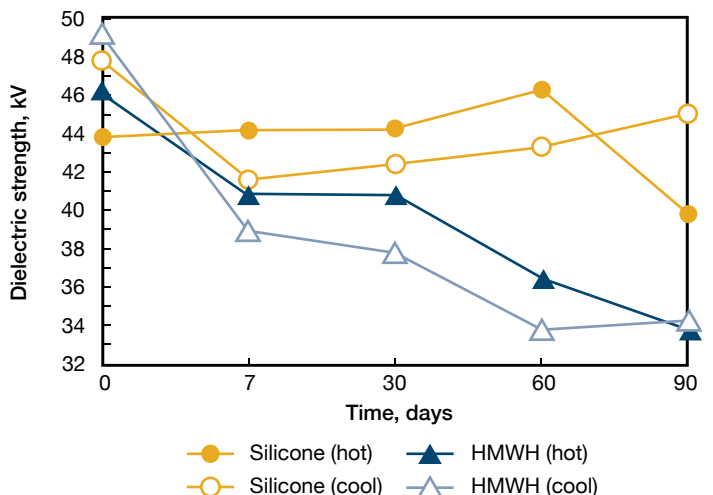


Figure 1.4 – Change in dielectric strength of silicone fluid with aging compared to high molecular weight hydrocarbons



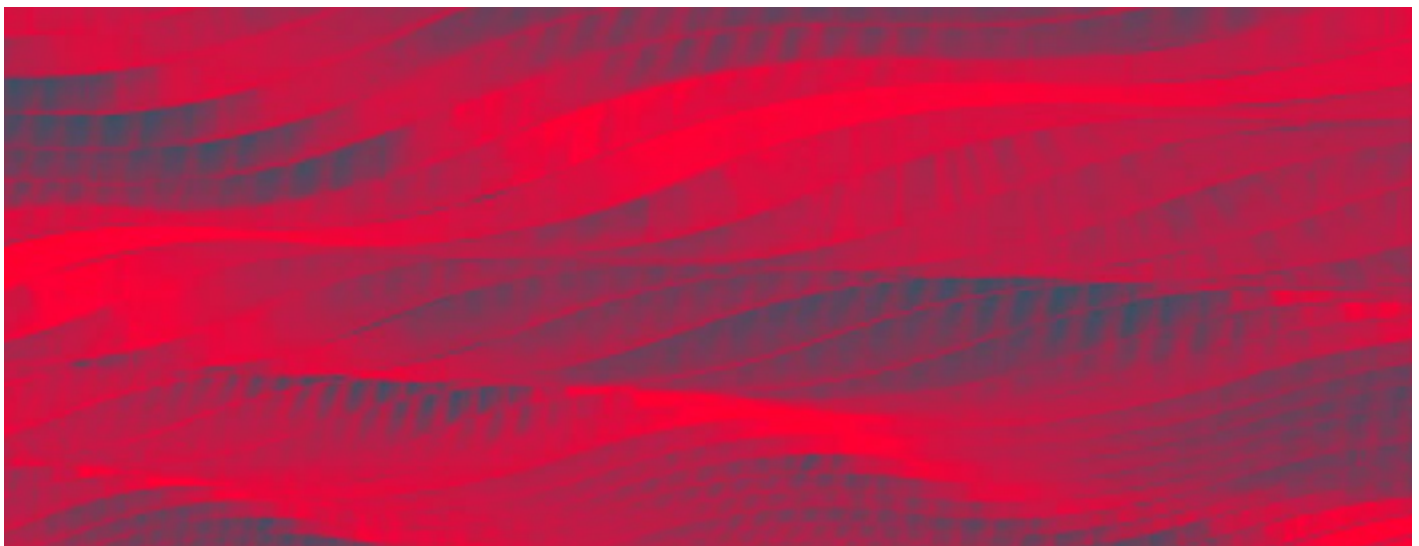
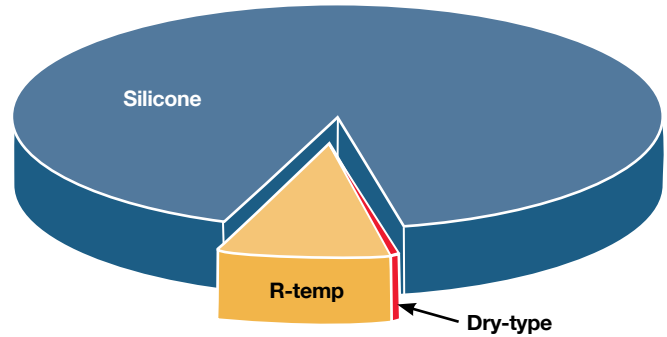
Widespread acceptance

Since 1974, XIAMETER™ 561 Silicone Transformer Liquid has been accepted by utilities and commercial property owners as well as industries ranging from food processing and pharmaceuticals to mining, paper mills, and transportation. In fact, a survey of utilities (figure 1.5) found that when askarel-filled transformers are replaced, nearly 91% of those units are being replaced with silicone-filled units, compared to 8.6% for R-Temp fluid and 0.3% for dry-type transformers.

With over 100,000 silicone-filled units in operation worldwide and more than 20 years of practical operating experience, Dow is not aware of any transformer filled with XIAMETER™ 561 Silicone Transformer Liquid that has failed to carry the load required for satisfactory performance.

In short, XIAMETER™ 561 Silicone Transformer Liquid has performed as expected — no problems caused by the liquid have ever been reported. In fact, even in rare cases where severe failure of protective devices has exposed the fluid to prolonged arcing and ignited the fluid, no thermal damage due to the fluid burning has occurred.

Figure 1.5 — Askarel fire-safe transformer replacement choices (Source: 1987 utility analysis follow-up survey where fire-safe transformers were used.)



1.5 Bibliographic resources

Dow has prepared a number of informational brochures, booklets, and technical articles to help you use XIAMETER™ 561 Silicone Transformer Liquid safely and efficiently. Following is a list of these resources, many of which can be ordered by contacting your Dow representative. Others resources mentioned can be obtained directly from IEEE, ASTM or listing agencies such as Factory Mutual or Underwriters Laboratories.

How to use these bibliographic resources

We believe the technical information contained in these reports is accurate even though specific references may be to codes and standards or regulatory requirements that have changed since the time of writing. Information on current requirements relative to transformer fluid is available from Dow. Please contact your local Dow representative if needed.

General properties

- G1. "Dielectric Properties of Silicone Fluids," Hakim, R.M., IEEE Conference, Paper #C74-262-2. Lit. no. 10-255
- G2. "Structure Property Relationships in Silicone Fluid Dielectrics," G. Vincent, G. Fearon, T. Orbeck, Annual Report, Conference on Electric Insulation and Dielectric Phenomena, 1972, pp. 14–22, CA 79 (8),43156d. Lit. no. 10-256
- G3. "Environmentally Acceptable Insulating Fluids May Replace Askarel," D. Duckett, RTE Corp., General Meeting of Transmission and Distribution Committee, Edison Electric Institute, May 8, 1975
- G4. "Small Power Transformer Alternatives," S. Mort and W.H. Bishop, Canadian Electricity Forum, April 1992. Lit. no. 10-519A
- G5. "A Comparison of Non-liquid Power Transformers with Silicone-filled Units," J. Goudie, Dow Corning. Lit. no. 10-512
- G6. "Silicone Materials for Electrical Insulation that Yield Low Heat Release Rates and Low Levels of Toxic Products During a Fire," E.A Reynaert, and W.C. Page, Environmentally Friendly Fire Retardant Systems Conference, Sept. 22-23, 1992. Lit. no. 10-534
- G7. "Silicone as a PCB Replacement Fluid," J. Goudie, Dow Corning Corp., 5th Annual Industry & PCBs Forum, Canadian Electricity Forum, Vancouver, B.C., June 1991
- G8. *Dow Corning Dielectric Liquids for Power Transformers*
- G9. Dielectric Properties of Dow Corning Silicone Fluids, Lit. no. 22-328
- G10. "Less Flammable Transformer Liquids Gain Acceptance," *CEE News*, February 1993. Lit. no. 10-544
- G11. "Performance Testing of Silicone Transformer Coolant Using 25 kVA Distribution Transformers: Test Facility," D.F. Christianson and F.C. Dall, Dow Corning Corp.

Performance and service life

- P1. "Performance and Safety Capabilities of Silicone Liquids As Insulating Liquids for HV Transformers," W. Page and T. Orbeck, IEEE, 24th Annual Petroleum & Chemical Industry Conference, Dallas, Texas, Sept. 12-14, 1977. Lit. no. 10-257
- P2. "Service Experience and Safety with Silicone Liquid-Filled Small Power Transformers," K. Evans and T. Orbeck, 1984 Doble Engineering Client Conference, April 13, 1984. Lit. no. 10-259
- P3. "Silicone Transformer Liquid: Use Maintenance/Safety," R. Miller, *IEEE Trans. of Ind. Appl.*, Vol. 1A-17, No. 5, September/October 1981, Paper IPSD 79-54. Lit. no. 10-208
- P4. "Evaluation of the Long Term Thermal Capability of High Temp. Insulating System Using Silicone Liquid as a Dielectric Coolant," L. Gifford and T. Orbeck, *IEEE Trans. of Ind. Appl.*, Vol. IA-20, No. 2, March/April 1984, Paper PID 83-34. Lit. no. 10-253
- P5. "Liquid Filled Transformers Having Temperature Operating Capabilities," D. Voytik, IEEE, 1981, Ch1717-8/81/0000-0203. Lit. no. 10-260
- P6. "Secondary Substation Transformer Selection Critical to Total System Planning," C.C. Rutledge, *Industrial Power Systems*, June 1984
- P7. "Load Break Switching in Silicone Transformer Fluid," S. Mort, J. Goudie, D. Ristuccia, Electrical Manufacturing Technologies Expo, October 1993. Lit. no. 10-578
- P8. "Test Results Confirm the Ability of the LBOR II Switch to Operate Properly in XIAMETER™ 561 Silicone Transformer Liquid," ABB Load Break Switch Test Confirmation, June 8, 1992
- P9. "High Temperature Operating Capabilities of Silicone Transformer Fluid," G. Toskey, Electrical Manufacturing Technologies Expo, October 1993. Lit. no. 10-577
- P10. "Interpretation of Dissolved Gases in Silicone Transformer Fluids," Lit. no. 10-593.

P11. "Silicone Materials in New High Temperature Liquid Transformer Designs," J. Goudie, Proceedings of the Electrical/Electronics Insulation Conference, IEEE, September 1997

Fire safety

F1. "Classification and Application of PCB Alternative Fluids, Confusion or Progress?" K. Linsley and T. Orbeck, Doble Conference, April 1985. Lit. no. 10-254

F2. "Fact-finding Report on Flammability of Less Flammable Liquid Transformer Fluids," Underwriters Laboratories Inc., December 16, 1987

F3. "Study of Explosion and Fire Hazards of Silicone Liquid Under Arc Conditions," H. Kuwahara *et al.*, IEEE International Symposium on Electrical Insulation, Montreal, Canada, June 1976, Paper No. E-7. Lit. no. 10-245

F4. "Fire in a Cast Resin Transformer," K. Herberich, January 1979, *Brandschutz/Deutsche Feuerwehr Zeitung*. Lit. no. 10-265

F5. "Silicone Liquids in Transformers," R. Miller, *Electrical Energy Management*, May 1980. Lit. no. 22-779

F6. "Silicone Transformer in a Fire Situation," J. Dirnbock, *Electrotechnische Zeitschrift (ETZ)*, Vol. 16, July/August 1984. Lit. no. 10-266

*F7. Transformer Fluids, Factory Mutual Approval Guide 1993

*F8. Transformers, Factory Mutual Engineering Corp. Loss Prevention Data Sheet 5-4, 14-8, September 1986

F9. "Characterization of Transformer Fluid Pool Fires by Heat Release Rate Calorimetry," M. Kanakia, SwRI Project No. (33-5344-001, March 1979, 4th International Conference on Fire Safety, January 1979. Lit. no. 22-708

F10. "A Model for Combustion of Poly(Dimethylsiloxanes)," J. Lipowitz and M. Ziemelis, *Journal of Fire and Flammability*. Vol. 7, pp. 482-503, October 1976.

F11. "Flammability Tests of Askarel Replacement Transformer Fluids," R. Hemstreet, *Factory Mutual Research, Heat Release Rate*, FMRC No. 1A7R3.RC, August 1978.

F12. "Flammability of Poly(Dimethylsiloxanes) II. Flammability and Fire Hazard Properties," J. Lipowitz and M. Ziemelis, *Journal of Fire and Flammability*, Vol. 7, pp. 504-529, October 1976

F13. "PCB Alternatives — An Update," K. Linsley, IEEE, 1987, CH2479-4

F14. "Fire Safety Properties of Some Transformer Dielectric Liquids," J. Lipowitz, J. Jones and M. Kanakia, IEEE, 1979, CI-11510-7-EL

F15. "Fire Safety Upgrades in Conjunction with Mineral Oil Decontamination," J. Goudie and R. Savard. EPRI, September 1993. Lit. no. 10-580

F16. "Combustion Properties of Contaminated Dielectric Fluids as Determined in the Cone Calorimeter," J. Goudie and R.R. Buch. IEEE/DEIS International Symposium on Electrical Insulation, Baltimore, MD, June 7-10, 1992

F17. Nine-minute video of fire testing performed by UL. Request 561 Transformer Fluid Video. Lit. no. 10-347 (For video substantiation information, request document F2.)

F18. Ten-minute video of explosion testing to gain "less flammable" UL classification. Request Explosion/UL video. Lit. no. 10-503 (For video substantiation information, request document C6.)

High voltage strength

H1. "Partial Discharge Characteristics of Silicone Liquids," H. Kuwahani, *et al.*, 1975 Winter Meeting, IEEE/Power Engineering Society, New York, Jan. 30, 1975, Paper #C75 236-5

H2. "Study of Dielectric Breakdown of Kraft and Aramid Papers Impregnated with Silicone," W. Brooks and T. Orbeck, Paper E-8, 1976 IEEE International Symposium on Electrical Insulation, Montreal, Canada. Lit. no. 10-290

H3. "Comparative Impulse Dielectric Strength Tests of Transformer Oil and 561 Silicone Liquid," Report ET86-138-P from Ontario Hydro, Research Division, 11/24/86

H4. "Surface Breakdown Test Results of Mineral Oil and Silicone Oil with Kraft Paper and NOMEX," D.O. Wiltanen, J. Goudie, and H.A. Rojas Teran; IEEE/DEIS International Symposium on Electrical Insulation, Baltimore, MD, June 7-10, 1992

H5. "Impulse Strength Studies of Polydimethyl Siloxane Fluid," R.E. Miller, T. Orbeck, and J. Bosco; Presentation at the 1978 Winter meeting of the IEEE Power Engineering Society; New York, NY, 1/30/75

Water contamination

- W1. "Water Contamination of Silicone Filled Transformers," G. Coffman and T. Orbeck, Proceedings of the 15th Electrical/Electronic Insulation Conference, October 1981. Lit. no. 10-272
- W2. "Effects of Water and Silicone Fluids," G. Vincent, Conference on Electrical Insulation & Dielectric Phenomena, Dowington, PA, Oct. 21-23, 1974. Lit. no. 10-273

Environmental

- E1. "Polydimethylsiloxane: Opinion Regarding Use as Coolants in Transformers," *Federal Register*, Vol. 41, No. 112, June 9, 1976, p. 23226
- E2. "The Environmental Fate and Ecological Impact of Organosilicon Materials: A Review," C. Frye, Health and Environmental Sciences, Dow Corning. Lit. no. 10-370
- E3. "Disposal Options for 561 Transformer Fluid from Dow Corning," R.E. Ransom. Dow Corning. Lit. no. 10-518

Toxicological

- T1. "Are There Health Risks Associated with the Use of Amorphous Silicas?" R. McCunney, Corporate Medical Director, Cabot Corp. Memo, Feb. 23, 1984
- T2. "Toxicologic Classification of Thermal Decomposition Products of Synthetic and Natural Polymers," Y. Alarie, R. Anderson, *Toxicology and Applied Pharmacology*, 57, 1981
- T3. "Report of Mortality Following Single Exposure to Thermal Decomposition Products of Test Samples," A. Little, Rep. C-54695, November 1985
- T4. "Screening Materials for Relative Toxicity in Fire Situations," C. Hilado, *Modern Physics*, 1977
- T5. "Toxicity of Pyrolysis Gases from Silicone Polymers," C. Hilado, *et al.*, *Journal of Combustion Toxicology*, Vol. 5, May 1978. Lit. no. 10-264
- T6. "State-of-the-Art Review: Pyrolysis and Combustion of PCB Substitutes," SCS Engineers, Inc., EPRI (Electric Power Research Institute) E1-4503, Project 2028-12, March 1986. Lit. no. 10-293

*Codes and standards**

- *C1. "Standard Specification for Silicone Fluid Used for Electrical Insulation," ASTM D4652-87, March 1987, 545-546
- *C2. *IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment*, C57.106-1991
- *C3. *IEEE Guide for Acceptance and Maintenance of Less-Flammable Hydrocarbon Fluid in Transformers*, C57.121-1988, Table 1
- *C4. *IEEE Guide for Acceptance of Silicone Insulating Fluid and its Maintenance in Transformers*, C57.111-1989, Table 1
- *C5. *1991 Gas and Oil Equipment Directory*, Underwriters Laboratories
- C6. "New UL Classification for Silicone Transformer Fluid," J. Goudie and S. Mott, Electrical Manufacturing Technologies Expo, June 1994. Lit. no. 10-579
- C7. "Silicone Transformers: An Update on Current Product Listings, Codes and Standards," S. Mort, EPRI PCB Seminar September 1993. Lit. no. 10-581

*Items F7, F8, and C1-C5 can be obtained through the appropriate group or agency

Section 2: Safety

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 - 2.5.4 Smoke and combustion products
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 - 2.5.6 UL fact-finding report

2.1 Safety data sheet

A safety data sheet (SDS) for XIAMETER™ 561 Silicone Transformer Liquid is supplied when the material is shipped. Many customers will have one on file in their purchasing, procurement, or receiving department.

The health and safety information and recommendations reported on an SDS can change periodically as new information becomes available. Therefore, the SDS should not be photocopied or widely distributed.

If additional copies of the SDS for XIAMETER™ 561 Silicone Transformer Liquid are needed, please contact Dow to obtain copies of the most up-to-date version or visit www.consumer.dow.com.

2.2 Health and environmental aspects

2.2.1 Toxicology

Oral — The oral toxicity of polydimethylsiloxane (PDMS) is extremely low. No deaths have resulted in rats at single doses as high as 30 mL/kg of body weight for 0.65-12,500 cSt viscosity grade fluids. More specifically, the 50 cSt PDMS used in XIAMETER™ 561 Silicone Transformer Liquid has been dosed as high as 50 mL/kg with no observed effects. Subacute and chronic oral studies in mice, rats, rabbits, and dogs have uniformly failed to yield any results of toxicologic significance. The Food and Drug Administration (FDA) permits levels of up to 10 ppm of 350 cSt PDMS fluid to be added in many food-processing operations. It is also used as an antifatulent in medical applications.

Skin response — A number of human repeated-insult patch tests have been conducted with PDMS fluids. In no case has there been an indication that the materials are skin sensitizers or skin-fatiguing agents. Dermal absorption studies have yielded no absorption in significant amounts. Instead, the soothing and nonirritating action of PDMS fluid on the skin has resulted in the use of many types of silicones, including PDMS fluids, in hand creams, shaving soaps, deodorants, and cosmetics.

Eye response — Instillation of PDMS into the eye causes transitory conjunctival redness that disappears within 24 hours. The effect is probably caused by the water-repellency of the silicone fluid that produces a feeling of dryness. This effect is a physical and not a chemical effect, which is similar to the eye sensation that appears after long exposure to the wind. It has produced no serious health problems. Touching the eyes or facial skin close to the eyes may also result in this temporary eye redness.

When handling XIAMETER™ 561 Silicone Transformer Liquid, care should be taken to avoid contacting the fluid with the eye to prevent any temporary discomfort that may result.

Inhalation — XIAMETER™ 561 Silicone Transformer Liquid has a very low vapor pressure and thus presents essentially no inhalation hazard. Further, in inhalation studies of pyrolysis and combustion products from XIAMETER™ 561 Silicone Transformer Liquid, no significant toxicological hazards were observed when compared to normal combustion products.

2.2.2 Environmental toxicity

All studies conducted indicate a very low order of toxicity for PDMS fluids. No evidence has been obtained to suggest accumulation in the flesh of fish or birds, and there appears to be no significant transfer of the material to the eggs of chickens. The details of the studies done are available in the literature or upon request.

2.2.3 Environmental entry

Since XIAMETER™ 561 Silicone Transformer Liquid is used in closed systems, the environmental exposure risk is relatively low even in the event of an accidental release. PDMS fluids are nonvolatile and do not evaporate to the atmosphere, thus entry points are limited to soil, surface water, landfill or a wastewater treatment plant. PDMS will preferentially adhere to soil particles so its propensity to migrate towards groundwater is extremely limited. This characteristic also simplifies clean-up since the fluid will tend to remain near the spill source.

2.2.4 Environmental fate and effects

The fate of PDMS is partly a function of where it enters the environment. Studies have shown that PDMS will degrade into lower molecular weight compounds, primarily Me₂Si(OH)₂, when in contact with soils. Testing under a variety of representative conditions has confirmed this observation in a wide range of different soils, indicating that the phenomenon is widespread in nature.

Significant degradation to lower molecular weight compounds has been noted after only a few weeks of soil contact. The actual rate and extent of degradation vary as a function of soil moisture content and clay type. These lower molecular weight degradation products have been shown to further oxidize in the environment, both biologically and abiotically, to form naturally occurring substances: silica, carbon dioxide, and water.

No effects from PDMS (or its degradation products) have been observed on seed germination, plant growth/survival, or plant biomass. In addition, research has shown no adverse effects from PDMS on terrestrial life forms such as insects or birds, even under highly exaggerated exposure conditions.

Aquatic environments — If nonvolatile PDMS fluid should enter the aquatic environment, the material attaches to particulate matter and is removed from the water column by the natural cleansing process of sedimentation. Testing on aquatic plant and animal life has revealed no ecologically significant effects, even under highly exaggerated exposure conditions. PDMS fluids do not partition back into the water column, and they have no detectable biological oxygen demand (BOD). Bioconcentration is not a significant concern with PDMS. The size of the molecules makes them too large to pass through biological membranes in fish or other organisms. Specific testing has shown that PDMS does not bioaccumulate in benthic organisms or various terrestrial species, including earthworms.

Wastewater — Municipal treatment plants are designed to facilitate the natural degradation of waste by microscopic organisms. Biomass (i.e., sludge) is generated by this degradation and eventually disposal is required. Because the water solubility of silicone fluids is essentially nil, they become a minor constituent of the sludge as they attach to suspended

materials in wastewater systems. In a municipal system, treated sludge is typically incinerated, landfilled, or used as fertilizer. Wastewater treatment monitoring and simulation studies have confirmed that PDMS fluid will be almost completely absent from the treated effluent.

PDMS does not inhibit the microbial activity by which wastewater is treated. Test levels far exceeding those expected in the environment have shown no effect on the activated sludge process, other than the expected benefit of foam control. The ultimate fate of nonvolatile PDMS depends on the treatment process. If the sludge is incinerated, the silicone content converts to amorphous silica, which presents no further environmental consequence when the ash is landfilled. When treated sludge is used as fertilizer, very low levels of PDMS can be introduced to the soil environment, where it is subject to soil-catalyzed degradation. Similar soil-catalyzed degradation can also occur if sludge-bound PDMS is landfilled. Overall, there is no evidence of any adverse effects of PDMS fluids on WWTP operations.

Using the analytical test method specified by the U.S. Environmental Protection Agency, silicone fluid discharged into a wastewater sewer will be detected as an “oil and grease” type of material. However, the test method specified by the EPA also identifies other nonhydrocarbon materials as “oil and grease” materials.

Most municipalities have an “oil and grease” concentration limit of 100-200 parts per million for each customer connected to the sewer system. Minor leaks and spills of silicone fluid are unlikely to lead to a customer’s waste stream exceeding this limit. However, large spills of any material, including silicone fluid, should not be discharged to a sewer system. See section 2.4 for more information on clean up of spills. In support of their compliance responsibilities, Dow can provide suggestions to customers on how best to minimize silicone fluid losses to the sewer.

2.3 Regulatory facts

This section includes regulatory facts that can make it easier for safety and environmental professionals to determine how XIAMETER™ 561 Silicone Transformer Liquid might be regulated according to current government law.

- XIAMETER™ 561 Silicone Transformer Liquid is 100% trimethyl-end-blocked polydimethylsiloxane
- The Chemical Abstracts Service (CAS) number for the material is 63148-62-9
- This material is not classified as hazardous when discarded under the Resource Conservation and Recovery Act (RCRA) (40 CFR 261)
- The material is halogen-free — there is no chlorine or bromine present
- The material contains no additives such as pour-point depressants, flow modifiers, antioxidants, or thermal stabilizers
- The material contains no hazardous ingredients as defined by Occupational Health and Safety Act (OSHA) regulations under the Hazard Communication Standard (29 CFR 1910)
- The material is not listed under SARA Title III for hazardous or toxic materials.

2.4 Spill information

2.4.1 Minor spills

Minor spills on paved surfaces can be cleaned using absorbent materials. Use of a suitable solvent or partial solvent will facilitate cleanup. Flammability and toxicity should be a prime consideration in the choice of a solvent to clean up spills. Solvents should not be used on asphalt surfaces since they will dissolve the asphalt.

Table 2.1 — Solvents and partial solvents for silicone fluids

Solvents	Partial solvents
Amyl acetate	Acetone
Cyclohexane	Butanol
Ethylene dichloride	Dioxane
2-Ethyl hexanol	Ethanol
Hexyl ether	Heptadecanol
Mineral spirits	Isopropanol
Naptha VM&P	
Stoddard solvent	
Toluene	
Turpentine	
Xylene	
Gasoline	
Kerosene	
Methylethyl ketone (MEK)	
Methylisbutyl ketone (MIBK)	

2.4.2 Spills on water

Section 311 of the Federal Clean Water Act imposes strict reporting requirements when certain substances are spilled onto navigable waters.

The requirement to report is not triggered by a specified quantity of spilled material, rather it is triggered by the discharge of an amount of material that causes a sheen on the water. Thus, if PDMS fluids are spilled in large quantities on navigable waters and produce a visible sheen, the U.S. Coast Guard must be notified immediately at 1-800-424-8802.

Since silicone fluids are nearly insoluble in water and are lighter than water, they will remain at the surface of the water and can be removed using hydrophobic materials such as polypropylene mats, pads, or booms. The polypropylene material will soak up the silicone fluid while repelling the water. Once the absorbent material becomes saturated with fluid, it can be discarded as a nonhazardous solid waste or regenerated by squeezing the pad, mat, or boom to release the fluid for disposal or recovery. For more information on recovery of silicone fluids, see section 6.5 for recycling and disposal of silicone transformer fluid.

A silicone/water mixture can also be passed through a filter containing treated cellulose such as ABSORBENT W, which can selectively absorb the silicone fluid while allowing the water to pass through. Table 2.2 is a list of recommended absorbent materials and filter media for treating silicone fluid that has been spilled into water.

2.4.3 Spills on roadways

The chief concern in a roadway spill is the loss of tire traction caused by the lubricating action of the silicone fluid. On concrete or asphalt, silicone fluids have about the same degree of lubricity as motor oil.

Spills of silicone fluid on paved surfaces should be cleaned up as quickly as possible to avoid unnecessary spread of the material or potential contact with water or precipitation that could then require additional cleanup action. Spilled silicone fluid can be absorbed with materials that are commonly used to soak up oils and solvents. These include plastic fibers and pads, cellulose-based fibers and granules, and expanded clay solids. In an emergency, dry sand can be used, but it is less absorbent than the other types of materials.

The choice of absorbent may be dictated by the final disposal option. For example, the silicone fluid/absorbent mixture may be landfilled as nonhazardous solid waste, provided there is no free liquid in the absorbent mixture. If the landfill operator prefers a nonbiodegradable absorbent for burial, the plastic fiber or expanded clay would be a better choice than biodegradable cellulose. If incineration was selected as the final disposal option, the cellulose product would be preferred since it would be fully combusted and would not contribute to ash residue.

For a silicone fluid spill on a paved surface, absorption of the fluid followed by thorough sweeping of the surface with clean absorbent should be adequate to prevent fluid runoff if the surface is subsequently wetted with water. Solvent cleaning of roadway surfaces is usually unnecessary. Residual silicone will attach to the paving material and act as a water-repellent agent.

The time required to remove XIAMETER™ 561 Silicone Transformer Liquid depends on the physical absorbent and the amount of fluid present. Periodic replenishment with fresh absorbents speeds up the removal.

2.4.4 Spills on soil

A minor spill of XIAMETER™ 561 Silicone Transformer Liquid on soil can be cleaned up by removal of the soil until there is no visual discoloration of the remaining soil. In most states, the collected discolored soil can be legally landfilled as a solid nonhazardous waste.

Should such a cleanup operation be necessary, Dow recommends that the appropriate state and local government officials be contacted before landfilling any material.

2.4.5 Recommended absorbents

Dow performed a laboratory evaluation to assess the efficiency of nine commercially available absorbents for XIAMETER™ 561 Silicone Transformer Liquid. Absorbency was measured for both the silicone fluid and for a water/silicone mixture.

The best results were observed using polypropylene pad materials. Polypropylene is a hydrophobic material that repels water while attracting nonpolar fluids and oils. For absorbing spilled fluid on a dry surface, a stitched polypropylene pad soaked up 12 times its original weight, while a pillow configuration absorbed 13 times its weight. Both products can be reused

by squeezing them to release most of the trapped fluid. When silicone fluid was poured onto a water surface, the polypropylene pillow and the stitched pad again performed the best.

Products that absorbed the least amount of fluid included ground corn cobs (SLICKWIK), untreated cellulose (ABSORBENT GP), and cotton fiber (Conwed Sorbent Rug). These results are summarized in tables 2.2 and 2.3. Expanded clay and vermiculite (kitty litter) products were not tested since loose products are not practical for absorbing and recovering silicone fluids on water surfaces.

The better performing absorbents were able to selectively remove 90-95% of the fluid from the surface of the water. To remove any remaining visible sheen, best results were achieved by passing the mixture through a filter packed with treated cellulose fiber (ABSORBENT W). This second filtration/absorption step reduced the silicone content in the water to below 10 ppm.

2.4.6 Spill containment

Federal, state, and local regulations can impose different requirements that should be reviewed. In addition, good manufacturing practices (GMP) and product stewardship policy will dictate some form of spill containment for materials that have risk factors that warrant such protection.

Examples of risk exposure consideration include:

- Proximity to waterways
- Potential for fire and fire water runoff
- Potential for spillage from material transfer activities

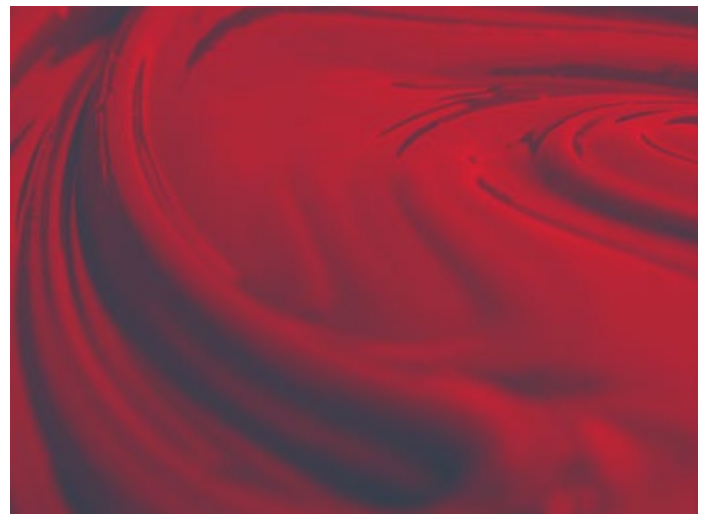
Because silicone fluids are neutral and lighter than water, spill containment, when deemed prudent, can consist of an “over and under” baffled sump similar to a small household septic tank. This configuration will trap and retain the fluid while allowing water to pass through for routine disposal.

Table 2.2 — Relative performance of absorbents with XIAMETER™ 561 Silicone Transformer Liquid in water

Rank	Type	Product name	Supplier	Contact
1	Polypropylene pillow	PIL 203 J	New Pig Corporation	800-468-4647
2	Polypropylene stitched mat	MAT212 J	New Pig Corporation	800-468-4647
3	Polypropylene mat pad	MAT215 J	New Pig Corporation	800-468-4647
4	Polypropylene quilted pad	MAT403 J	New Pig Corporation	800-468-4647
5	Ground corn cobs	SlickWik	Andersons Company	
6	Polypropylene plain pad		Hazwick	
7	Treated cellulose	Absorbent W	Minnesota Absorption Corp.	612-642-9260
8	Blue cotton fiber roll	Conwed 76700 Sorbent Rug	Sansel Supply Company	216-241-0333
9	Untreated cellulose	Absorbent GP	Minnesota Absorption Corp	612-642-9260

Table 2.3 — Relative performance of absorbents with XIAMETER™ 561 Silicone Transformer Liquid on dry surface

Rank	Type	Performance
1	Polypropylene pillow	13x
2	Polypropylene stitched mat	12x
3	Polypropylene mat pad	10x
4	Polypropylene quilted pad	10x
5	Polypropylene plain pad	7x
6	Blue cotton fiber roll	5x
7	Ground corn cobs	4x
8	Treated cellulose	3x
9	Untreated cellulose	2x



2.5 Fire safety

The excellent reliability, performance, and economics of conventional fluid-filled transformers have been well established by end-users. They have a strong interest in transformer liquids that can replace askarels as well as meet present and future safety requirements.

The concept of the fire hazard of systems is replacing the narrower concept of flammability of materials. The most valid fire-hazard tests are those that evaluate the entire system under conditions that closely simulate use under realistic worst-case scenarios. The following characteristics are related to the fire hazard to buildings and people:

- Heat release
- Smoke and fire gases
- Fire growth/flame spread
- Arc gases
- Oxygen depletion
- Ease of ignition
- Extinguishment

Most of the current fire-hazard data for transformer fluids has been generated by conducting large-scale pool-fire tests.

2.5.1 Pool-fire burning characteristics

The effect of the diameter of the burning pool of fluid on the combustion rate (rate of heat release) has been studied extensively for hydrocarbon fires over a wide range of pool diameters. The flame height in a hydrocarbon fire has been shown to be 2.5 times the diameter of the pool for pans 4 feet in diameter and larger. The combustion rate of silicones decreases with increasing pan size. The flame height stabilizes at 1 to 2 feet at a pan size of approximately 4 feet.

Silicone transformer fluid will reach a maximum sustained rate of heat release (RHR) after ignition. This peak value is maintained for several minutes. The RHR then decreases with time. This is in contrast to hydrocarbons that typically reach a steady-state RHR that is maintained until the material is consumed. It is the peak RHR that is reported and used to assess potential hazard. The silicone peak value is 10 to 18 times lower than the average value for hydrocarbons. Figures 2.1 and 2.2 from pan-burn studies show the characteristically different burn behavior of silicones.

The fire hazard to buildings, structures, and equipment can be assessed by the heat released. The rate of heat release is therefore important. Insurance companies in the U.S. use the RHR value to classify materials used in transformers.

By adding external heat to a pool fire, the behavior of the fluid toward an external fire can be studied. Figure 2.3 shows that the convective RHR will increase as the external heat flux is increased for two high-fire-point hydrocarbon transformer fluids. The RHR for silicone fluid shows little increase with increasing external heat flux. The data suggest that a high-fire-point hydrocarbon could dramatically fuel a fire, but a silicone fluid would make little or no contribution.

Figure 2.1 — Rate of heat release for transformer fluids in 12-inch diameter pan-burn test

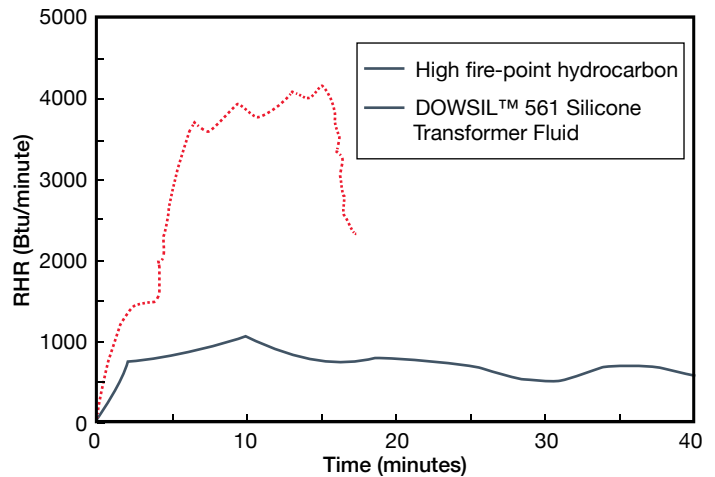


Figure 2.2 — Rate of heat release for DOWSIL™ 561 Silicone Transformer Liquid in 24-inch diameter pan-burn test

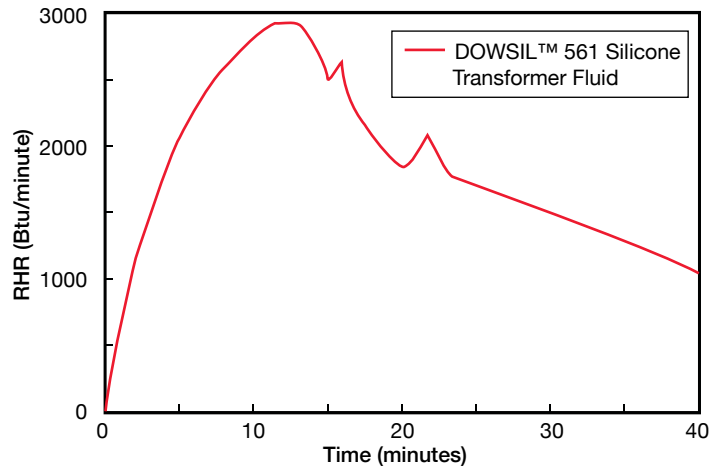


Figure 2.3 — Convective rates of heat release for transformer fluids in 4-foot diameter test

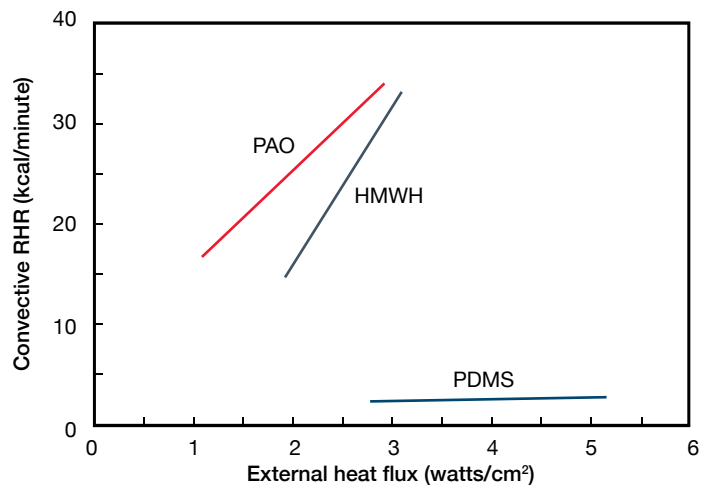


Figure 2.4 — Burning rate per unit area as a function of pool (or droplet) diameter

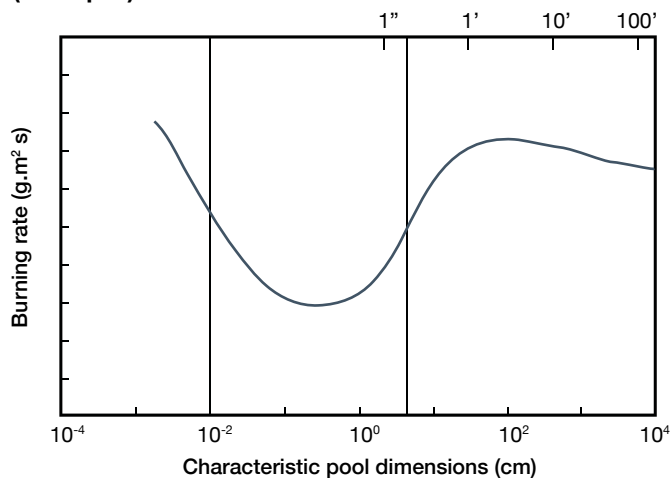
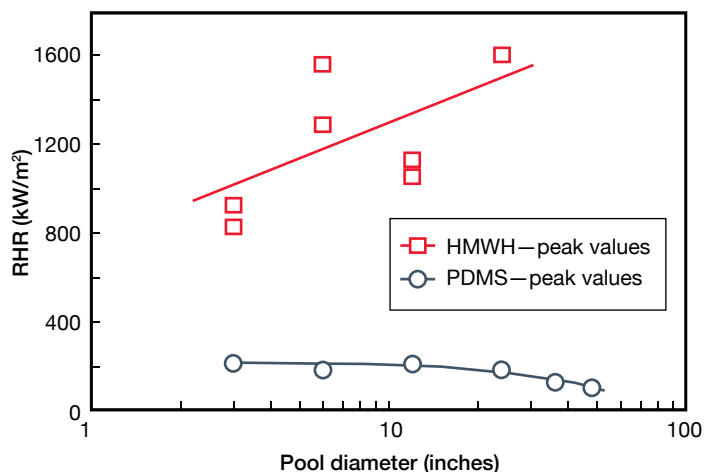


Figure 2.5 — Peak rate of heat release for transformer fluids



The normalized value of RHR (RHR/area) has been used to predict the RHR of larger pan sizes. Figure 2.4 shows the relationship between burning rate and pool size for hydrocarbon burns. The RHR/m² will typically level off at a 4-foot diameter pan for hydrocarbons.

For hydrocarbons, the normalized heat release rate shows a dramatic increase as pan size increases (see figure 2.5). The change in the normalized heat release rate as silicone burn size increases, in the same figure, is much less dramatic. The data in table 2.4 was generated for high-fire-point hydrocarbons and XIAMETER™ 561 Silicone Transformer Liquid.

The decrease in the RHR/area with increased pan size and the decreasing RHR with time in a pool fire result from the progressive formation of a crust of ash and silica that forms over the surface during a pool fire involving the silicone transformer fluid. The ash consists of a continuous pattern of white silica “domes” approximately 1 cm in diameter. A brown or black gel layer is formed beneath the domes. Energy feedback from the flame is inhaled sufficiently to result in self-extinguishment, leaving a pool of clear, colorless, unburned fluid beneath the ash and gel.

Table 2.4 — Summary of normalized RHR data (all data in kW/m²)

	Dow	FMR	Independent test lab
Poly- α -olefin (PAO)	1430	1020	1240
High-FP hydrocarbon	1200	1050	1270
XIAMETER™ 561 Silicone Transformer Liquid	65	104	109

2.5.2 Extinguishment

Extinguishing a fire involving XIAMETER™ 561 Silicone Transformer Liquid can best be accomplished using high-expansion foam, protein-based foam, or carbon dioxide or dry chemical extinguishers.

Industrial sprinkler systems are also effective. Tests using an indoor calibrated sprinkler system show that silicone fluid fires are extinguished in 20 to 30 seconds with 0.15 gpm/ft² of water. As is common practice, high-velocity water streams should never be used to extinguish an electrical or chemical fire.

2.5.3 Threat to adjacent buildings

Fires associated with transformers located outdoors can pose a severe threat to adjacent buildings. Several NFPA and IEEE standards, as well as Factory Mutual Engineering and Research Loss Prevention Data Sheet 5-4 on transformers, recommend minimum distances between transformers and adjacent buildings. Despite the availability of this information, applying the data to actual transformer installations is not well understood.

Dow commissioned a study by Factory Mutual Research Corporation to determine safe distances between fluid-insulated power distribution transformers located outdoors and adjacent buildings. This “safe distance” would prevent a transformer fire from spreading to an adjacent building or structure. The study was performed for transformers with ratings up to 5000 kVA.

The general approach to the problem included:

- An examination of loss experience regarding transformer fires reported to Factory Mutual
- A theoretical analysis of fire conditions

This approach was followed for several types of transformer fluids — including mineral oil, high molecular weight hydrocarbons (HMWH), and silicone — and for common types of building construction — wooden walls, asphalt roofs, steel on steel frame (noncombustible) walls, and one-hour- or two-hour-rated walls. In the report, the results are presented in the form of graphs, tables, and/or equations.

It was found that for a typical fluid-insulated distribution transformer fire, the safe separation distance from a wooden structure is 14.8 m (49 ft) for the case of mineral oil fluid, 12 m (39 ft) for HMWH fluid, and 2.5 m (8 ft) for silicone fluid. Similar trends were reported for other building materials.

For more information on this study, contact your local Dow representative.

2.5.4 Smoke and combustion products

Smoke from silicone transformer fluid fires is typically 3 to 5 times less dense than high-fire-point hydrocarbon smoke. The smoke consists of tan-gray particulates that are almost entirely amorphous silica. The O₂-depletion rate for testing at the same smoke density has been measured at 600 liters/minute. Animal studies have indicated that the combustion products of silicone transformer fluid have little or no potential to cause serious injury, especially as compared to the affects of the combustion products of mineral oil or askarel.

2.5.5 Basic thermochemical properties

Table 2.5 is a summary of the thermal stability properties and burning properties of XIAMETER™ 561 Silicone Transformer Liquid.

2.5.6 UL fact-finding report

The UL fact-finding report for less flammable transformer fluids is available from Dow.

Table 2.5 — Summary of thermal stability and burning properties of XIAMETER™ 561 Silicone Transformer Liquid

Property	Value
Viscosity	50 cSt
Flash point	572°F (300°C) minimum
Fire point	>600°F (350°C)
Autoignition temperature	435°C
Volatility	<0.5%
Thermal conductivity	0.00036 cal/sec-cm·°C @ 50°C
Limiting oxygen index	18.5-19% O ₂
Heat of combustion	6.7 kcal/g
Rate of heat release	100-120 kcal/m ² (4-ft pan)

Section 3: Transformer design information

Section content

- 3.1 Dielectric data
 - 3.1.1 Dissipation factor, Df
 - 3.1.2 Dielectric constant, DK
 - 3.1.3 Electrical breakdown
- 3.2 Thermal capabilities
- 3.3 Pressure increases
- 3.4 Partial discharge characteristics
- 3.5 Load-break switching performance
- 3.6 Medium and large power transformer applications
- 3.7 Material compatibility
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 - 3.8.1 Vapor pressure
 - 3.8.2 Volume expansion
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 - 3.8.4 Viscosity-temperature relationship
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 - 3.8.6 Density
- 3.9 Lubricity
- 3.10 Retrofill considerations
 - 3.10.1 Material and component compatibility
 - 3.10.2 Temperature rise/heat transfer
 - 3.10.3 Fire safety considerations

3.1 Dielectric data

This section presents and discusses a variety of typical dielectric properties that are important to the performance of transformer fluids.

3.1.1 Dissipation factor, Df

XIAMETER™ 561 Silicone Transformer Liquid is a low-loss, nonpolar material as measured by dissipation factor or power factor. Dissipation and power factors are related by the following equations:

If Θ is the phase angle and δ is the loss angle,

$$\Theta + \delta = 90^\circ$$

$$\text{Power factor} = \cos\Theta$$

$$\text{Dissipation factor} = \tan\delta$$

For XIAMETER™ 561 Silicone Transformer Liquid, typical values of the dissipation factor are approximately equal to the power factor. Figures 3.1 through 3.3 show the dissipation factor versus temperature, frequency, and voltage stress. Figures 3.4 and 3.5 compare the dissipation factor of silicone with mineral oil using two commonly used transformer insulation types.

Figure 3.1 — Typical dissipation factor values versus temperature

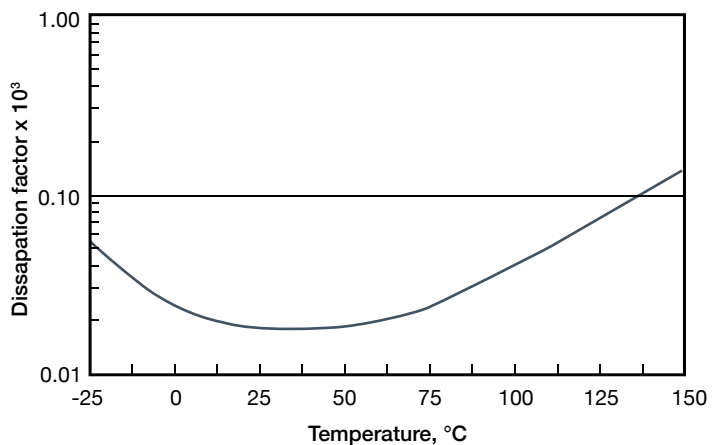


Figure 3.2 — Frequency response of dissipation factor

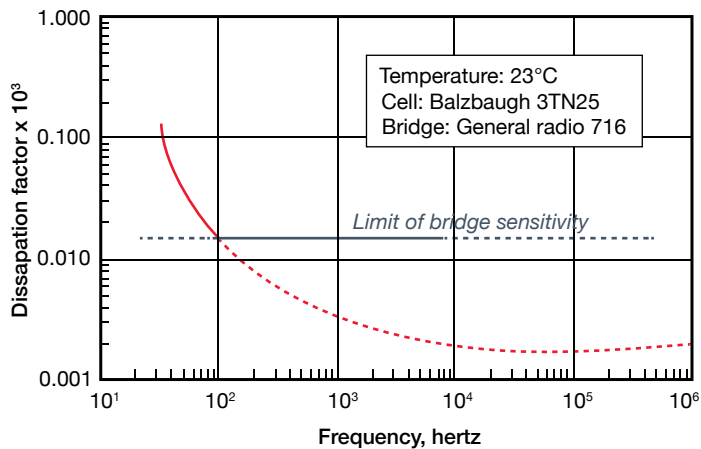


Figure 3.3 — Dissipation factor versus voltage stress

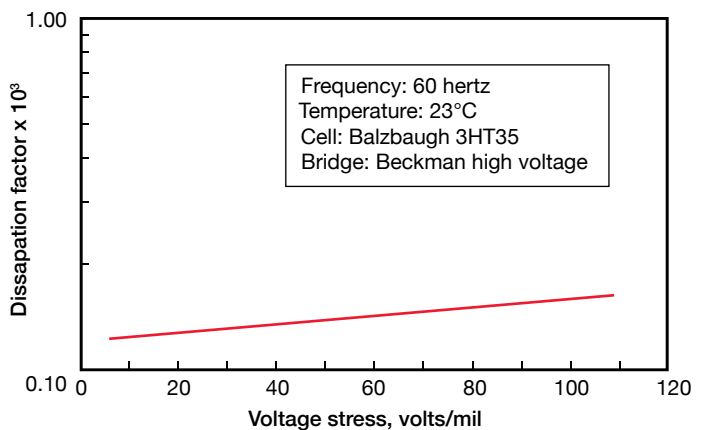


Figure 3.4 – Dissipation factor of kraft paper impregnated with transformer fluids

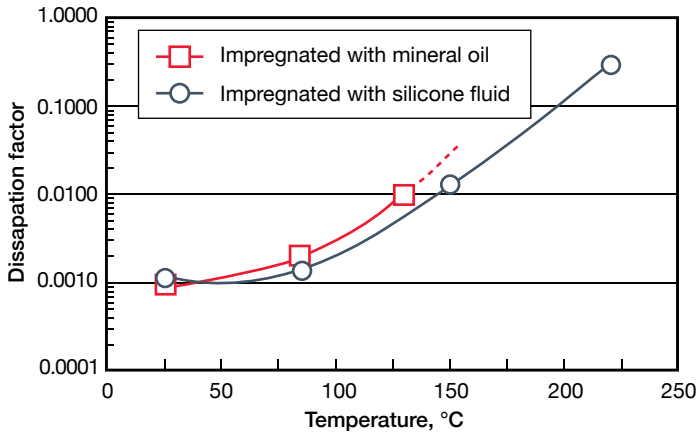


Figure 3.5 – Dissipation factor of NOMEX 410 impregnated with transformer fluids

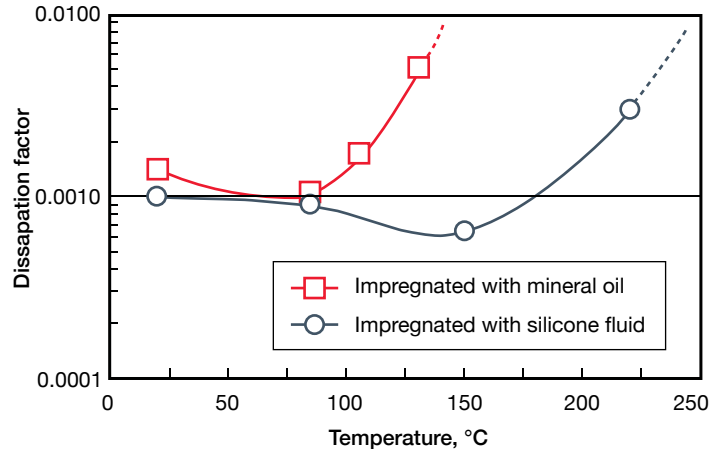


Figure 3.6 – Typical values of dielectric constant versus temperature

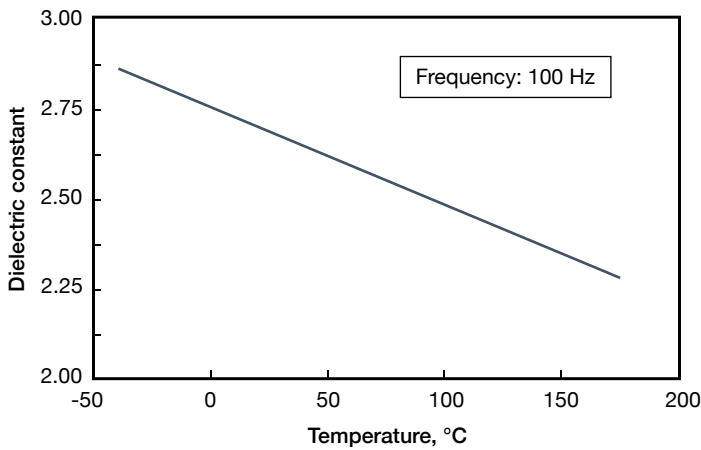


Figure 3.7 – Frequency response of the dielectric constant

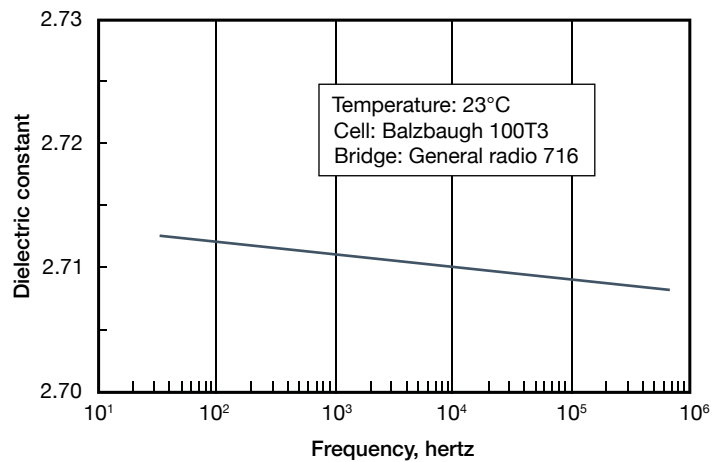
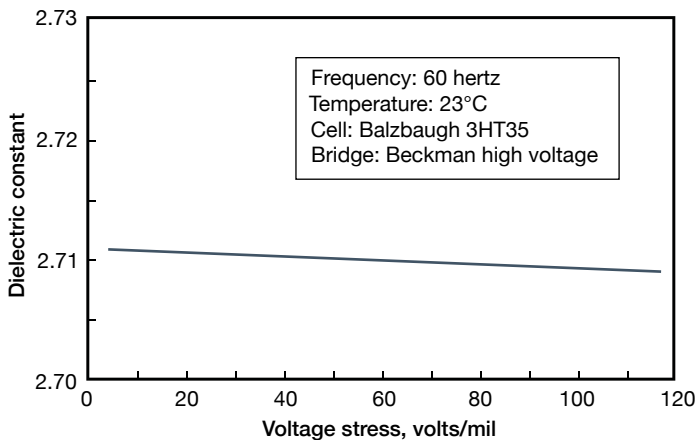


Figure 3.8 – Dielectric constant versus voltage stress



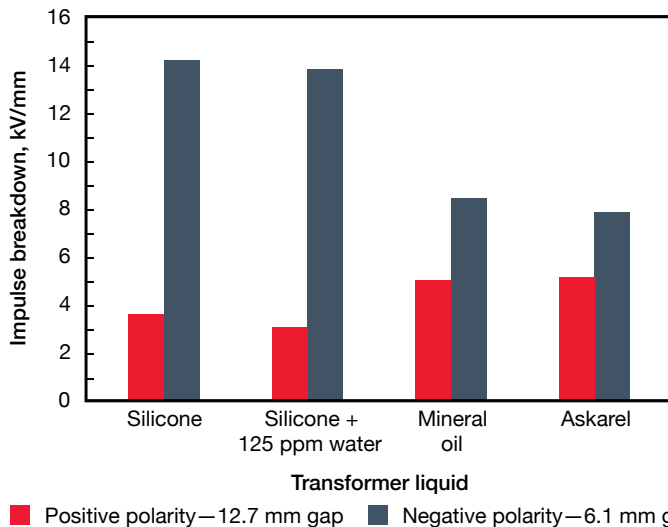
3.1.2 Dielectric constant, DK

Dielectric constant (sometimes referred to as permittivity, capacitance, or specific inductive capacity) is the ratio of the capacitance of the material in a particular test configuration to the capacitance of the same configuration in air. Figures 3.6 through 3.8 show the dielectric constant of XIAMETER™ 561 Silicone Transformer Liquid as a function of temperature, frequency, and voltage stress.

3.1.3 Electrical breakdown

The dielectric breakdown of silicone fluid according to D877 is discussed in section 6.1, periodic inspection and testing. The effect of water contamination on the results of this test is discussed in section 6.2, contamination. The current section deals with the impulse breakdown strength of XIAMETER™ 561 Silicone Transformer Liquid and its breakdown strength in combination with paper insulation. Since the nature of this testing is such that comparisons are the most valuable, figures 3.9 and 3.10 include data for other transformer fluids. Figure 3.11 reports the uniform field breakdown of silicone fluid at various levels of water content for two different ASTM tests.

Figure 3.9 — Sphere-to-sphere impulse breakdown levels for transformer fluids



The electrical-breakdown data presented in tables 3.1 through 3.4 and figures 3.12 and 3.13 provide general information as to the relative performance of silicone in specific test configurations.

Figure 3.11 — Impact of water content on uniform field breakdown for silicone fluid

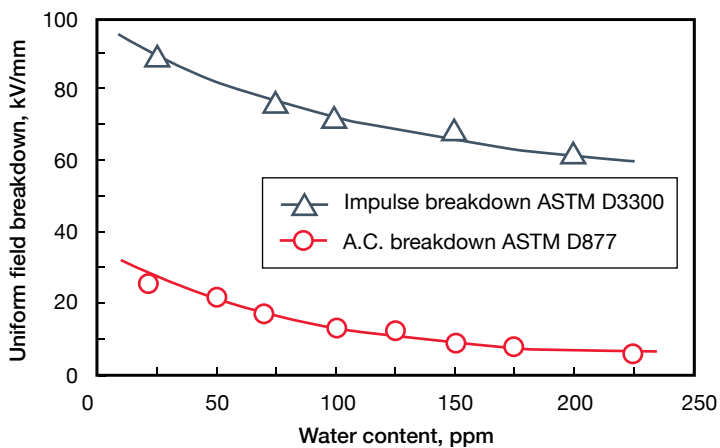


Table 3.1 — Breakdown of 10-mil aramid paper/fluid composite insulation (sphere-to-ball electrodes at 25°C)

	Silicone	Mineral oil
<i>60 Hz, 3 kV/second rate of rise</i>		
Breakdown voltage, V/mil	1923	1966
Standard deviation, V/mi	124	233
Number of tests	12	20
<i>60 Hz, 1 kV/second step rise</i>		
Withstand voltage, V/mil	1200	1205
Standard deviation	146	94
Number of tests	18	18
<i>1.2 x 50 μs positive impulse</i>		
Withstand voltage, V/mil	3159	3054
Standard deviation, V/mi	146	126
Number of tests	18	16

Figure 3.10 — Impulse breakdown of 2x10 mil fluid-impregnated paper (sphere-to-sphere electrodes)

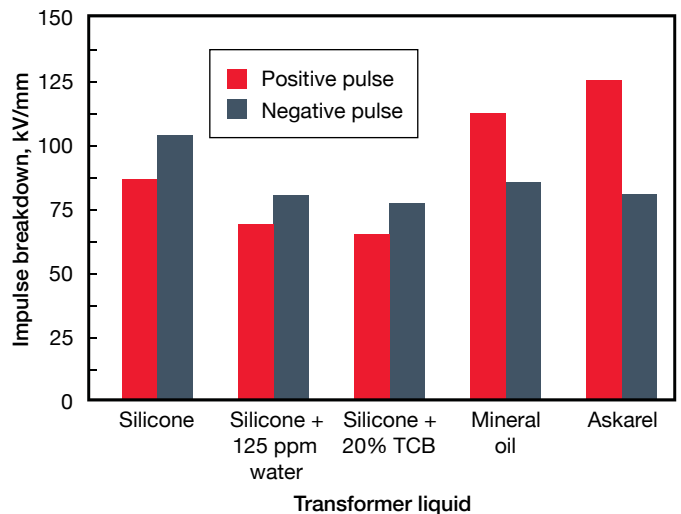


Table 3.2 — Breakdown of 10-mil kraft paper/fluid composite insulation (sphere-to-plane electrodes at 25°C)

	Silicone	Mineral oil
<i>60 Hz, 3 kV/second rate of rise</i>		
Breakdown voltage, V/mil	1570	1894
Standard deviation, V/mi	94	195
Number of tests	75	20
<i>60 Hz, 1 kV/second step rise</i>		
1-min withstand voltage, V/mil	1211	1183
Standard deviation	78	72
Number of tests	10	12

Figure 3.12 — Influence of gap length on surface flashover impulse voltage—positive impulse

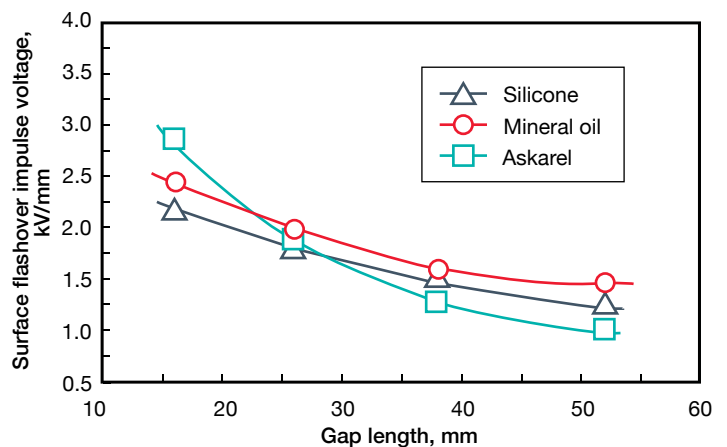


Figure 3.13 – Influence of gap length on surface flashover impulse voltage—negative impulse

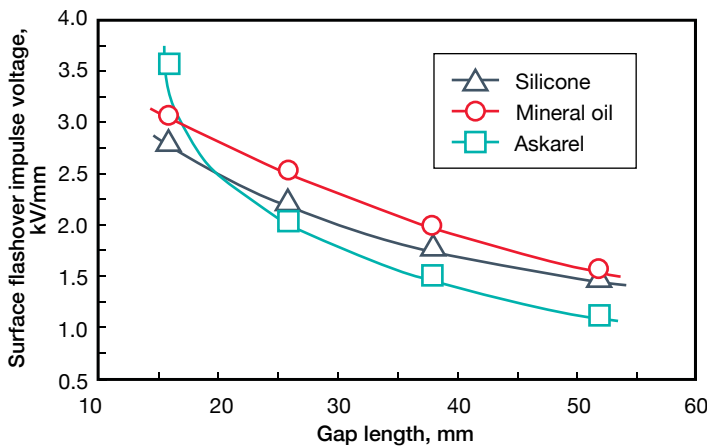


Table 3.3 – Repeat breakdown – initial penetration from 40 kV impulse discharge; repeat strength at 60 Hz, 25°C and 3 kV/s rate of rise

	Silicone	Mineral oil	Askarel
Breakdown, mean, V/mil	942	277	0
Number of tests	18	20	19
Number of O's observed	3	10	19

Table 3.4 – Breakdown strength versus humidity and water exposure – 60 Hz, 25°C and 3 kV/s rate of rise

Exposure	After vacuum	7 days @ 85% RH	60 days with water interface
<i>10-mil kraft paper/silicone fluid composite insulation</i>			
Breakdown voltage, mean, V/mil	1559	1442	1584
Standard deviation, V/mi	104	149	43
Number of tests	24	24	20
<i>10-mil kraft paper/mineral oil composite insulation</i>			
Breakdown voltage, mean, V/mil	1899	1735	1745
Standard deviation	216	238	127
Number of tests	8	8	14

Results from a recent study using low-density kraft board and low-density NOMEX board indicated that XIAMETER™ 561 Silicone Transformer Liquid and mineral oil perform similarly when subjected to negative and positive lightning impulses and 60 Hz ac power. Electrical breakdowns under positive impulse voltages are generally lower than those under negative impulse voltages. Permittivity matching appears to be a factor in the dielectric strength of the interface to impulse voltages. For ac voltages, poor resistance to partial discharges may override this effect. Figures 3.14 and 3.15 show the average breakdown voltages on low- and high-density kraft and NOMEX pressboard.

Figure 3.14 – Mean breakdown voltages on both high- and low-density kraft paper board (Bars with a + symbol represent breakdown voltages with positive impulse voltages; bars with a – symbol represent negative impulses; and bars with 'ac' represent alternating current impulses.

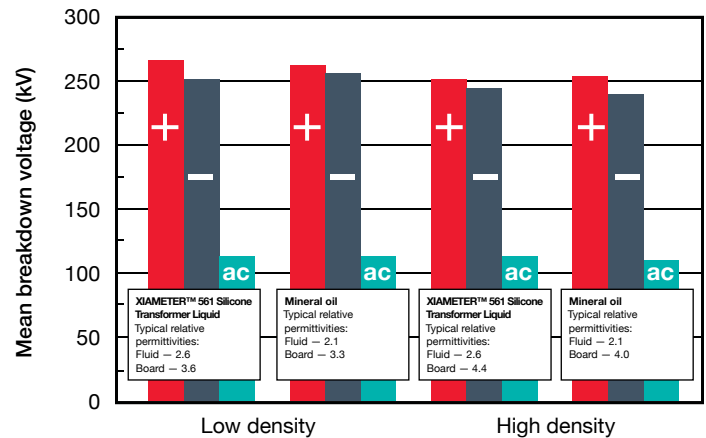
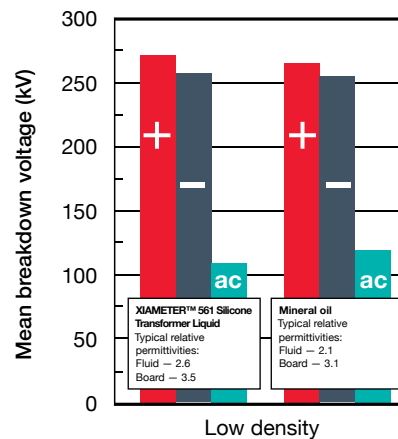


Figure 3.15 – Mean breakdown voltages on low-density NOMEX paper board



3.2 Thermal capabilities

Silicone transformer fluid differs from mineral oil and askarel in that, aside from a controlled molecular-weight distribution, it is chemically homogeneous and not a mixture containing some relatively volatile constituents. It is more heat stable than the other two fluids. These characteristics allow silicone transformer fluid to be subjected to very high temperatures — well above normal transformer operating temperatures — without creating excessive vapor pressure or corrosive by-products. Silicones are chemically inert, have good oxidation resistance, and are compatible with conventional insulating materials at transformer operating temperatures.

Table 3.5 summarizes the results of a test conducted to demonstrate the dramatic difference in thermal stability between silicone fluid and conventional transformer fluid. Open test tubes containing the two fluids were aged in a heat bath for 500 hours at 160°C. The aging caused gross volatilization and oxidation of the mineral oil; all that remained at the end of the test was a dark sludge. In contrast, no change was observed in the silicone fluid; there was no evidence of volatilization or oxidation. Although no transformer fluid is intended to be subjected to these temperatures, the data illustrate the enhanced behavior of the silicone fluid.

Table 3.5 — Thermal stability of silicone and mineral oil transformer fluids (open tube, 160°C)

	Mineral oil				Silicone transformer fluid		
Aging time	Initial	24 hr	100 hr	500 hr	Initial	100 hr	500 hr
<i>Physical properties</i>							
Appearance	Pale yellow	Medium brown	Dark brown	Black	Clear, colorless	Clear, colorless	Clear, colorless
Weight loss, %	—	14.4	33.7	75.1	—	0.053	0.141
Viscosity, cSt @ 23°C	17.8	19.0	24.5	62.0	49.0	49.5	49.0
<i>Dielectric properties</i>							
Dielectric constant, 100 Hz 23°C	2.26	2.27	2.29	2.46	2.72	2.72	2.72
Dissipation factor, 100 Hz 23°C	0.0014	0.00075	0.0039	0.0072	0.000018	0.000018	0.000053
Volume resistivity, ohm-cm, 23°C	8.4x10 ¹²	8.7x10 ¹²	2.4x10 ¹²	9.5x10 ¹²	7.1x10 ¹⁴	1.1x10 ¹⁴	5.9x10 ¹⁴

The pronounced difference in stability between these two types of fluids can be understood by examining what takes place in these fluids at high temperatures. Mineral oil begins to volatilize and oxidize rapidly at temperatures above 105°C. Oxidation results in the formation of many objectionable degradation products. These products, which include organic acids and sludge, cause problems in a transformer by reducing the dielectric properties of the insulation and by corroding metals.

There are two modes of degradation for silicone fluid: thermal breakdown and oxidation. Thermal breakdown of silicone fluid begins at temperatures above 230°C (450°F). At these temperatures the longer polymer chains will slowly begin to degrade to form more volatile cyclic silicone material.

Oxidation of silicone fluid will take place very slowly (in the presence of oxygen) at temperatures above 175°C (342°F). When it oxidizes, silicone fluid polymerizes, gradually increasing in viscosity until gelation occurs. This process takes place *without* the formation of objectionable acids or sludges. In addition, the dielectric properties of the longer-chain silicone molecules are similar to the dielectric properties of fresh silicone fluid.

The temperatures at which thermal and oxidative degradation take place are well in excess of the hot-spot temperatures expected in 65°C-rise transformers. In the limited-oxygen atmosphere of sealed transformers, silicone transformer fluid can be used at temperature rises that are above standard rises of other transformer fluids.

The silicone transformer fluid is not expected to degrade in any significant manner over the useful service life of a 65°C-rise transformer.

Insulation systems using silicone fluid in combination with solid insulating materials having high-temperature capabilities have shown significantly improved thermal capabilities and longer insulation life. Several studies have been reported regarding such a system. Work conducted by both Westinghouse and Dow examined the thermal capability and long-term

performance and reliability of high-temperature capability model transformers. Researchers at Westinghouse constructed such a transformer using a 25 kVA type S-CSP 7200 240/120V Westinghouse distribution transformer.

The insulation system consisted of silicone fluid in combination with baked aromatic polyester amide/imide (OMEGA), NOMEX paper, and glass materials. The unit was loaded electrically for life-test aging, with the loading adjusted to maintain a hot-spot temperature of 225°C, as monitored by a thermocouple in the hot-spot area of the high-voltage coil. The top liquid temperature was approximately 145°C.

The researchers reported that after 10,000 hours of operation at a hot-spot temperature of 220°C, the unit was in excellent condition. Based on IEEE Standard 345-1972, this would correspond to over 200 times the life expectancy (in hours) of a 65°C-rise distribution transformer operating at 220°C. The silicone fluid was still a clear water white in color. The results of fluid characterization tests performed during the aging study are shown in table 3.6.

Table 3.6 — Properties of 50 cSt PDMS fluid in life-test transformer at 220°C hot-spot temperature

	Original	After 1650 h	After 9000 h	After 10,000 h
General condition	Clear	Clear	Clear	Clear
Dielectric strength, kV	35	28	33	28
Power factor, % @ 60 Hz, 25°C	0.007	0.01	0.004	0.006
Interfacial tension, dynes/cm	44.6	40.9	33.7	32.9
Neutralization number, mg KOH/g	0.002	0.03	0.05	0.02

A similar study performed by Dow showed comparable results. In this study, two 25 kVA distribution transformers with high-temperature insulation systems were aged 10,000 hours at a hot-spot temperature of 200°C. Top liquid temperatures were approximately 105°C. After 10,000 hours of aging, the flash and fire points of the silicone fluid were 324°C and 343°C, respectively, unchanged from typical values for new fluid.

Thermal analysis data have also indicated that 50 cSt PDMS fluid is considerably more thermally stable than mineral oil. Sealed-tube thermal-aging studies of kraft paper and FORMVAR-based enameled wire in 50 cSt PDMS fluid indicated that the useful life of both materials is similar whether aged in silicone fluid or mineral oil. However, the silicone fluid was relatively unaffected by either the degradation of the solid insulation materials or the thermal exposure.

3.3 Pressure increases

When temperature increases, XIAMETER™ 561 Silicone Transformer Liquid expands more than mineral oil or askarel. Classical gas-compression/pressure equations predict that this increase will create higher pressures in silicone-filled transformers than those observed in askarel-filled units. Relief valves, lower fluid levels, and tank redesign have been considered. However, in pressure versus temperature experiments comparing mineral-oil-filled, askarel-filled, and silicone-filled transformers, transformer manufacturers have found that there is actually very little difference in the final pressure developed and that the pressure developed is significantly less than predicted values.

In the laboratory, Dow conducted pressure versus temperature experiments in a sealed pressure bomb and collected the data shown in table 3.7.

Table 3.7 — Pressure in sealed bombs containing transformer fluids

	Silicone	Askarel
Initial pressure after filling and sealing at 23°C	0.0 psig	0.0 psig
Equilibrium pressure at 100°C	4.8 psig	4.2 psig
Calculated pressure at 100°C	23.2 psig	10.3 psig
Equilibrium pressure at 0°C	~3.6 psig	~4.2 psig

This data was collected in a steel pressure bomb with an air-to-silicone fluid ratio of 0.176. When the bombs were first heated to 100°C, the pressure of the silicone-filled bomb rose to 7.25 psi, but equilibrated at 4.8 psi. The pressure of the askarel-filled bomb rose to 7.3 psi and equilibrated at 4.2 psi. Both fluids took about 23 hours to equilibrate. Although rate data were limited, it appeared that the silicone equilibrated a little faster. The pressure reduction following equilibration is probably a result of gas absorption.

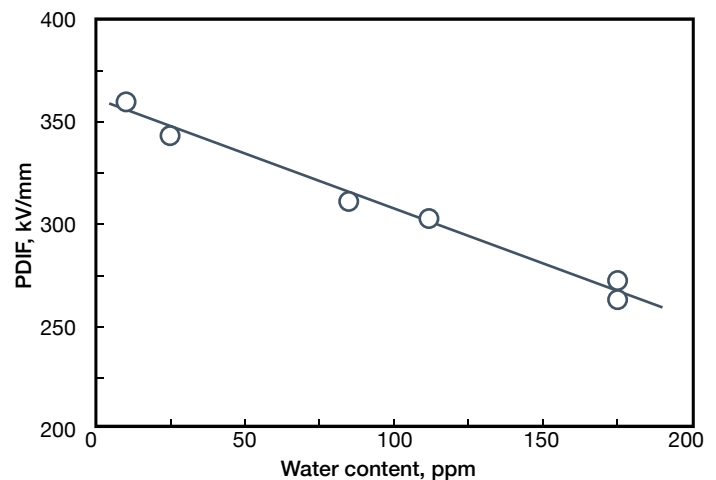
These data indicate that neither the silicone nor the askarel generate the high pressures predicted. They also show that the pressure resulting from the use of silicone fluid is not sufficiently greater than the askarel liquid to be of concern in transformers.

Refer to section 3.8, physical characteristics, for information on volume expansion and gas solubility.

3.4 Partial discharge characteristics

According to one study, the partial discharge inception field strength (PDIF) of clean silicone transformer fluid is similar to that of mineral oil presently used in transformers.¹ If the silicone transformer fluid is contaminated with water, the PDIF decreases linearly with increasing water content. That relationship is shown in figure 3.16.

Figure 3.16 — Changes on mode value of PDIF with water content XIAMETER™ 561 Silicone Transformer Liquid



Measurement of pulse amplitudes and rates at discharge conditions show that although the inception phenomenon is very similar in both silicone transformer fluid and mineral oil, the development and growth of the partial discharges are quite different. The chemical and physical properties of the silicone transformer fluid suppress the large discharge pulses observed in mineral oil at higher voltage stresses.

Gelled polymer substances are formed by longtime high-level partial discharges in the silicone transformer fluid. The quantity of gelled material is dependent on the total amount of the partial discharge energy dissipated in fluid. The gel consists of cross-linked polymer structures of Si—CH₂—Si, Si—OH, and Si—H.

The investigation indicated that in the design of high-voltage equipment with silicone transformer fluids, it is important to keep stress levels below the critical corona conditions that are necessary for the formation of the polymerized substances.

Studies conducted by Dow have produced the partial discharge data listed in tables 3.8 and 3.9.

¹Kuwahara, H.; Tsuruta, K.; Munemura, H.; Ishii, T.; and Shimoi, H.; "Partial Discharge Characteristics of Silicone Liquids," IEEE 1975 Winter Power Meeting, Paper No. 3, 75, 236-5.

Table 3.8 — Discharge characteristics as determined by needle-plane screening test

	DIV, kV	DEV, kV
XIAMETER™ 561 Silicone Transformer Liquid	16.4	15.2
Mineral oil (10 cSt)	19.3	17.0
Askarel	20	20

Table 3.9 — Discharge characteristics of impregnated 0.01 µF capacitors (two layers of 0.5-mil polypropylene film)

	DIV, volts	DEV, volts
XIAMETER™ 561 Silicone Transformer Liquid	2600	600
Mineral oil (10 cSt)	2200	600
Askarel	2300	1700

3.5 Load-break switching performance

Disconnect switches and fuses are commonly applied in pad-mounted transformers. The LBORII three-phase rotary disconnect switch from ABB Transformer Components Division is a typical choice. To satisfy the demand for a fire-safe fluid in those units, an evaluation of this switch’s performance in a 50-cSt dielectric-grade silicone fluid was undertaken.

The load-switching tests were performed in accordance with ANSI 037.71, “Three-Phase, Manually-Operated Sub Surface Load Interrupting Switches for AC Systems” at the PSM High Power Laboratories in East Pittsburgh, PA. Extensive material analyses were completed in Dow’s laboratories and in the ABB Materials Labs formerly located in Sharon, PA.

The key findings of this study were:

- All structural and gasket materials were found to be compatible with the silicone fluid from room temperature up to 125°C. These tests were performed in accordance with ASIM D-3455, “Standard Tech Methods for Compatibility of Construction with Electrical Insulating Oil of Petroleum Origin.”
- No mechanical problems or visual signs of excessive wear were observed in the switch after over 11,000 operations in the silicone fluid.
- The switch and silicone fluid performed well in over 120 load-switching operations, including fully inductive load switching and currents of up to 300 A at 15 kV.
- The dielectric strength of the fluid remained above the IEEE-recommended values for continuous use in transformers throughout the tests.
- All physical properties, including the flash and fire points of the fluid, were maintained throughout the tests. No discoloration of the fluid was noted, even after exposure to temperatures up to 125°C for as long as 164 hours.
- There was no evidence of gelling of the silicone fluid.

The reports detailing this performance are available from Dow and are listed in section 1.5, bibliographic resources, as items P7 and P8.

3.6 Medium and large power transformer applications

XIAMETER™ 561 Silicone Transformer Liquid has over 20 years of proven performance in small power transformers. These transformers have primary voltages of 69 kVA or less. However, the thermal stability and environmental and fire-safe characteristics of silicone fluid have resulted in growing interest for certain medium and large power transformer applications. Mobile transformers, for example, must deliver maximum MVA output with a minimum of size, weight, and environmental hazard for transportation over public roadways.

Medium and large power transformer applications can differ in several respects from the traditional applications of silicone fluid in small power transformers. Among these differences are higher primary voltage rating and basic impulse levels (BIL), pumped fluid cooling rather than convective flow, use of load-tap changers in the fluid and, of course, a higher power-handling capability within the unit. Care must be taken to evaluate the pertinent dielectric, lubricity, and heat-transfer properties of silicone to achieve a proper design of the unit and its components.

Lubricity requirements and effects of low-current arcing from on-line load-tap changes can drive design requirements for load-tap changers immersed in silicone fluid. Lubricity is discussed in section 3.9.

Resistance to partial discharges and partial discharge inception and extinction field strengths, as well as surface creepage strength, can drive dielectric stress design requirements. Dielectric data for silicone fluid and comparisons with mineral oil are provided in section 3.1. Additional data on dielectric properties of silicone fluids can be obtained by requesting copies of the technical papers listed in section 1.5, bibliographic resources, under the subheading “high voltage strength” or by contacting your Dow representative.

Fluid compatibility with cooling pump design and other materials of construction is also an important consideration. Types of pumps that have proven to be suitable are discussed in section 5.4, and material compatibilities are covered in section 3.7. Heat-transfer properties of silicone fluids are discussed and compared with mineral oil in section 3.10.2.

3.7 Material compatibility

Compatibility and thermal stability are closely related. Materials that are compatible at room temperature may become incompatible at elevated temperatures because of increased solvent action or chemical activity at the higher temperatures. Also, when thermal degradation of one material begins, the products of degradation may attack other materials in the insulation system. Regardless of the initial cause of degradation, the result of this type of incompatibility can be failure of the entire insulation system.

Silicone transformer fluid has acceptable compatibility with most of the materials used in askarel-filled transformers and

Table 3.13a — Transformer materials that are compatible with silicone fluids*

Metals	Insulation	Plastics and resins	Wire enamels
Copper	Kraft paper	Nylon	Amide-imide
Phosphor bronze	Pressboard	Polystyrene	Polyester
Aluminum	NOMEX (polyamide paper)	Modified acrylics	Amide
Stainless steel	QUINTEX (asbestos paper)	Polycarbonates	FORMVAR
Cold-rolled steel	MYLAR (polyester film)	Phenolics	ALKANEX
Hot-rolled steel	KAPTON (polyimide film)	PTFE	
Nickel	Polypropylene film	Silicone resins	
Magnesium	Cross-linked polyethylene	Diphenyl oxides	
Zinc	Wood	Epoxies	
Cadmium	Mica	Polyesters	
Duralmin			
Titanium			
Silver			
Monel			
Tin			
Brass			

*Laboratory tests have shown these materials to be compatible with silicone fluids. However, as materials vary somewhat in composition from one manufacturer to another, compatibility should be evaluated for the specific combination of materials to be used.

with those used in mineral-oil-filled transformers. A large number of materials have been tested for compatibility with silicone transformer fluid. The tests vary from simple immersion to sealed-container accelerated aging to full-scale model testing. Table 3.13 is a list of many of the materials tested and found suitable in silicone transformer fluid.

Care is needed to properly select seal and gasket materials. Some plasticizers can be leached from some rubber formulations by silicone fluids. Because of the large number of formulations available, individual testing of each potential seal or gasket material is recommended. Table 3.14 is intended as a guide to the selection of seal and gasket materials.

Silicone rubber has been used as a gasket material for askarel-filled transformers. Silicone rubber and silicone transformer fluid are very similar materials. The fluid is absorbed readily into the rubber, causing swelling and loss of physical properties. Silicone-rubber parts may be found in power transformer bushing seals, top-cover gaskets, tap changers, filling ports, instrumentation, and other openings. If silicone rubber is found in a transformer, it should be replaced with a nonsilicone seal material that is approved for use with askarel.

When choosing a dielectric material with no history of either prior use or testing with silicone fluids, compatibility testing is recommended. Dow representatives can advise you of appropriate compatibility screening and performance-testing methods for silicone fluid.

3.8 Physical characteristics

3.8.1 Vapor pressure

Vapor-pressure data for XIAMETER™ 561 Silicone Transformer Liquid are reported in table 3.15. The data can be extrapolated below 1 torr using a Cox chart, such as the one shown in figure 3.17. The vapor pressure may vary from lot to lot depending on specific conditions during manufacture. If the curve is extrapolated to very low temperatures, the vapor pressure values that fall on the extrapolated curve may be higher than are typical for the bulk fluid. These high values are due to the presence of a very small amount of low-molecular-weight silicone.

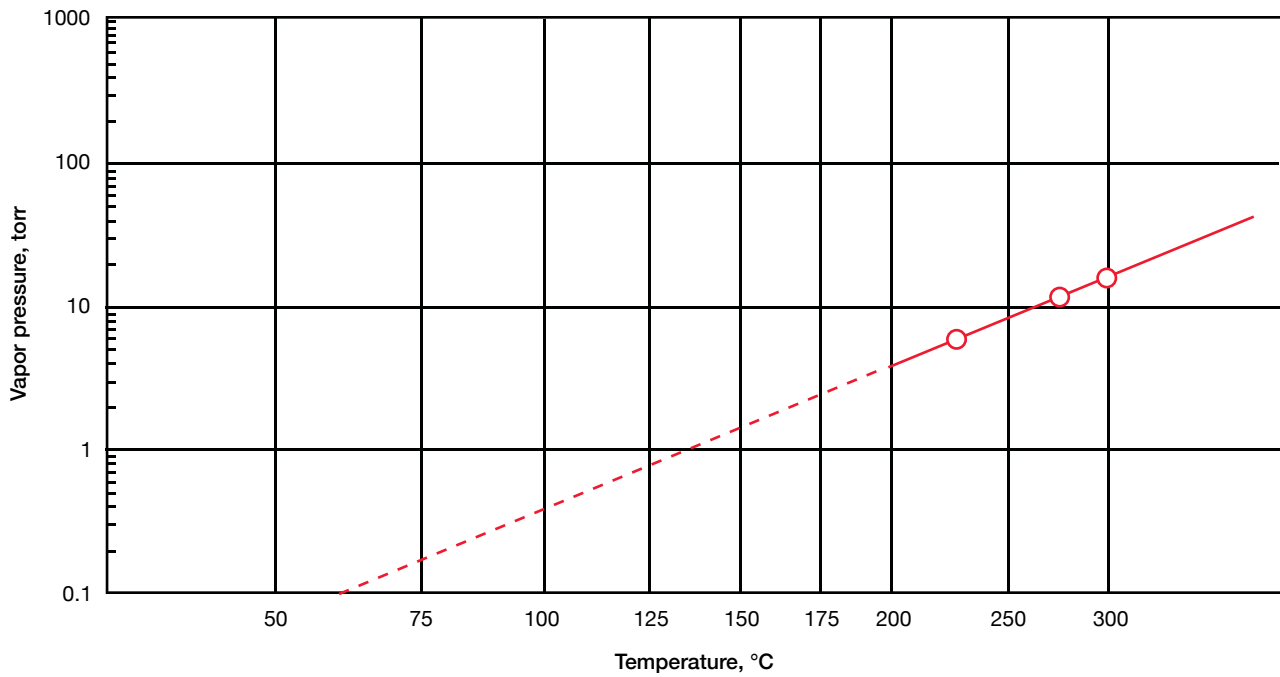
Table 3.13b — Transformer materials of questionable compatibility (should be tested individually)

Plastic	After 30-day immersion
Cellulose acetate butyrate	Stiffens
Polyacetal	Stiffens and crazes
Polyethylene	Stress cracks
Linear polyethylene	Some stress cracks
Polyvinyl chloride	Shrinks and hardens

Table 3.14 — Compatibility ratings for seal and gasket materials

Material	Not compatible	Compatible	Testing recommended
Natural rubber		●	
KEL-F		●	
Fluorosilicone rubber		●	
Silicone rubber	●		
Neoprene			●
TEFLON		●	
VITON		●	
G.R.S.			●
EPDM		●	
Nitrile rubber			●
Buna-N	●		
Polypropylene			●
HYPALON	●		
S.B.R.			●
E.P.R.			●
CORPRENE			●

Figure 3.17 — Cox chart for XIAMETER™ 561 Silicone Transformer Liquid



A test that is often better at low temperatures than vapor-pressure measurements is a low-temperature volatility test under vacuum. Vapor-pressure measurements begin at 2 to 4 torr. Values below these have been extrapolated.

3.8.2 Volume expansion

The temperature coefficient of volume expansion of XIAMETER™ 561 Silicone Transformer Liquid is shown in table 3.16. The relationship is shown in figure 3.18. The curve may be extrapolated above and below the given temperature with reasonable accuracy. As shown in the table, the coefficient of expansion of silicone fluid is greater than those of conventional transformer fluids.

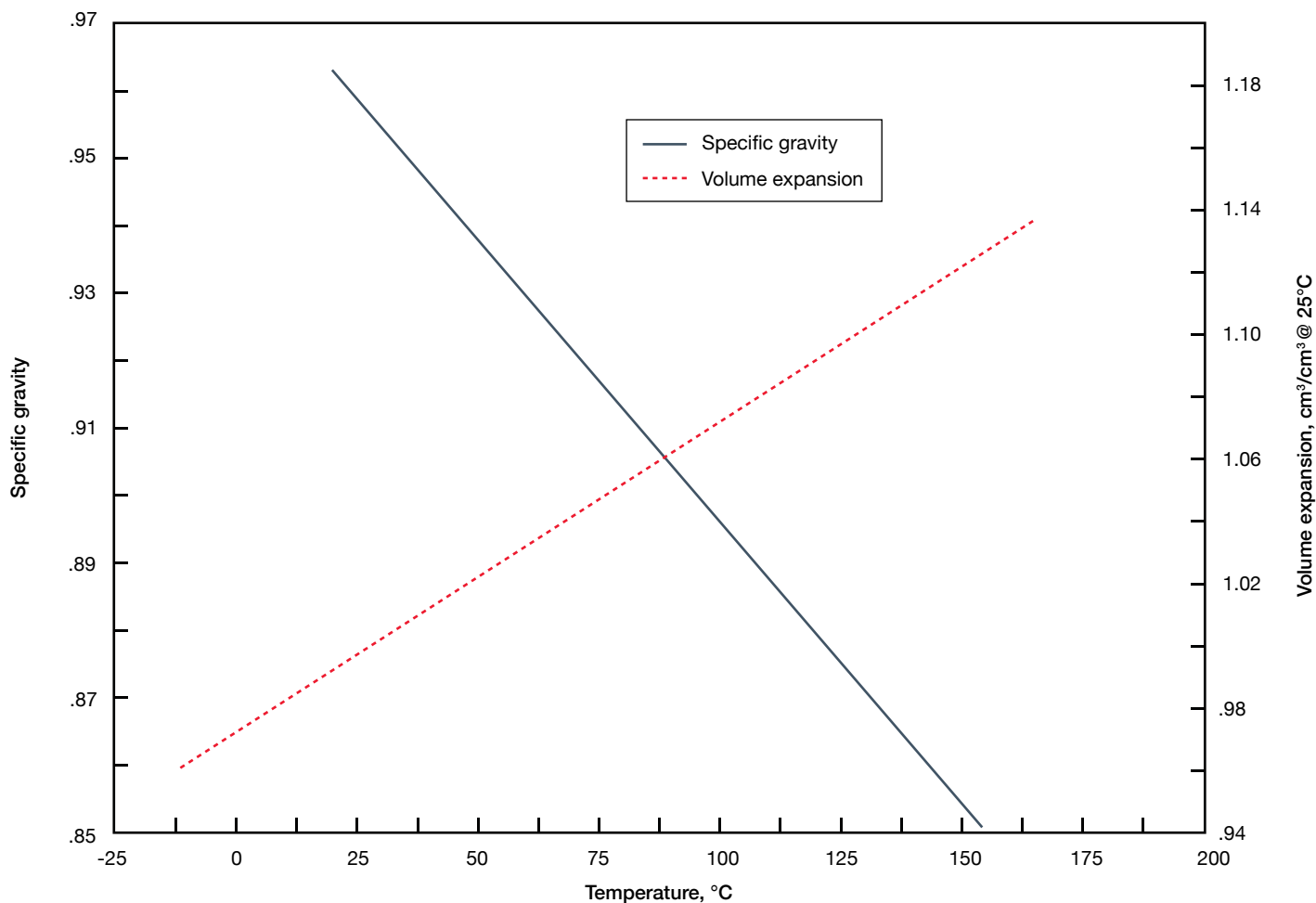
Table 3.16 — Coefficients of expansion for transformer fluids

Fluid	Coefficient of expansion (cm ³ /cm ³ .°C)
Silicone transformer fluid	0.00104
Mineral oil	0.00073
Askarel	0.00070

Table 3.15 — Vapor pressure of XIAMETER™ 561 Silicone Transformer Liquid

Temperature, °C	Vapor pressure, torr
231	6
277	11
300	16
313	21
322	26
330	31
336	40
340	47
345	54
348	61
353	71
356	80
358	91.5
360	102.5
363	113.5
365	124.5
372	136.5
375	150

Figure 3.18 — Changes in volume expansion and specific gravity of XIAMETER™ 561 Silicone Transformer Liquid with temperature



Classical gas-compression versus pressure equations suggest that mineral-oil-filled and askarel-filled transformers could experience pressures in excess of their pressure ratings. However, other factors preclude this from happening. It appears that the transformer fluid absorbs excess gas as the pressure increases. Although silicone fluid expands more than mineral oil or askarel, the expansion is partially offset by its ability to absorb more gas, as shown in table 3.17.

Table 3.17 — Air solubility of transformer fluids

Fluid	Air solubility (25°C @ 1 atm)
Silicone transformer fluid	16.5%
Mineral oil	10.0%
Askarel	5.7%

Section 3.3 reports laboratory pressure data that are consistent with these concepts; pressure increases in sealed pressure vessels were less than predicted and the pressure increases experienced with silicone fluids were not enough higher than askarel fluids to be of concern.

In pressure-temperature experiments in actual transformers and in 81 silicone-filled transformers monitored for a 3-year

period under various service conditions, no unusual pressure or vacuum conditions developed.

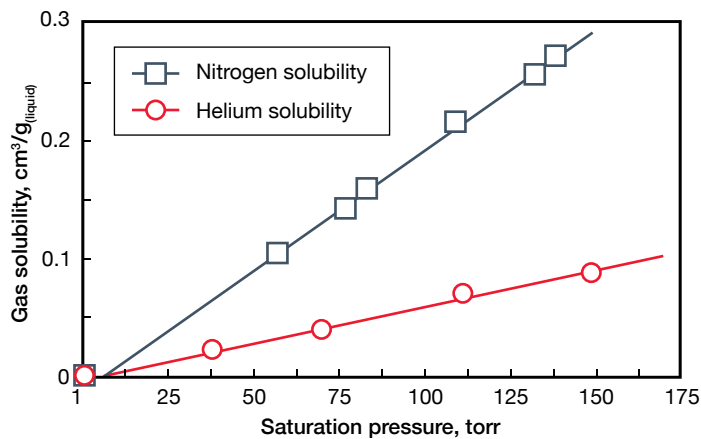
3.8.3 Solubility of gases

Table 3.18 reports solubility data for several gases in XIAMETER™ 561 Silicone Transformer Liquid at 80°C. The data are presented in terms of volume of gas (STP) per unit volume of silicone transformer fluid. Figure 3.19 shows the solubility of helium and nitrogen in XIAMETER™ 561 Silicone Transformer Liquid versus pressure.

Table 3.18 — Gas solubility data for XIAMETER™ 561 Silicone Transformer Liquid

Gas	Solubility %
H ₂	8.7
CO	12
CO ₂	73
CH ₄	29
C ₂ H ₂	76
C ₂ H ₄	85
C ₂ H ₆	108
N ₂	11

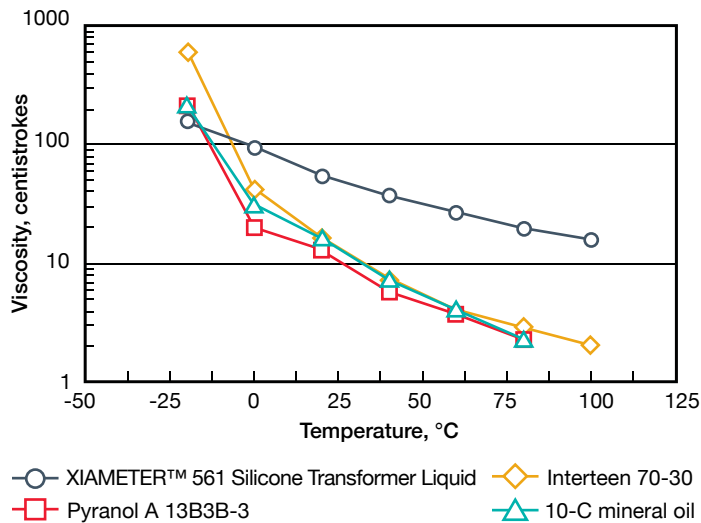
Figure 3.19 – Solubility of nitrogen and helium in XIAMETER™ 561 Silicone Transformer Liquid



3.8.4 Viscosity-temperature relationship

Figure 3.20 compares the temperature-viscosity relationship of XIAMETER™ 561 Silicone Transformer Liquid with common askarels and mineral oil at various temperatures. PYRANOL A-13B3B-3 and INERTEEN 70-30, are the only askarel formulations for which Dow has viscosity-temperature data.

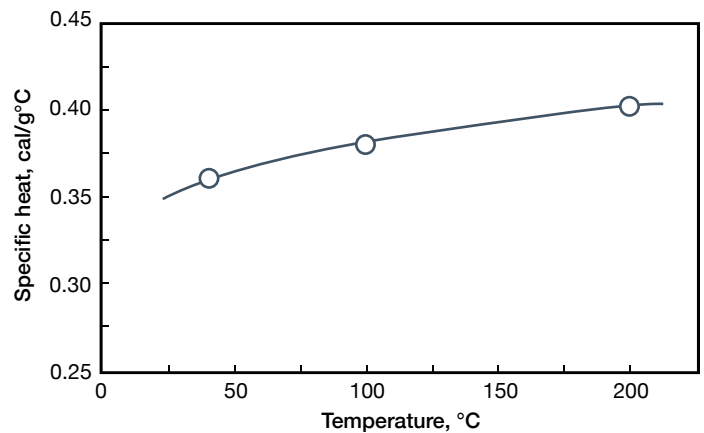
Figure 3.20 – Viscosity-temperature relationships for transformer fluids



3.8.5 Specific heat

Figure 3.21 shows how the specific heat of XIAMETER™ 561 Silicone Transformer Liquid changes with changes in temperature. Over a normal operating temperature range the specific heat is fairly constant.

Figure 3.21 – Specific heat of XIAMETER™ 561 Silicone Transformer Liquid



3.8.6 Density

The change in density of XIAMETER™ 561 Silicone Transformer Liquid with respect to temperature can be determined from figure 3.18 since:

$$\rho = \text{Specific gravity} \times \rho_{\text{water}}$$

Alternatively, density can be determined using the following equation:

$$\rho_T = \rho_{25} \left[\frac{1}{1 + 0.00036 (T - 25^\circ\text{C})} \right]$$

where $\rho = 0.9572 \text{ g/mL}$

3.9 Lubricity

Polydimethylsiloxane (PDMS) is usually not recommended for use as a metal-to-metal lubricant. It lacks the lubricity required for many mechanical applications that involve sliding friction between metals. However, when rolling friction is involved, XIAMETER™ 561 Silicone Transformer Liquid has good lubricity and good load-carrying capacity between many common combinations of materials.

PDMS fluid is one of the best lubricants for fiber and plastic gears or bearings constructed of natural and synthetic rubber, polystyrene, phenolics, and most other plastics. However, compatibility with each these types of materials should be checked individually.

Tables 3.19, 3.20, and 3.21 contain a list of metal combinations that are rated as “poor,” “questionable,” and “good,” respectively, when used with XIAMETER™ PMX 200 Fluid as a lubricant. These ratings are merely for comparison; no actual measurements have been made of the absolute lubricating properties of XIAMETER™ 561 Silicone Transformer Liquid. The data result from a simple sliding test between two metal plates.

Every application that uses silicone fluid as a lubricant is different, and each combination should be thoroughly tested before any final design recommendations are made.

Table 3.19 – Metal combinations rated “poor” when lubricated with XIAMETER™ PMX 200 Fluid

Slider	Plate
Aluminum	Aluminum Babbitt Cadmium Steel
Babbitt	Babbitt Copper Magnesium Stainless steel Tin
Brass	Babbitt Copper Stainless steel
Bronze	Brass Magnesium Stainless steel Tin
Cadmium	Magnesium
Cold-rolled steel	Babbitt Brass Chromium Copper Magnesium Silver Tin Zinc
Nickel	Brass Magnesium Nickel
Silver	Cadmium Magnesium Silver
Tin	Brass Cadmium Magnesium Zinc
Zinc	Babbitt Chromium Copper Magnesium Silver Stainless steel

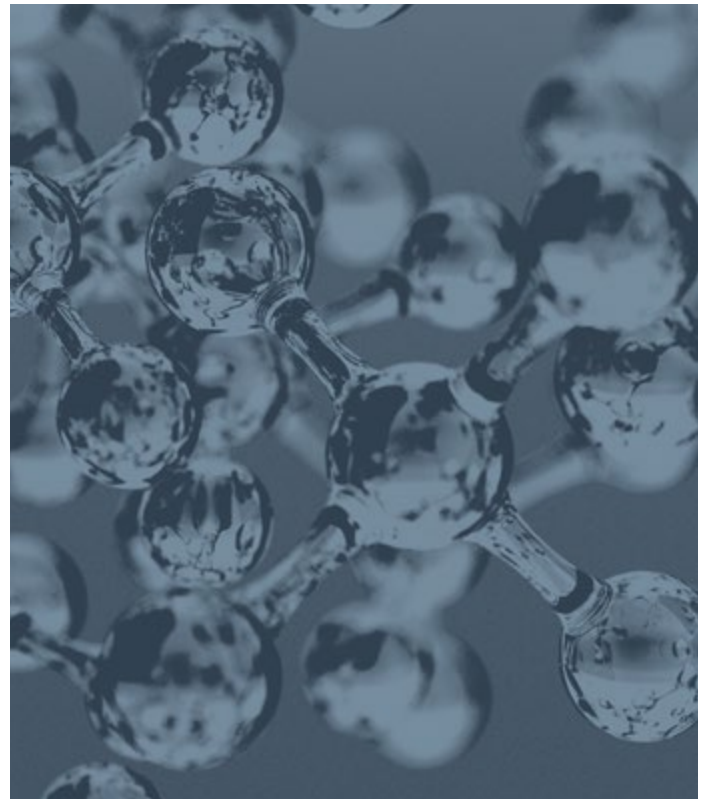
Table 3.20 – Metal combinations rated “questionable” when lubricated with XIAMETER™ PMX 200 Fluid

Slider	Plate
Aluminum	Stainless steel Silver Tin
Babbitt	Aluminum
Brass	Magnesium Silver
Chromium	Aluminum Babbitt Brass Cadmium Chromium Copper Magnesium Nickel Silver Stainless steel Tin Zinc
Cold-rolled steel	Aluminum Stainless steel
Copper	Stainless steel
Magnesium	Aluminum Babbitt Copper Magnesium
Nickel	Babbitt Cadmium Copper Stainless steel Zinc
Tin	Silver

Table 3.21 – Metal combinations rated “good” when lubricated with XIAMETER™ PMX 200 Fluid

Slider	Plate
Aluminum	Brass Chromium Copper Magnesium Nickel Zinc
Babbitt	Brass Cadmium Chromium Nickel Silver Steel Zinc
Brass	Aluminum Brass Cadmium Chromium Nickel Tin Zinc
Bronze	Aluminum Babbitt Cadmium Chromium Copper Nickel Nylon Silver Steel Zinc
Cadmium	Aluminum Babbitt Cadmium Chromium Copper Nickel Silver Stainless steel Steel Tin Zinc
Cold-rolled steel	Cadmium Graphitar Nickel Nylon
Copper	Aluminum Babbitt Brass Cadmium Chromium Copper Magnesium Nickel Silver Tin Zinc

Slider	Plate
Magnesium	Cadmium Chromium Nickel Tin
Nickel	Aluminum Chromium Silver Tin
Silver	Aluminum Babbitt Brass Chromium Copper Nickel Stainless steel Steel Tin Zinc
Tin	Aluminum Babbitt Chromium Copper Nickel Stainless steel Steel



3.10 Retro fill considerations

3.10.1 Material and component compatibility

When retrofitting a transformer for final fill with silicone fluid, consideration should be given to the compatibility of the materials and devices within the transformer with the new fluid. The primary areas to consider involve the insulation materials, sealing and gasket materials, and any moving parts.

Silicone transformer fluid has acceptable compatibility with most of the materials used in askarel-filled and mineral-oil-filled transformers. A large number of materials have been tested for compatibility with silicone transformer liquid. Section 3.7, material compatibility, discusses compatibility issues in more detail and provides lists of compatible materials. Compatibility of gasket materials is more often of concern than insulation materials and can require that gaskets be changed. A list of compatible gasket materials is also provided in section 3.7

Lubricity is a key compatibility consideration if moving parts are present. Although mineral oil is usually an excellent lubricant, the efficacy of silicone fluid as a lubricant depends on specific circumstances. Considerations involve whether the parts in friction are metal or plastic, which metal or plastic is involved, and whether the parts involve sliding or rolling friction. Section 3.9, lubricity, provides detailed information on the lubricity of silicone transformer fluid. This information — along with knowledge of the application such as the expected frequency of operation of a device like a switch or tap changer — will help determine the compatibility of the silicone transformer fluid.

The compatibility of oil-immersed load-break devices with silicone transformer fluid has recently been tested. Results show the acceptability of silicone fluid under arcing conditions. Specific data is given in section 3.5, load-break switching performance.

It is strongly recommended that retrofills be undertaken only by experienced transformer service companies and only after consultation with the transformer manufacturer.

3.10.2 Temperature rise/heat transfer

The effectiveness of a fluid as a heat-transfer medium is dependent not only on viscosity, but also on the following properties:

- Density
- Thermal conductivity
- Heat capacity
- Coefficient of thermal expansion

The effect of these properties is dependent on the heat-transfer mechanism within the transformer — whether it is free convection, forced convection in laminar flow, or forced convection in turbulent flow.

Although the higher viscosity of the silicone transformer fluid may tend to reduce the liquid flow, the increased density difference between cool and warm fluid will increase thermal siphoning in free-convection flow in the transformer. This observation is supported by practical experience in transformers. Table 3.22 shows heat-run data from two identical new transformers. One transformer contained INERTEEN, a Westinghouse askarel, and the other contained DOWSIL™ 561 Silicone Transformer Liquid.

Table 3.22 — Heat-run data for transformer fluids in 2500 kVa, 13.8 kV, Delta 450 LV WYE transformer

Temperature rating, °C	Transformer fluid	Load, percent	Load losses, watts	Rise in windings by resistance measurements		Top fluid rise, °C
				H.V.	L.V.	
55	INERTEEN liquid	100	27900	50.90	50.10	49.90
65	INERTEEN liquid	100	—	60.00	60.00	56.00
55	XIAMETER™ 561 Silicone Transformer Liquid	100	28000	46.88	46.03	53.00
65	XIAMETER™ 561 Silicone Transformer Liquid	100	—	57.52	57.28	61.00

Table 3.23 — Heat-run data for alternative transformer designs

	Askarel	Silicone
<i>2240 kVA, 3/60 13800 — 480 Y</i>		
Primary rise, °C	61.5	62.7
Secondary rise, °C	61.7	65.9
Top fluid rise, °C	60.0	67.2
<i>2000 kVA, 3/60 13800 — 480 Y</i>		
Primary rise, °C	57.3	54.0
Secondary rise, °C	53.8	57.5
Top fluid rise, °C	51.8	58.3

The results show that, in spite of differences in winding temperature distribution, the heat-transfer performance for XIAMETER™ 561 Silicone Transformer Liquid is comparable to INERTEEN for this particular design. Table 3.23 shows heat-run data for two other transformer designs; both designs were originally filled with askarel, drained, and refilled with silicone fluid.

Table 3.24 lists the heat-transfer characteristics of XIAMETER™ 561 Silicone Transformer Liquid compared to other commonly used transformer fluids.

Historically the vast majority of transformer retrofills have involved replacing askarel with silicone transformer fluid. More recently the retrofill of mineral-oil-filled transformers with silicone fluid has increased. In the retrofill of mineral-oil-filled units some consideration should be given to resulting temperature-rise performance. Depending on the transformer design and loading of the unit, it may be possible to see higher than original design rating temperatures of the fluid. The fluid itself is unaffected by typical over temperatures. However, the aging rate of conventional insulation materials, such as cellulose, can be affected by operation at temperatures higher than design limits.

Designers can compensate for the higher temperatures by adjusting loading levels such that the design temperature rise is not exceeded or by adding external radiator fans to increase cooling of the fluid. Mineral-oil-filled transformers retrofilled with silicone fluid that previously operated at less than full load will be less likely to exceed design temperatures.

The heat-transfer performance of silicone transformer fluid is highly dependent on the transformer design; some designs are better optimized to take advantage of the heat-transfer characteristics of the fluid. For example, if a layered-winding design is used, vertical channels will maximize the thermal siphoning effects produced by the high coefficient of expansion. Disc windings, however, are more complex and can obstruct the vertical free flow of the liquid.

Table 3.25 provides comparative fluid temperature rises of both mineral-oil-filled and silicone filled transformers in a test station. The transformers were tested both as-new and after retrofilling with the silicone fluid. Two different size transformer pairs of similar design were used in the test. Pair 1 (consisting of units no. 1 and 2) was initially filled with mineral oil (21 gallons each) and operated at 25 kVA, 2400/4160Y, 240/480 with 1.6% and 1.7% impedance. Pair 2 (consisting of units no. 3 and 4) was initially filled with silicone fluid (29 gallons each) and operated at 50 kVA, 2400/4160Y, 240/480, with 1.8% impedance.

Table 3.24 – Heat-transfer properties of transformer fluids

Fluid	Viscosity, centistokes	Specific gravity	Coefficient of expansion, 1/°C	Thermal conductivity, cal/(s·cm ² ·°C/cm)	Heat capacity, cal/g·°C
XIAMETER™ 561 Silicone Transformer Liquid	50	0.960	0.00104	0.00036	0.363
AROCLOR 1242	17.2	1.380	0.00119	0.00023	0.290
AROCLOR 1254	46.4	1.540	0.00123	0.00021	0.260
WEMCO C (mineral oil)	15	0.898	0.00073	0.00036	0.488

Table 3.25 – Temperature versus load data for 25 and 50 kVA transformers

Transformer pair no. 1 – 25 kVA								Transformer pair no. 2 – 50 kVA							
Tested as received with mineral oil								Tested as received with XIAMETER™ 561 Silicone Transformer Liquid							
Unit 1				Unit 2				Unit 3				Unit 4			
Load %	Amb °C	Top oil °C	Oil rise	Load %	Amb °C	Top oil °C	Oil rise	Load %	Amb °C	Top oil °C	Oil rise	Load %	Amb °C	Top oil °C	Oil rise
75	28	52	24	75	29	63	34	75	26	56	30	75	26	59	33
100	30	69	39	100	30	72	42	100	28	80	52	100	26	82	54
125	31	65	34	125	31	69	38	125	31	92	61	125	31	94	63
150	32	71	39	150	32	73	41	150	28	110	82	150	28	108	80
175	23	75	52	175	23	77	54	175	24	120	96	175	24	119	95
Tested after retrofill with XIAMETER™ 561 Silicone Transformer Liquid								Retrofilled with mineral oil				Rerun with XIAMETER™ 561 Silicone Transformer Liquid			
Unit 1				Unit 2				Unit 3				Unit 4			
Load %	Amb °C	Top oil °C	Oil rise	Load %	Amb °C	Top oil °C	Oil rise	Load %	Amb °C	Top oil °C	Oil rise	Load %	Amb °C	Top oil °C	Oil rise
100	4	39	35	100	4	37	33	100	4	44	40	100	4	42	38
136	14	60	46	136	14	57	43	126	14	68	54	126	14	69	55
162	16	63	47	162	16	63	47	153	15	91	76	153	30	105	75
187	20	82	62	187	20	82	62	175	30	103	73	175	30	105	75

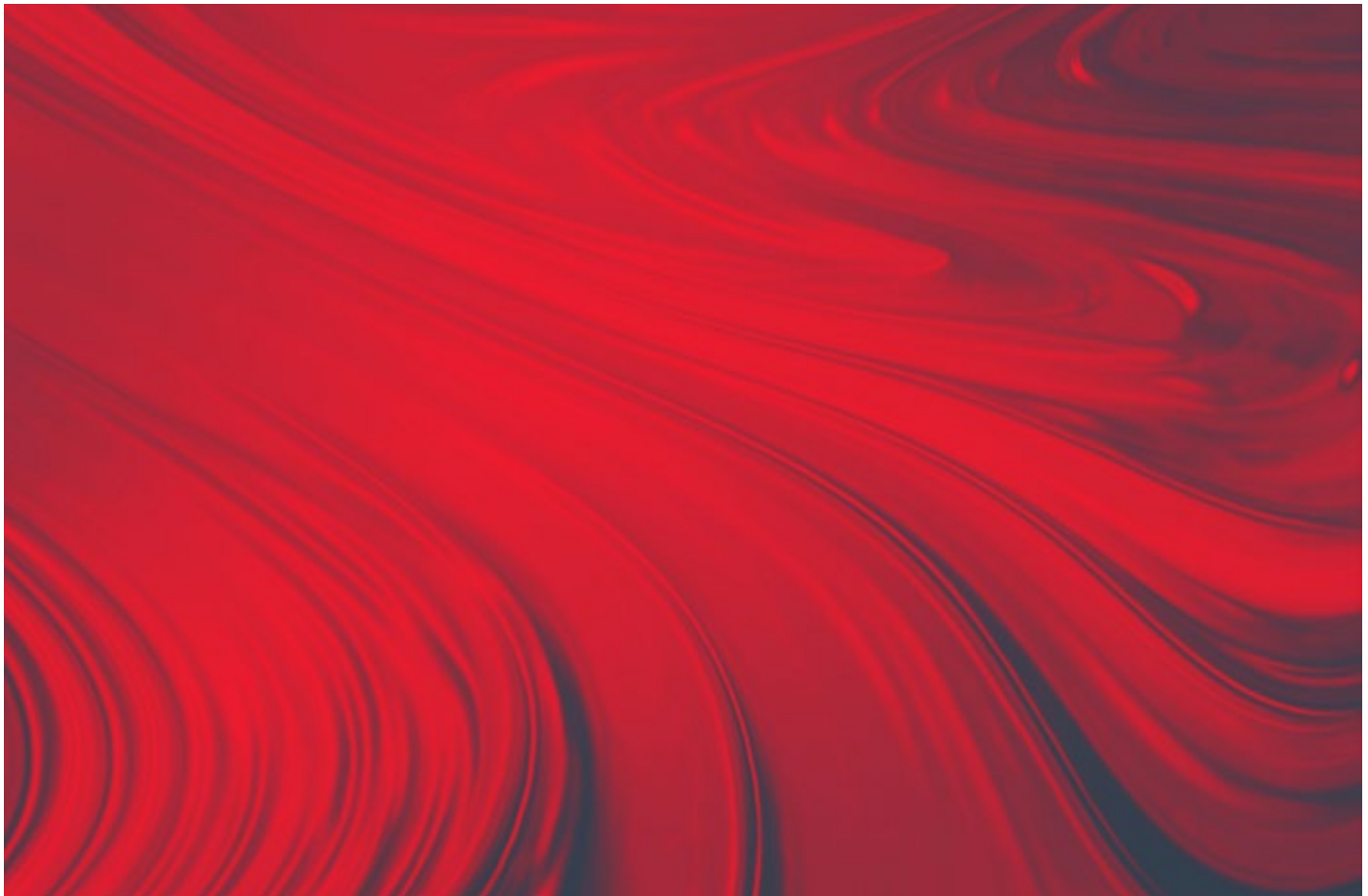
3.10.3 Fire safety considerations

When refilling a mineral-oil-filled transformer with silicone fluid there will always be some residual oil left in the unit. This residual oil is soluble to a certain extent in silicone transformer fluid and can decrease the flash and fire points of the fluid. Table 3.26 provides data on the effect of various levels of residual mineral oil on the flash and fire points of the transformer fluid.

The data suggest that a maximum contaminant level of 3% is allowable before the flash and fire points of the silicone fluid decline significantly. Procedures such as rinsing the drained tank with silicone fluid prior to final filling can minimize residual mineral oil. Experience has shown that retrofilled mineral-oil transformers can achieve “less-flammable” status given sufficient care in removing residual mineral oil from the tank.

Table 3.26 — Effect of mineral oil contamination on flash and fire points of silicone transformer fluid

Mineral oil level %	Flash point °C	Fire point °C
0	322	>343
1	241	>343
2	229	>343
3	202	332
5	193	241
10	179	207



Section 4: Specifying DOWSIL™ 561 Silicone Transformer Liquid

Section content

- 4.1 Model specification
- 4.2 Applicable standards
 - 4.2.1 1996 National Electrical Code
Section 450-23
 - 4.2.2 1996 National electrical safety code
Section 15. Transformers and regulators
 - 4.2.3 ASTM standards
 - 4.2.4 IEEE Guide
- 4.3 Product listings
 - 4.3.1 Factory mutual approval
 - 4.3.2 UL classification marking

4.1 Model specification

Dow's technical service engineers have compiled a model that specifiers can use to develop complete specifications for transformer fluids. The model is in outline form and is found on the following pages. It includes references to the most common publications, standards, and classifications used to characterize the performance and safety of transformer fluids.

Section 16XXX – Transformer liquids

1.0 Part 1 – General

1.01 Section includes

- A. Mineral oil
- B. Less-flammable liquids

1.02 References

The publications listed below form a part of this specification to the extent referenced. The publications are referred to in the text by the basic designation only.

American Society for Testing and Materials (ASTM)

ASTM D 117	1989 Electrical Insulating Oils of Petroleum Origin
ASTM D 445	1988 Test Method for Kinematic Viscosity of Transparent and Opaque
ASTM D 2161	1987 Standard Practice for Conversion of Kinematic Viscosity to Saybolt Universal Viscosity or to Saybolt Furol Viscosity
ASTM D 2225	1992 Standard Methods Testing Silicone Fluids Used for Electrical Insulation
ASTM D 3455	1989 Test Methods for Compatibility of Construction Material with Electrical Insulating Oil of Petroleum Origin
ASTM D 3487	1988 Mineral Insulating Oil Used in Electrical Apparatus
ASTM D 4652	1992 Standard Specification for Silicone Fluid Used for Electrical Insulation

Factory Mutual Engineering and Research Corporation (FM)

FM P7825	1993 Approval Guide
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Institute of Electrical and Electronics Engineering (IEEE)

ANSI/IEEE C37.71	1984 (R 1990) Three-phase, Manually Operated Subsurface Load Interrupting Switches for Alternating Current Systems
ANSI/IEEE C57.111	1989 IEEE Guide for Acceptance of Silicone Insulating, Fluid and Its Maintenance in Transformers

National Fire Protection Association (NFPA)

NFPA 70	1996 National Electrical Code
NEC450-23	Less-Flammable Liquid-Insulated Transformers
NEC450-26	Oil-Insulated Transformers Installed Indoors
NEC450-27	Oil-Insulated Transformers Installed Outdoors

Underwriters Laboratories Inc. (UL)

Gas and Oil Equipment Directory

EOUV — Dielectric Mediums

EOVK — Transformer Fluids

1.03 Submittals

1.03.1 Data

A. Submit Underwriters Laboratories Category EOVK Classification Marking as provided by transformer fluid manufacturer.

1.03.2 Reports

A. Submit technical report on load break switch testing in specified transformer fluid

1.04 Operation and maintenance data

1.04.1 Include transformer liquid manufacturer's recommended procedures for (sampling/storage/handling/disposal/recycling)

1.04.2 Submit transformer fluid manufacturer's operation and maintenance manual.

2.0 Part 2 — Products

2.01 Nonflammable liquids

2.01.1 Do not provide nonflammable transformer liquids including askarel and insulating liquids containing polychlorinated biphenyls (PCBs) and tetraachloroethylene (perchloroethylene), chlorine compounds, and halogenated compounds.

2.02 Mineral Oil

2.02.1 Liquid shall comply with requirements as set forth in ASTM D 3487, Type II, as tested in accordance with ASTM D 117 test procedures.

2.03 Less-Flammable Liquids

2.03.1 Less-flammable liquids shall have a fire point not less than 300°C per NFPA 70.

2.03.2 Shall comply with requirements set forth in ASTM D 4652 and tested per ASTM D 2225.

2.03.3 The fluid shall be approved per Factory Mutual P7825. Total heat release rate shall not exceed 150 kW/m².

2.03.4 The fluid shall be classified by Underwriters Laboratories as a dielectric medium per UL category EOUV. The fluid shall also be classified as a transformer fluid per UL category EOVK. Category EOVK classification marking use restrictions for maximum allowable fault energy shall not be less than 700,000 I²t for 45 kVA transformers ranging to 14,000,000 ft for 10,000 kVA transformers.

2.03.5 Less-flammable transformer liquids used as a switching medium for liquid-immersed type load-break switches shall have load-switching tests performed in accordance with ANSI/IEEE C37.71. Fire point and dielectric strength shall meet or exceed specified values in C57.111 after 120 energized load-switching operations, including full inductive load switching, and load currents up to 300 amperes at 15 kV.

2.03.6 Compatibility of less-flammable transformer liquids with sealing and gasketing materials shall be proven by tests conducted in accordance with ASTM D 3455.

2.03.7 Liquid viscosity shall not exceed 100 nm²/s at 0°C as tested per ASTM D 445, D 2161.

3.0 Part 3 — Execution

3.01 Installation

3.01.1 Electrical installations shall conform to NFPA 70 and to the requirements specified herein.

3.01.2 Indoor Installations

3.01.2.1 Mineral-oil-insulated transformers shall be installed per NEC Section 450-26.

3.01.2.2 Less-flammable liquid-insulated transformers shall be installed per NEC Section 450-23 and in compliance with either Factory Mutual listing requirements or the UL Classification Marking of the liquid.

3.01.3 Outdoor Installations

3.01.3.1 Mineral-oil-insulated transformers shall be installed per NEC Section 450-27. Safeguards and clearance requirements shall be based on Factory Mutual Loss Prevention Data Sheet 5-4/14-8.

3.01.3.2 Less-flammable liquid-insulated transformers shall be installed per NEC Section 450-23 and in compliance with either Factory Mutual listing requirements or the UL Classification Marking of the liquid.

4.2 Applicable standards

Most of the applicable standards for transformer fluids are listed in the reference section of the model specification in the preceding text. Complete copies of these references can be obtained from the issuing organization.

4.2.1 1996 National Electrical Code

The National Electrical Code (NEC), Section 450-23, provides requirements for the installation of less-flammable liquid-filled transformers. The NEC now reflects acceptance of less-flammable fluids for outdoor transformer installations as well as indoor installations. The National Electrical Code can be requested from the National Fire Protection Agency (NFPA) by contacting:

National Fire Protection Agency

1 Batterymarch Park
P.O. Box 9146
Quincy, MA 02269-9959
Telephone: (800) 344-3555

Relevant text from the 1996 National Electrical Code is printed below.

Section 450-23

Less-flammable fluid-insulated transformers. Transformers insulated with listed less-flammable fluids having a fire point of not less than 300°C shall be permitted to be installed in accordance with (a) or (b).

(a) Indoor installations. In accordance with (1), (2), or (3):

- (1) In Type I or Type II buildings, in areas where all of the following requirements are met:
 - a. The transformer is rated 35,000 volts or less.
 - b. No combustible materials are stored
 - c. A liquid confinement area is provided.
 - d. The installation complies with all restrictions provided for in the listing of the liquid.
- (2) With an automatic fire extinguishing system and a liquid confinement area, provided the transformer is rated 35,000 volts or less.
- (3) In accordance with Section 450-26.

(b) Outdoor installations. Less-flammable liquid-filled transformers shall be permitted to be installed outdoors attached to, adjacent to, or on the roof of buildings, where installed in accordance with (1) or (2):

- (1) For Type I and Type II buildings, the installation shall comply with all restrictions provided for in the listing of the liquid.

(FPN): Installation adjacent to combustible material, fire escapes, or door and window openings may require additional safeguards such as those listed in Section 450-27.
- (2) In accordance with Section 450-27.

(FPN No. 1): Type I and Type II buildings are defined in *Standard on Types of Building Construction*, NFPA 220-1995.

(FPN No. 2): See definition of “listed” under Article 100.

4.2.2 1996 National Electrical Safety Code

Relevant text from the 1996 National Electrical Safety Code (NESC) is printed below. These sections also recognize the use of less-flammable transformer fluids. Copies of the NESC can be requested from IEEE at the address shown in Section 4.2.4.

Section 15. Transformers and regulators

152. Location and arrangement of power transformers and regulators

A. Outdoor installations

1. A transformer or regulator shall be so installed that all energized parts are enclosed or guarded so as to minimize the possibility of inadvertent contact, or the energized parts shall be isolated in accordance with Rule 124. The case shall be grounded in accordance with Rule 123.
2. The installation of liquid-filled transformers shall utilize one or more of the following methods to minimize fire hazards. The method to be applied shall be according to the degree of the fire hazard. Recognized methods are the use of less flammable liquids, space separation, fire-resistant barriers, automatic extinguishing systems, absorption beds, and enclosures.
3. The amount and characteristics of liquid contained should be considered in the selection of space separation, fire-resistant barriers, automatic extinguishing systems, absorption beds, and enclosures that confine the liquid of a ruptured transformer tank, all of which are recognized as safeguards.

B. Indoor installations

1. Transformers and regulators 75 kVA and above containing an appreciable amount of flammable liquid and located indoors shall be installed in ventilated rooms or vaults separated from the balance of the building by fire walls. Doorways to the interior of the building shall be equipped with fire doors and shall have means of containing the liquid.
2. Transformers or regulators of the dry type or containing a nonflammable liquid or gas may be installed in a building without a fireproof enclosure. When installed in a building used for other than station purposes, the case or the enclosure shall be so designed that all energized parts are enclosed in the case grounded in accordance with Rule 123. As an alternate, the entire unit may be enclosed so as to minimize the possibility of inadvertent contact by persons with any proof the case or wiring. When installed, the pressure-relief vent of a unit containing a nonbiodegradable liquid shall be furnished with a means for absorbing toxic gases.
3. Transformers containing less flammable liquid may be installed in a supply station building in such a way as to minimize fire hazards. The amount of liquid contained, the type of electrical protection, and tank venting shall be considered in the selection of space separation from combustible materials or structures, liquid confinement, fire-resistant barriers or enclosures, or extinguishing systems.

4.2.3 ASTM standards

The primary ASTM standards of interest in specifying silicone transformer fluids are:

- ASTM D 4652-92 — “Standard Specifications for Silicone Fluid Used for Electrical Insulation,” *1996 Annual Book of ASTM Standards*, Vol. 10.03, Electrical Insulating Liquids and Gases; Electrical Protective Equipment.
- ASTM D 2225-92 — “Standard Methods of Testing Silicone Fluids Used for Electrical Insulation,” *1996 Annual Book of ASTM Standards*, Vol. 10.03, Electrical Insulating Liquids and Gases; Electrical Protective Equipment.

Copies of these ASTM standards (and other ASTM standards) can be obtained by contacting:

ASTM

1916 Race Street
Philadelphia, PA 19103-1187

Telephone: (215) 299-5400

Fax: (215) 977-9679

4.2.4 IEEE guide

The *IEEE Guide for Acceptance of Silicone Insulating Fluid and its Maintenance in Transformers* (IEEE C57-1 | 1-1989) can be obtained from the Institute of Electrical and Electronics Engineers (IEEE) by contacting:

IEEE

345 East 47th Street
New York, NY 10017

4.3 Product listings

Among the National Electrical Code requirements for less-flammable fluid-filled transformers is that the fluid must be “listed.” According to the NEC, Section 70, the term “listed” refers to:

Equipment or materials included in a list published by an organization acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of listed equipment or materials, and whose listing states either that the equipment or material meets appropriate designated standards or has been tested and found suitable for use in a specified manner.

Currently two major agencies have established listings for less-flammable liquids per the NEC Factory Mutual Research Corporation (FM) and Underwriters Laboratories (UL). However, each has developed somewhat different requirements. UL criteria is based on explosion prevention of the transformer tank. FM requirements involve both preventive protection of the transformer and protection of the facility structure, which are based on the burning characteristics of the liquid. Specific applications can lend themselves to the use of one or the other listing. Normally, either listing is acceptable for compliance with the NEC.

Additional information regarding product listings is available UL, FM, and Dow.

4.3.1 Factory mutual approval

XIAMETER™ 561 Silicone Transformer Liquid is approved by Factory Mutual Research Corporation and can be used indoors without additional fire protection when installed in compliance

with NEC Section 450-23 and the restrictions of the FM listing. Qualification for FM approval includes testing of the rate of heat release when the fluid is involved in a fire. Heat release is analyzed with respect to the ability of the building to withstand a fire.

In testing performed by FM, XIAMETER™ 561 Silicone Transformer Liquid produced the lowest heat release rates of approved materials. See table 4.1.

Table 4.1 — Heat release rates for XIAMETER™ 561 Silicone Transformer Liquid

Heat release mechanism	Heat release rate (kW/m ²)
Radiative	25
Convective	53
Total	78

4.3.2 UL classification marking

XIAMETER™ 561 Silicone Transformer Liquid is classified by Underwriters Laboratories as both a “dielectric medium and as less flammable per NEC 450-23.” The material is also classified as a less-flammable liquid in compliance with the National Electrical Code, when used in 3-phase transformers with the following restrictions:

- Use only in 3-phase transformers with tanks capable of withstanding an internal pressure of 12 psig without rupture.
- Pressure-relief devices must be installed on the transformer tank in accordance with table 4.2 to limit pressure build-up and prevent tank rupture from gas generation under low current arcing faults.
- Overcurrent protection having I²t characteristics not exceeding the values in table 4.2 must be provided for the primary circuit to limit possible high-current arcing faults. If the fuse is designed to vent during operation (such as an expulsion fuse), it shall be located external to the transformer tank.

Table 4.2 — Pressure relief and overcurrent protection requirements for silicone-filled transformers

Transformer rating, kVA	Pressure-relief capacity ^a , SCFM@15 psig	Overcurrent protection ^b , A ² s
45	35	700,000
75	35	800,000
112.5	35	900,000
150	50	1,000,000
225	100	1,200,000
300	100	1,400,000
500	350	1,900,000
750	350	2,200,000
1000	350	3,400,000
1500	700	4,500,000
2000	700	6,000,000
2500	5000	7,500,000
3000	5000	9,000,000
3750	5000	11,000,000
5000 to 10,000	5000	14,000,000

Section 5: Material handling

Section content

- 5.1 Storage
- 5.2 Bulk handling
- 5.3 Sampling
 - 5.3.1 Sampling from shipping containers
 - 5.3.2 Sampling from apparatus
- 5.4 Pumping
- 5.5 Filling transformers
 - 5.5.1 Filling under vacuum
 - 5.5.2 Filling without vacuum
- 5.6 Vacuum degasification
- 5.7 Silicone solutions for mineral oil foaming
- 5.8 Paint and paintability
 - 5.8.1 Surface preparation
 - 5.8.2 Paint additives

5.1 Storage

As is recommended practice for all high-purity dielectric fluids, when handling, storing, sampling, and inspecting silicone transformer fluid and when operating silicone-filled transformers, every precaution should be taken to protect the silicone fluid from exposure to high humidity or moisture contamination. Shipping drums should be stored indoors in an area especially selected for this purpose. If it is necessary to store drums or cans containing silicone transformer fluid outdoors, they should be stored in a covered area or otherwise protected from the weather and direct contact with water. In exposed locations, drums should be stored with the bungs down to prevent collection of water around the bung. Drums should be kept sealed until the fluid is actually needed. Partially empty drums should be tightly resealed and stored in the same manner as above.

Bulk storage of XIAMETER™ 561 Silicone Transformer Liquid can be protected from excess moisture by an inert gas (nitrogen) or dry-air blanketing system or a desiccant vent dryer system. The storage tank design, materials of construction, and moisture protection systems should be evaluated to determine the best arrangement at each site prior to delivery.

Bulk storage tanks should be mounted on piers above the ground and easily accessible for leak inspection. There should be a curb or dike on the ground around the tanks to contain any spills or leaks. Check with state and local agencies to determine exact containment requirements in your area.

Stainless steel is recommended as the best material of construction for piping and storage tanks. Carbon steel is adequate for piping, and carbon steel with a zinc primer or an epoxy paint-on coating or liner is suitable for storage tanks. Fiberglass and aluminum storage tanks have also been used

successfully. Because of the variety of binders and alloys available, we recommend testing the specific material of construction for suitability prior to use.

The useful lifetime of XIAMETER™ 561 Silicone Transformer Liquid is virtually unlimited when it is stored properly. However, failure to properly store and protect drums or bulk storage of silicone transformer fluid as specified above can result in contamination by water.

5.2 Bulk handling

Loading of tank trucks — Proper preparation of tank trucks for receiving XIAMETER™ 561 Silicone Transformer Liquid is critical. Tank trucks must be clean and moisture-free. Prior to loading, tank trucks are usually purged with dry air or nitrogen to protect the fluid from absorbing moisture from humid air inside the tank. Once loaded, the tank truck is then pressurized to approximately 5 psig. This helps to prevent the vacuum relief valve on tank truck from “breathing” outside air. Breathing is usually caused by significant outside temperature variations that will affect the relative humidity of the air within the tank truck.

Tank truck transfer — To completely protect the product from moisture during product transfer, the receiving site should plan the best way to vent the tank truck. A common practice is to vent the tank out of the dome area, as would be done on typical product transfers. However, this procedure will affect the product moisture specification, especially during a long transfer.

There are two methods of providing ample venting to the tank truck while keeping moisture under control. One way is to simply provide clean, dry compressed air or nitrogen back to the tank truck. This method can be used to unload the tank truck or it can be used in conjunction with a transfer pump.

The second method employs a closed-loop venting system. Here, the tank truck vent is connected to the storage tank vent to equalize pressure during the transfer. Making proper connections and using the correct vent hose size is very important so as not to restrict the venting between the storage tank and tank truck. Once the vents have been connected and the lines vent valves opened, the product can then be pumped into the storage tank.

5.3 Sampling

5.3.1 Sampling from shipping containers

The dielectric strength of any dielectric fluid is affected by small amounts of certain impurities, particularly water. To avoid contamination and to obtain accurate test results, it is important that great care be taken in obtaining and handling samples. Poor dielectric test results that have been reported in the field have often been found, on investigation, to have resulted largely from careless handling. The following instructions, based on specifications from the American Society for Testing Materials (ASTM), must be followed to ensure accurate results.

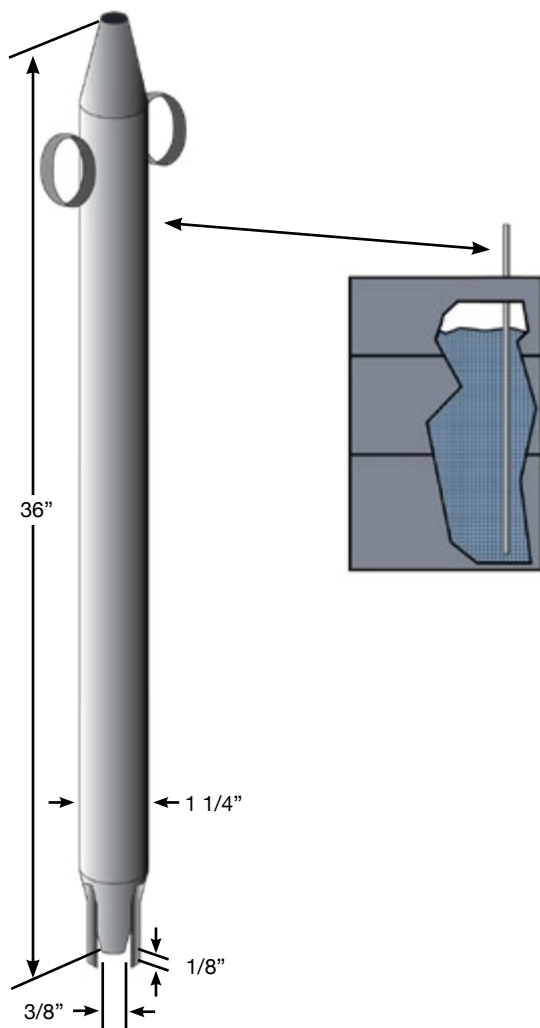
Sample bottle — The sample container should be made of glass, of at least 16 oz capacity, and should be clean and dry. Glass bottles are preferable to a metal container since glass may be examined to verify that it is clean. It also allows visual inspection of the silicone transformer fluid for separated water and solid impurities before testing.

The clean, dry bottle should be thoroughly rinsed with Stoddard solvent (or another suitable solvent) that has previously withstood a dielectric test of at least 25 kV in a standard test cup and then allowed to drain thoroughly. It is preferable to heat both the bottle and cap to a temperature of 100°C (212°F) for 1 hour after draining. The bottle should then be tightly capped and the neck of the bottle dipped in melted paraffin to seal.

Glass jars with rubber gaskets or stoppers must not be used. Silicone transformer fluid may easily become contaminated from the sulfur in natural rubber. Polyethylene-lined caps are preferred.

Thieves for sampling — A simple and convenient “thief” can be made for sampling 55-gallon drums. The dimensions should be as shown in figure 5.1. Three legs equally spaced around the thief at the bottom and long enough to keep the opening 1/8 inch from the bottom of the drum being sampled will help secure a representative sample. Two rings soldered to opposite sides of the tube at the top will allow you to conveniently hold the thief by slipping two fingers through the rings, leaving the thumb free to close the opening. In an emergency, a 36-inch-long piece of tubing can be used. For tank trucks and railcars, a thief that uses a trap at the bottom may be used.

Figure 5.1 — Drum thief and common technique for sampling drums



The thief should be capable of reaching the 36” bottom of the container, and the sample should be taken with the thief not more than 1/8 inch from the bottom. Thieves should be cleaned before and after use by rinsing with Stoddard solvent or another suitable solvent; be sure that no lint or fibrous material remains on them. When not in use, they should be kept in a hot, dry cabinet or compartment at a temperature not less than 37.8°C (100°F) and stored in a vertical position in a rack having a suitable drainage receptacle at the base.

Samples should not be taken from containers that have been moved indoors until the silicone fluid is at least as warm as the surrounding air. Enough moisture can condense from a humid atmosphere on the cold fluid surface to affect the insulating properties. Sampling silicone transformer fluid from containers located outside is undesirable because of the possibility of moisture condensation; it should be avoided whenever possible. (Samples should never be taken in the rain.)

Recommended procedure — The drums to be sampled should be arranged in a line with bungs up and then numbered. The bung seals should be broken and the bung removed and laid with the oil side up beside the bungholes. The unstoppered sampling container can be placed on the opposite side of the bungholes. The top hole of thief should be covered with the thumb, the thief thrust to the bottom of the container and the thumb removed. When the thief is filled, the top hole should be re-covered by the thumb, thief quickly withdrawn, and the contents allowed to flow into the sample container.

The lower holes should not be closed with the fingers of the other hand. The free hand should not be used to guide the stream of silicone transformer fluid except by touching the thief, and this only when necessary. The silicone transformer fluid should not be allowed to flow over the hand or fingers before it flows into the sampling container.

When the sampling container is full, it should be closed quickly. The drum bung should be replaced and tightened, and the sampling container, now closed and under cover, should be taken to the testing laboratory as quickly as possible. After use, all thieves and sampling containers should be thoroughly cleaned as outlined above.

Tank trucks and railcars of silicone transformer fluid should be sampled by introducing the thief through the manhole on top of the car, the cover of which should be removed carefully so as not to contaminate the fluid with dirt. The sample should be taken as near as possible to the bottom of the tank car. Atmospheric precipitation should be excluded while sampling.

It may also be possible to sample the fluid through a drain valve on the bottom of the tank car. This may be done after allowing a volume of fluid equal to the volume of the drain valve to pass. This will help ensure that you obtain a representative sample.

When separate samples are being taken from a consignment or part of a consignment, care should be taken to prevent contamination of the samples. A separate thief should be used for each sample, or the thief previously used should be well drained and then thoroughly rinsed with fluid from the next container to be sampled. Any silicone transformer fluid used for rinsing should be discarded before the next sample is taken.

Enough thieves should be provided to ensure thorough drainage of each thief after rinsing with silicone transformer fluid before using it to withdraw the actual sample. Two thieves are sufficient if only a few samples are involved; for a large number of samples (for example, sampling a carload of drummed silicone transformer fluid), six or more thieves are desirable.

When one average sample of a consignment or batch is being taken, the same thief may be used throughout the sampling operation, and it is not necessary to rinse the thief with fluid before obtaining any of the portions that go to make up the total average sample.

Quantity of sample — It is recommended that one 16-oz bottle of silicone fluid be taken as a sample for dielectric tests, and a 1-quart sample be taken when complete physical and chemical tests are to be made. At least one sample should be taken from each tank car of silicone fluid. One sample may be taken from each drum or, if desired, a composite sample may be made by combining samples from all drums, provided all drums are air tight. When the bung is first loosened, you should hear a hissing sound, indicating that the drum is air tight. If the test of the composite sample is unsatisfactory, individual samples from each of the drums must be tested.

When drums have been stored exposed to the weather, a sample from each drum should be tested. The sample should be examined for separated water. If water is noted, refer to section 6.2, contamination. If water appears in samples taken from a tank car, follow the same procedure.

5.3.2 Sampling from apparatus

When taking samples of silicone transformer fluid from apparatus in which a thief cannot be used, use the sampling valve and follow the procedure outlined above as far as is practical.

Care should be taken to procure a sample that fairly represents the silicone transformer fluid at the bottom of the tank. A sufficient amount of fluid should be drawn off before the sample is taken to ensure that material in the sampling pipe is not sampled. For this reason, the valve and the drain pipe should be sufficiently small to be emptied with convenience and yet sufficiently large to allow an even flow of fluid and avoid clogging by sediment. Use of ¼-inch pipe and valves is recommended. This, of course, may be separate from the drain pipe and valve or it may be connected to the drain valve with a suitable reducer.

It is of the utmost importance that the sample of silicone fluid represents the actual condition of the silicone fluid in the apparatus. Every precaution should be taken to keep the sample and container free from contamination by impurities or moisture during the sampling process. If the apparatus is installed outdoors, care must be taken to prevent contamination of the sample by precipitation.

A glass bottle is recommended as a sample container, so that any water present may readily be visible. If the sample contains separated water, it is not suitable for dielectric testing and the sample and bottle should be discarded. A second sample should be taken after at least 2 quarts of silicone fluid have been withdrawn. If separated water is still observed in the sample then refer to section 6.2, contamination.

5.4 Pumping

Although pumps suitable for XIAMETER™ 561 Silicone Transformer Liquid are readily available, not all pumps are suitable. Taking the care necessary to properly select a pump will ensure good performance and long pump life.

The two main considerations in selecting a proper pump for silicone transformer fluid are lubricity and seal compatibility. Information on lubricity can be found under section 3.9, lubricity. Information necessary to select proper seal and gasket materials can be found under section 3.7, material compatibility.

Pumps with metal-to-metal friction requiring lubrication by the medium being pumped will either be unacceptable in silicone or will result in excessive wear and short pump life. Gear pumps and helical pumps are examples of this type. Pump suitability should be confirmed by the pump manufacturer. It is also possible to evaluate the pump's suitability by circulating a small quantity of silicone transformer fluid through the pump for an extended period of time and checking the pump for excessive wear.

Table 5.1 is a list of manufacturers that can provide pumps that are suitable for XIAMETER™ 561 Silicone Transformer Liquid. Consultation with the pump manufacturer is advised for selection of the best pump for your application. To properly size pumps, engineers should know that:

- XIAMETER™ 561 Silicone Transformer Liquids essentially Newtonian at all practical shear rates.
- Specific gravity, vapor pressure, coefficient of expansion, and viscosity-temperature relationship information can be found in section 3.8, physical characteristics.
- Good engineering practice dictates the addition of a filter between a pump and a piece of electrical equipment. Other engineering considerations may include appropriate meters, valves, and other relief or control devices.

Table 5.1 — Pump manufacturers

Manufacturer	Location	Phone	Type/specifications
Gorman-Rupp Ind.	Bellville, OH	(419) 886-3001	Centrifugal, magnetic drive — specify O-ring seal material
March Manufacturing	Glenview, IL	(847) 729-5300	Centrifugal — specify seal material
Blackmer Pump Co.	Grand(Rapids, MI	(800) 759-4067	Rotary positive displacement — specify seal material
Visiting Pump Division	Cedar Falls, IA	(319) 266-1741	Rotary gear pumps — specify silicone service

5.5 Filling transformers

Before putting a new transformer into service, verify that the transformer tank is free of moisture and any other foreign material.

Procedures to be used for filling transformers with XIAMETER™ 561 Silicone Transformer Liquid do not differ significantly from methods used for filling transformers with mineral oil or askarel. Although the following procedures are typical, they may not represent the only way or the best way to fill transformers with silicone fluid. If it is necessary to fill a transformer outside, particularly on a humid or rainy day, care should be taken to prevent moisture from entering the system. To avoid condensation, the temperature inside the transformer should be kept several degrees above the outside air temperature. It is preferable to prepare and fill outdoor apparatus on a clear, dry day.

5.5.1 Filling under vacuum

Since entrapped air is a potential problem in all fluid-filled transformers, it is desirable to fill transformers under vacuum. This is done for transformers shipped from the factory and, if practical, should be done when transformers are filled in the field. If the transformer case is designed to withstand full vacuum, an arrangement similar to that in figure 5.2a can be used. If the transformer case has not been designed for full vacuum and you must get the maximum winding impulse strength immediately, the transformer should be filled with silicone transformer fluid under full vacuum by placing the entire transformer assembly in an auxiliary vacuum tank, as is shown in figure 5.2b.

If you don't have an established procedure for vacuum filling transformers, the following procedures can be used regardless of whether vacuum is applied directly to the transformer case or the entire transformer is placed in an auxiliary vacuum tank.

1. Apply and maintain a continuous vacuum of 50 torr for at least ½ hour to units rated 25 kV or below, or for 4 hours to units rated above 25 kV.

2. While holding vacuum, slowly fill the transformer with silicone transformer fluid to the normal 25°C level or, where it may be impossible to gauge properly, with about 90% of the required volume.
3. Maintain the specified vacuum for at least ½ hour after filling.
4. Add sufficient silicone fluid to adjust the level to normal and seal the transformer tank. To avoid condensation on the surface of the silicone transformer fluid, do not reopen the transformer until the temperature at the top of the fluid is equal to or higher than the ambient temperature.

5.5.2 Filling without vacuum

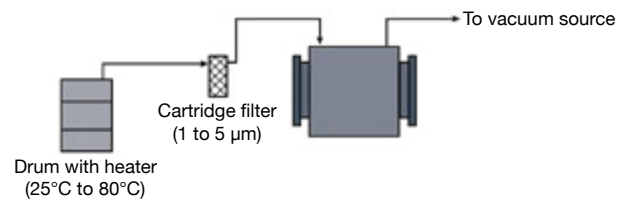
In cases in which the transformer can not be filled under vacuum, full voltage should not be applied to the windings for at least 24 hours after the silicone transformer fluid has been added to the transformer case. This is necessary to allow air bubbles to escape.

When practical, fill the transformer through the drain valve, as shown in figure 5-2c, to minimize aeration, and vent the top of the transformer tank to allow air to escape. Be sure all valves and pipe connections between the main tank and any silicone-filled transformer compartments are open to allow free circulation of both gas and fluid. Otherwise, trapped air or gas could cause the silicone-fluid level in some parts of the transformer to remain below the safe operating level.

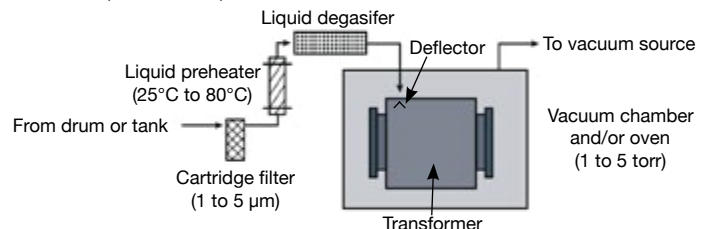
The transformer tank and compartments, if any, should be filled at ambient temperature to the point on the gauges marked "25°C fluid level." If the ambient temperature varies greatly from 25°C (77°F) when filled, the level should be rechecked as soon as the average fluid temperature equilibrates to the ambient temperature. Silicone transformer fluid should be added to or drained from the tank to bring the level to the proper height. The transformer should never be operated or left standing, even if out of service, without the proper silicone-fluid level indicated on the gauge.

Figure 5.2 — Configurations for filling transformers with fluid

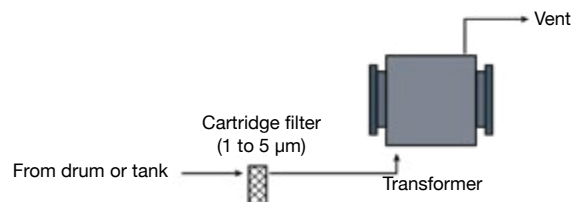
a. Filling with transformer case under vacuum



b. Filling with transformer case placed in a vacuum chamber



c. Filling from bottom when vacuum filling is not feasible



5.6 Vacuum degasification

Dielectric fluids should be filtered and degassed before being put into service in power transformers. Ideal transformer fluids are low in impurities to maintain good dielectric properties; they also must maintain very low levels of dissolved air and water. A fluid with a dissolved-air level that is well below its saturation point will dissolve air bubbles trapped inside the transformer insulation and eliminate those potential insulation system weak spots. Vacuum degasifiers can reduce both water and dissolved-air content. The efficiency of water and air removal depends on many factors such as:

- Fluid temperature
- Level of vacuum pulled
- Initial water content of fluid
- Fluid film thickness
- Time of exposure to vacuum
- The presence of boiling promoters (e.g., agitation, sharp points, rough surfaces, etc.)

Effective removal of dissolved water by vacuum degasification requires specialized equipment. Table 5.2 is a list of manufacturers who can supply portable, semiportable, or permanent vacuum-degasification equipment.

Refer to section 3.8, physical characteristics, for information on vapor pressure, volume expansion, viscosity/temperature relationships, and gas solubility. This information may be important in specifying systems for silicone transformer fluid.

Simply exposing transformer fluids to vacuum or spraying the transformer fluid through a nozzle into a vacuum chamber or a transformer under vacuum may not provide sufficient degasification. Spray degasification can be inefficient because under vacuum, in the absence of air or gas, dispersed fluid droplets tend to adopt a spherical shape that minimizes surface exposure. Unless the droplets are very small, the diffusion path for degasification is too long.

For efficient degasification, a very thin film maximizes the transformer fluid's exposure to vacuum. The most efficient degasification processes use columns that spread the transformer fluid over a large surface area to create a thin film while the fluid is exposed to vacuum. Under these conditions, the fluid degases readily. Degassing columns may consist of more than one stage, with two-stage columns being quite common. The surface area of degassing columns is increased by distributing the transformer fluid onto thin-walled steel rings or saddles that fill the column. These materials, called column packings, are made in a variety of configurations such as Rashig, Pall, or Norton rings or Berl and Kirschbaum saddles.

To reduce viscosity during degassing, the transformer fluid can be heated. The appropriate temperature depends on the viscosity/temperature relationships and composition of the fluid in use.

The purpose of vacuum filling a transformer tank is primarily to provide better impregnation by removal of air from voids in the solid insulation. Degasification and drying of the transformer fluid is minimal. Consequently, transformer fluids should have acceptable dielectric properties before the fluid is used to fill the transformer.

Table 5.2 — Vacuum processing equipment manufacturers

Manufacturer	Location	Phone
ABVAC Inc	St.Louis, MO	(800) 737-7937
Pall Industrial Hydraulics Corporation	East Hills, NY	(800) THE-PALL
Seaton Wilson, Div. of Systron Donner Corp.	Sylmar, CA	(818) 364-7204
Baron USA	Cookeville, TN	(615) 528-8476
Vacudyne	Chicago Heights, IL	(708) 757-5200
Enervac Corporation (enervac.com)	Cambridge, Ontario	(519) 623-9890
Kinney Vacuum Company	Canton, MA	(617) 828-9500

This is not intended to be a complete list of manufacturers and suppliers of vacuum systems. Consultation with technical representatives of these manufacturers and suppliers is recommended to select the best system for your operation.

5.7 Silicone solutions for mineral oil foaming

Contamination of mineral oil with some silicone fluids or other materials can cause severe foaming during processing. In severe cases, the foam is created in such large volumes that it prevents continued vacuum processing of the transformer fluid. Laboratory studies indicate that this problem exists at levels as low as 100 ppm.

The reverse problem — contamination of silicone transformer fluid by mineral oil causing foam — has not been observed. Instead, the problem with this type of contamination is a reduction of the flash and fire point of the silicone transformer fluid. See section 6.2, contamination, and section 3.10, retrofill considerations.

The ideal situation is to avoid contaminating the transformer fluid in the first place and there are practical ways to accomplish this. Contamination can be prevented by proper inventory control and by using equipment (pumps, hoses, etc.) that is dedicated exclusively to each fluid. In many production facilities, spilled and unused transformer fluid that may accumulate along the production line is returned to a common storage tank. This practice can result in contaminated fluid.

If the same equipment must be used for both fluids, nonpolar solvents can be used to remove the silicone transformer fluid from equipment. However, you must replace filter media and cartridges each time you change fluids — even after solvent cleaning. The practice of sharing equipment between two different transformer fluids is risky and is often unsuccessful because of incomplete removal of the silicone fluid. Contamination of either transformer fluid with the solvent is also a potential problem.

If a vacuum process results in a foaming condition, two antifoam materials have been proven to reduce the level of foam:

- 12,500 cSt XIAMETER™ PMX 200 Fluid
- 60,000 cSt XIAMETER™ PMX 200 Fluid

When testing the effectiveness and practicality of Dow silicone antifoams for industrial processes, an appropriate starting point is to add the antifoam to the foaming material at a concentration of 50 ppm. The results obtained at this concentration will indicate whether to increase or decrease the concentration of antifoam.

In tests using prediluted antifoams, it is sometimes desirable to repeat the test using a different diluent. Depending on the type of material that is foaming, certain diluents can alter the performance characteristics of the antifoam. Some diluents can enhance performance; others may reduce it. For example, an antifoam formulation consisting of 95% (by weight) mineral oil and 5% 60,000 cSt XIAMETER™ PMX 200 Fluid can be used to eliminate the foam. This formulation works at concentrations as low as 0.2 ppm of the active antifoam in the transformer fluid. However, the formulation requires frequent agitation to maintain uniformity. In contrast, adding 12,500 cSt XIAMETER™ PMX 200 Fluid with no diluent to a foaming mineral oil system may require as much as 50 ppm of the active ingredient.

Similarly, an antifoam formulation consisting of 95% (by weight) mineral oil and 5% 60,000 cSt XIAMETER™ PMX 200 Fluid can also eliminate the foam at levels as low as 0.2 ppm. However, it too requires frequent agitation to maintain uniformity.

For an antifoam to work efficiently, it must be well dispersed in the fluid it is going to defoam. It cannot just be dumped into the transformer-fluid storage tank. Figure 5.3 is a flow diagram of a typical vacuum degasification system. The ideal place to apply the antifoam is at a point upstream from the filters, meters,

valves, heaters, etc. The shear created by flow through these devices helps to disperse the antifoam. In addition, the antifoam may be partially retained on the filter medium and be released into the fluid gradually. The antifoam addition port can be either a point in the piping that can be opened or a fitting (e.g., a grease fitting) through which the antifoam can be injected or pumped.

Systems vary and it may be necessary to try several different-size antifoam injections to see how much fluid can be processed before the problem returns. For a first injection, try 5 to 10 µL of antifoam formulation. Comparing antifoam injection size with gallons of foam-free fluid will allow you to compute an ideal injection size and minimize the amount of antifoam used. Usually, smaller injections made more frequently will require far less antifoam formulation than larger injections made at longer time intervals.

The following equation should be helpful in determining the amount of antifoam to add.

$$\text{Antifoam to be added} = \frac{(\text{ppm antifoam}) \times (\text{Amount of solution to be defoamed}^a)}{(\% \text{ active ingredient in antifoam}^b) \times (10,000)}$$

^aMeasure the amount of antifoam added and solution to be defoamed in the same units; lb., gal., etc.

^bInsert 10 for 10% active, 30 for 30% active, etc.

The conversion table below should be helpful in translating the calculated amounts to common units and determining the best way to add the required amount of antifoam.

Figure 5.3 — Block flow diagram of vacuum degasification system with location of antifoam injection port



Table 5.3 — Conversion table

Parts per million	Percent	Household measure per 1000 lb	Household measure per 1000 gal
1	0.0001	—	1 teaspoon
10	0.001	1 teaspoon	8 teaspoons
100	0.01	3 tablespoons	1-2/3 cups



5.8 Paint and paintability

Silicone transformer fluid will not protect unpainted surfaces from corrosion. If severe moisture contamination occurs, corrosion could develop on unpainted surfaces. We recommend that transformers and storage tanks be primed with a corrosion-inhibiting paint, such as a zinc-chromate alkyd. Any paint is compatible with silicone transformer fluid after proper paint application and drying. However, the paint application can be affected if the surface to be painted has been contaminated with silicone fluid, just as if the surface were contaminated with motor oil, grease, or perspiration.

The best way to avoid application problems is to separate the areas where silicone fluid is handled and where the painting is done. For silicone fluid to interfere with paint application, it must get to the surface. Since the vapor pressure of XIAMETER™ 561 Silicone Transformer Liquid is very low, even at 100°C, vapor contact is unlikely to contaminate surfaces. Contamination usually occurs from rags, hands, or other items that have been in contact with silicone transformer fluid.

There are two different techniques that can be used to paint surfaces that are known to be contaminated. One is to remove the silicone contamination as part of the surface preparation procedures. The other is to use silicone paint additives to alter the wetting properties of the paint, making it compatible with the silicone contamination. Both are described in detail below.

5.8.1 Surface preparation

Although removing silicone from a contaminated surface may be somewhat more difficult than removing a conventional organic, and paintability problems may be encountered at lower levels with silicone contamination, the differences are a matter of degree, rather than of kind. In most cases, locating painting operations away from areas where silicone fluids are handled combined with routine surface preparation will prevent contamination. Should contamination occur, relatively simple cleanup procedures will render the surface paintable.

An appropriate refinishing procedure might consist of the following steps:

1. Wash the area to be repainted with a strong solution of automotive detergent in water. Many common household or industrial detergents are also satisfactory. Rinse the area thoroughly with water.
2. After the area has dried, wipe it down with a solvent such as turpentine, perchloroethylene, or xylene. Proprietary solvents (see table 5.4) designed to remove silicones are also excellent. Disposable rags should be used so that the silicones will be removed and not redeposited.
3. Apply masking tape, grind, and buff as necessary. For better paint adhesion, lightly sand all surfaces to be repainted.
4. Carefully remove all dust from the sanding and buffing operations. Again, wipe the surface clean with clean disposable rags soaked in solvent.

5. Wipe the surface with a prepared tack rag to remove all dust and lint.
6. Spray prime coat on any bare-metal surfaces and allow the primed surfaces to dry. Spray the entire area with the final paint or lacquer coats according to usual procedure.

Table 5.4 — Proprietary solvents for removing silicone contamination

Product	Supplier	Location	Phone
Fish Eye Eliminator	E.I. DuPont de Nemours Refinish Sales	Wilmington, DE	(800) 441-7515
No Fish Eye	Liquid Gaze, Inc.	Toccoa, GA	(706) 886-6853
Sila-Chek Additive V3 K 265	Sherwin-Williams Co.	Chicago, IL	(312) 278-7373

Procedures were developed in 1950 for repainting silicone-polished automobiles. These procedures involve washing with a strong detergent, followed by a solvent wipe. In order to prevent buildup of silicone in the solvent solution, disposable rags are recommended. These same procedures work well for the initial finishing of surfaces contaminated with silicone fluid and are recommended for the cleanup of relatively small numbers of units where a short-term contamination problem may exist. However, they would not be suitable for production-line operation.

Other methods are suitable for surface preparation on a production-line basis. For example, the feasibility of conventional vapor-degreasing techniques has been demonstrated. Standard paint panels were deliberately contaminated, cleaned in a vapor degreaser with trichloroethylene, and finished with both spray enamel and thermosetting acrylic powder.

After successfully cleaning and repainting ten heavily contaminated panels, silicone fluid was deliberately added to the bath after each panel to accelerate the buildup of fluid in the degreaser and to simulate long-term use. Twenty panels were repainted. There was no contamination caused by the vapor at silicone fluid concentrations of 11 parts of fluid in 7.51 parts of solvent.

5.8.2 Paint additives

Silicone transformer fluid itself may be used as a paint additive in solvent-borne paints. Only very small levels are required; from 0.01% to 0.05% will do the job effectively. It is important that the 0.05% level not be exceeded to avoid altering other paint properties. Paint additives from Dow should be used to eliminate silicone-paint problems since these additives are specially formulated to provide even dispersion and improved flexibility.

Section 6: Maintenance

Section content

- 6.1 Periodic inspection and testing
 - 6.1.1 Visual inspection
 - 6.1.2 Dielectric strength (ASTM D877)
 - 6.1.3 Water content
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- 6.2 Contamination
 - 6.2.1 Contamination with water
 - 6.2.2 Contamination with particulates
 - 6.2.3 Contamination with mineral oil
- 6.3 Filtration
 - 6.3.1 Removal of particulates
 - 6.3.2 Filtration to reduce water content
 - 6.3.3 Filtration equipment
- 6.4 Leaks
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 - 6.5.1 Recycling
 - 6.5.2 Incineration and landfill
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6.1 Periodic inspection and testing

Always follow the transformer manufacturer’s recommendations for periodic inspection and testing of the insulating (or dielectric) fluid. Dow recommends that — at a minimum — the fluid be sampled and tested after the first few days of operation, and the fluid level be checked regularly thereafter. Periodic inspection and testing of the fluid is also recommended. Such testing can alert you to a performance or reliability problem before it results in transformer failure. In fact, the ability to identify and correct problems before failure occurs is a significant advantage of fluid-filled transformers.

The inspection and testing frequency depends on the service to which the transformer is subjected. It is advisable to inspect silicone-filled transformers operating under extremely heavy loads more frequently than those in normal or light service. Referring to the station log and past test results should help identify an appropriate inspection and test frequency. The time between inspections should not be longer than one year, unless specific experience indicates that the time can be extended.

An appropriate test protocol is indicated in table 6.1. Although acid number testing is included, this test does not reliably detect the degradation of silicones. The results could, however, suggest whether contaminants are present.

Refer to ASTM D2225 “Standard Methods of Testing Silicone Liquid for Use in Electrical Insulation” for further direction in testing silicone fluid. Visual inspection, dielectric strength, and water content are discussed below in detail.

Table 6.1 — Recommended maintenance tests for silicone transformer fluid

Test	Reference	Acceptable results	Unacceptable results indicate...
<i>Minimum testing</i>			
Visual inspection	ASTM D-2129	Crystal clear — free of particles	Particulates, free water, color change
Dielectric breakdown	ASTM D-877	>35kV for fresh liquid >25kV in transformer	Particulates or water present
<i>Additional recommended testing</i>			
Water content	Modified Karl-Fisher, ASTM D-1533	<100 ppm	Excess water present
Volume resistivity	ASTM D-1169	>1x10 ¹²	Water or contamination present
Dissipation factor	ASTM D-1533	<0.2%	Polar/ionic contamination
Viscosity	ASTM D-445	50 ± 2.5 cSt	Degradation or contamination
Fire point	ASTM D-92	>340°C	Contamination by combustible material
Acid number	ASTM D-974	<0.2	Degradation of cellulose insulation or contamination

6.1.1 Visual inspection

XIAMETER™ 561 Silicone Transformer Liquid is a water-clear, virtually odorless fluid. Because of the stability and chemical inertness of the fluid, no change in its appearance is expected over the service life of the transformer.

Any color change — such as to a green, red, or blue tint — could indicate extraction of impurities from the solid insulation. If a distinct color change is observed, check the complete range of electrical characteristics, as well as the flash and fire points, and notify the transformer manufacturer. The electrical characteristics may be unimpaired. Color change (except for white, gray, or black) is not necessarily a danger signal since the color contamination alone is unlikely to impair dielectric strength.

All samples taken for visual inspection should be obtained from the bottom of the equipment. Particulates and water will settle to the bottom of silicone transformer fluid. When sampling, it is important that the procedures outlined in section 5.3, sampling, be followed closely. If particulate material, gross discoloration, or free water is found during visual inspection, refer to section 6.2, contamination.

6.1.2 Dielectric strength (ASTM D877)

Apparatus — The transformer and the source of energy must not be less than ½ kVA, and the frequency must not exceed 100 Hz. The rate of voltage rise should approximate 3000 volts per second. The voltage may be measured by any approved method that provides root-mean-square (rms) values.

The test cup for holding the sample of silicone fluid should be made of a material having a suitable dielectric strength. It must be insoluble in and not attacked by silicone fluid or solvents and nonabsorbent with respect to moisture, silicone fluid, and solvents.

The electrodes in the test cup between which the sample is tested should be square-edged circular discs of polished brass or copper, 1 inch in diameter. The electrodes should be mounted in the test cup with the axes horizontal and coincident, with a gap of 0.100 inch between their adjacent faces, and with the tops of the electrodes about ¼ inch below the top of the cup.

Procedure — The spacing of electrodes should be checked with a standard round gauge having a diameter of 0.100 inch, and the electrodes then locked in position. The electrodes and the test cup should be wiped clean with dry, calendered tissue paper or with a clean, dry chamois skin and thoroughly rinsed with Stoddard solvent (or another suitable solvent) until they are entirely free from fibers.

The test cup should be filled with dry toluene, and the voltage applied, increasing uniformly at the rate of approximately 3000 volts (rms) per second until breakdown occurs. If the dielectric strength is not less than 25 kV, the cup should be considered in suitable condition for testing the silicone transformer fluid. If a lower test value is obtained, the cup should be cleaned with solvent, and the test repeated. Observe the usual precautions in handling solvents.

Evaporation of solvent from the electrodes may chill them sufficiently to cause moisture to condense on their surface.

After the final rinsing, heat the cell gently to evaporate the solvent and prevent moisture condensation. This can be accomplished with a heat gun.

During testing the temperature of the test cup and the silicone fluid should be the same as that of the room—between 20 and 30°C (68 and 86°F). Testing at lower temperatures may produce misleading or nonreproducible results. For routine testing, air temperature should be maintained at 25°C and the relative humidity at 50%.

The sample in the container should be gently agitated with a swirling motion, to avoid introducing air, so as to mix the silicone fluid thoroughly before filling the test cup. This is even more important with used silicone fluid than with fresh, since impurities may settle to the bottom.

The cup should be filled with silicone transformer fluid to a height of no less than 0.79 inches (20 mm) above the top of the electrodes.

The silicone fluid sample should be gently agitated again by rocking the cup and allowing it to stand in the cup for 3 minutes before testing. This will allow air bubbles to escape.

Voltages should be applied and increased uniformly at a rate of approximately 3000 volts (rms) per second until breakdown occurs, as indicated by a continuous discharge across the gap. (Occasional momentary discharges that do not result in a permanent arc should be disregarded.)

Tests — Only one breakdown test may be made per cup filling. After each breakdown test, the test cup should be drained and the electrodes should be wiped clean with a lint-free disposable tissue to remove any arc decomposition products, which tend to adhere to the electrodes.

One breakdown test should be made on each of five successive fillings of the test cup. Compute the range of the five breakdown tests (maximum breakdown voltage minus minimum breakdown voltage) and multiply this range by 3. If the value so obtained is greater than the next-to-the lowest breakdown voltage, it is probable that the standard deviation of the five breakdown tests is excessive and the probability error of their average is also excessive.

If the five values meet the criteria above, the average value should be reported as the dielectric breakdown voltage. If they do not meet the criteria, one breakdown test on each of five additional cup fillings should be made and the average value from all ten breakdown tests should be reported as the dielectric breakdown voltage of the sample. No breakdown test should be discarded. When the dielectric breakdown voltage of a fluid is to be determined on a routine basis, one breakdown test may be made on each of two fillings of the test cup. If no value is below the specified acceptance value, the fluid may be considered satisfactory, and no further tests should be required. If either of the values is less than the specified value, a breakdown test should be performed on each of three additional cup fillings, and the test results analyzed as described above.

6.1.3 Water content

ASTM D2225 “Standard Methods of Testing Silicone Liquids Used for Electrical Insulation” specifies that water content should be determined in accordance with ASTM D1533, except that a 1:1 blend by volume of dry formamide and dry methanol is used instead of the chloroform/methanol solvent. This is known as the modified Karl-Fisher method. Silicone fluids can contain silanols or OH groups on the polymer chain. These silanols can react with normal Karl-Fisher reagent to generate water, resulting in a high reading. The modified Karl-Fisher method eliminates much of the problem.

A titration method also recognized by ASTM (and preferred by Dow) is an automatic Karl-Fisher titrator, such as the Aquatest IV by Photovolt. Automatic titrators tend to reduce interference problems even further. In fact, the Aquatest IV has been very effective in accurately measuring the water content of XIAMETER™ 561 Silicone Transformer Liquid to within 10 ppm.

6.1.4 Gas evolution/arc behavior

Evolution of gases in partial discharge tests — The absolute amount of gas that is generated in partial discharge tests is related to the specific test that is conducted. The linear relationship shown in figure 6.1 indicates that chemical changes in the silicone transformer fluid subjected to partial discharges depends on the electrical energy delivered to the discharge site.

Gas evolution due to arcing between electrodes — Previous studies have demonstrated that it is difficult to sustain an arc in silicone transformer fluid at low current levels. The breakdown of the silicone transformer fluid results in instant formation of solids between the two fixed electrodes. A “bridge,” consisting of silica and carbon held together by gelled fluid, forms across the electrode gap. The characteristics of this bridge are directly dependent on the initial energy input of the first arc current. The arc is generally extinguished and the generation of gas is reduced or eliminated completely.

Figure 6.1 — Evolved gas volume under partial discharge conditions

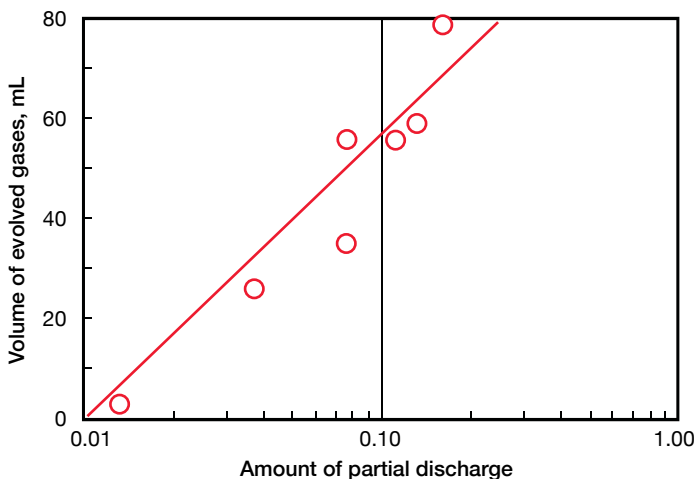


Figure 6.2 — Evolved gas volume due to arcing at moderate current levels for XIAMETER™ 561 Silicone Transformer Liquid

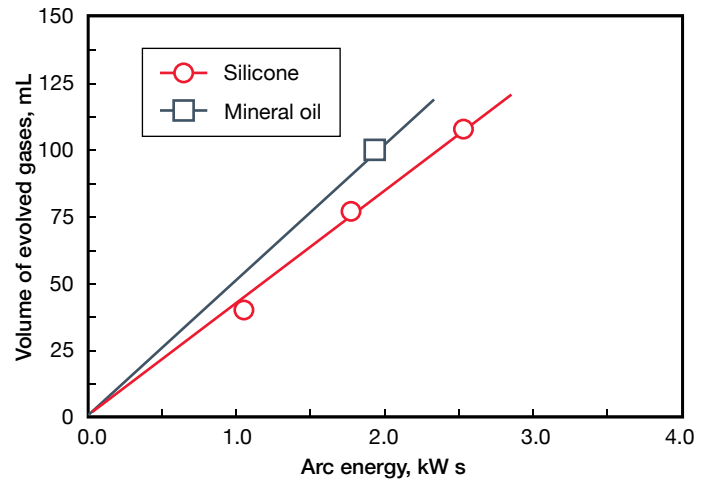
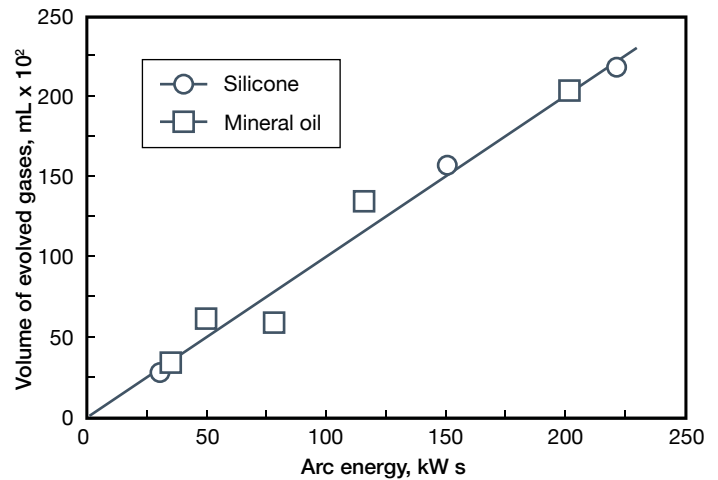


Figure 6.3 — Evolved gas volume due to arcing at high current levels for XIAMETER™ 561 Silicone Transformer Liquid



Under arcing conditions with moderate (figure 6.2) and high (figure 6.3) currents, the volume of evolved gases in silicone transformer fluid is similar to that evolved by mineral oil. This data indicates that the principles used to design transformer tanks for mineral-oil service can be applied to transformer tanks for silicone fluid.

As reported in table 6.2, analysis of the decomposition gases from low-current arcing in silicone transformer fluid showed hydrogen, H₂, to be the main component. However, substantial amounts of carbon monoxide, CO, were also evolved. Comparison tests showed that with mineral oil considerable acetylene, C₂H₂ is evolved in addition to H₂.

Interpretation of dissolved gases in silicone transformer fluid — For many years gas-in-oil analysis has been used to diagnose the condition of oil-filled transformers. The industry has attempted to apply this tool to silicone-filled transformers. Although the primary gases evolved under fault conditions in silicone fluid are similar to those evolved in mineral oil, the relative proportions of those gases differ. Standard procedures have been established for fluid sampling, analysis, and interpretation of gas-in-oil.

At present, the IEEE Insulating Fluids Subcommittee is developing a guide for the interpretation of gases generated in silicone-immersed transformers. More information on the development and interpretation of dissolved gases is available by requesting item P10 listed in section 1.5, bibliographic resources.

There is also increasing interest in applying furan analysis techniques to detect degradation within transformers. This

approach can be helpful in determining whether cellulosic insulation materials are being degraded, especially when the data are interpreted in combination with gas analysis data. However, since the technique is relatively new, not all testing services offer this type of analysis, and it is especially important to select an experienced testing organization to perform the analysis.

6.2 Contamination

Fluid contamination can occur in many ways. To ensure that XIAMETER™ 561 Silicone Transformer Liquid performs properly, it should be maintained in as clean and pure a state as possible. Even if contamination does occur, recovery of contaminated fluid is often possible. Table 6.3 is a summary of the information discussed in detail in the sections that follow.

Table 6.2 — Typical analysis of gas evolved in arc conditions with DOWSIL™ 561 Silicone Transformer Liquid and mineral oil

Current electrode	DOWSIL™ Silicone Transformer Liquid			Mineral oil		
	810 mA rotating @ 24 rpm	715 mA rotating @ 120 rpm	26.2 A fixed	345 mA rotating @ 24 rpm	1050 mA rotating @ 24 rpm	15.9 A fixed
<i>Analysis, volume percent</i>						
H ₂	74.6	75.6	77.1	65.0	68.3	73.4
CO	19.0	17.2	14.0	—	—	—
CH ₄	1.7	1.2	4.0	1.2	2.0	3.5
C ₂ H ₂	4.3	5.7	3.8	32.8	26.6	20.7
C ₂ H ₄	0.4	0.3	1.1	0.8	1.4	2.1
C ₂ H ₆	trace	trace	—	trace	trace	0.03
C ₃ H ₆	trace	—	—	0.02	0.02	0.02
C ₃ H ₈	—	—	—	trace	trace	trace
<i>Evolved gas, mL/kW-s</i>						
Measured	22	35	3	45	45	48
Calculated	88	89	82	65	57	47

Table 6.3 — Summary of common contamination problems and corrective action

Contamination	Liquid appearance	Detection testing	Corrective action	Suggested filter media	Comments
Water	Clear to milky white	Dielectric strength or modified Karl-Fisher titration, preferably with automatic titrator	Vacuum degasification	—	Free water should be siphoned, decanted or drained before processing the fluid
			Filter press	Paper or absorbent, e.g. diatomaceous earth	
			Cartridge filter	Absorbent cartridges	
Particulates	Clear with visible particles, hazy	Dielectric strength	Cartridge filter	None or diatomaceous earth as filter aid	
Mineral oil	Clear or two-phase, mineral oil odor	Flash and fire point or specialized testing	None	None	No economical methods exist for removing mineral oil from silicone fluid

6.2.1 Contamination with water

In most practical applications involving the handling of transformer fluids, the rate of water absorption and dissipation is very important. In practice, however, the determination of moisture pick-up rates is very difficult since the rate is dependent upon the equipment configuration. The size, shape, and area of contact between the fluid and its environment affects the rate at which the fluid approaches its equilibrium water content. In certain test configurations, the rate of water absorption of silicone transformer fluid was similar to askarel.

When opening a transformer in a humid-air environment, exposure time should be limited to minimize transport of water vapor into the fluid. The same guidelines that have been established for askarel-filled transformers are recommended.

Within most fluid-filled transformer configurations there is an extremely large solid-to-liquid interface. The cellulose-based materials commonly used as transformer insulation are very hygroscopic and can absorb almost as much water as silica gel. Any water dissolved in the insulation system will reach a steady-state equilibrium with the transformer fluid, with most of the water remaining in the insulation. Thus, dry cellulose immersed in wet transformer fluid will dehydrate the fluid, with most of the moisture absorbed by the cellulose. The reverse process is also true in that dry fluid will absorb water from wet cellulose insulation. Evaluating the water content of the system based on a single measurement of the fluid water content may be meaningless.

Silicone fluids behave similarly to mineral oils and askarels with respect to transport of moisture into the transformer insulation. However, the saturation and equilibrium condition of silicone fluids with insulation may be quite different from the other fluids. It is often more meaningful to consider the steady-state water content of the system than the water content of the fluid alone.

Experience in processing and manufacture of silicone fluid and silicone-fluid-filled transformers has shown that water can be removed from silicone fluid using conventional vacuum-drying techniques. Large manufacturers of silicone-fluid-filled transformers use the same vacuum temperature treatment of dry and fluid-saturated windings as those that have been established for mineral-oil-filled and askarel-filled transformers. Smaller manufacturers have found that oven drying the windings and applying vacuum to the tank after assembly will produce a transformer with excellent dielectric properties.

A procedure that applies a vacuum of 1 to 2 torr at 105°C for 18 to 24 hours can be used to accelerate the transport of moisture from the inner layers of the coil to the air interface and promote release of the moisture to the air. Higher temperatures may accelerate the drying time; however, the 105°C temperature minimizes thermal degradation of the cellulose and keeps the cost of the vacuum system relatively low. When repairing a winding that is already saturated, the drying period should be extended to 48 hours to compensate for the reduced diffusion and dissipation rates of the water. If field repairs are necessary and a vacuum system is not available, a 48-hour drying time is recommended.

Refer to section 6.3, filtration, for information on removing water from silicone transformer fluid using filtration. Refer to section 5.6, vacuum degasification, for additional information on removing water by vacuum treatment.

Effect of water contamination — Figure 6.4 shows that water is soluble to some extent in all common transformer fluids. Silicone fluid has a higher saturation water content than either fresh askarel or mineral oil. This is significant because, as shown in figures 6.5 and 6.6, some dielectric properties deteriorate rapidly in the presence of moisture. Despite its higher water content at saturation, silicone transformer fluid maintains good dielectric properties at much higher water levels than askarel or mineral oil.

Dissipation factor and dielectric constant are not affected by the water content of the fluid alone. However, the dissipation factor of silicone-impregnated paper is affected by water. Volume resistivity will decrease linearly with water content in much the same way as dielectric breakdown. The relationship between volume resistivity and water content is shown in figure 6.7. The partial discharge characteristics will also change with water content as shown in figure 3.14.

Figure 6.4 — Solubility of water in various transformer fluids

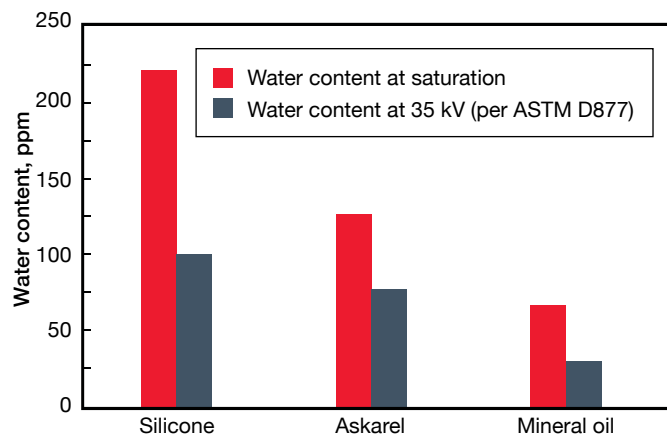


Figure 6.5 — Decrease in dielectric strength with water content for XIAMETER™ 561 Silicone Transformer Liquid

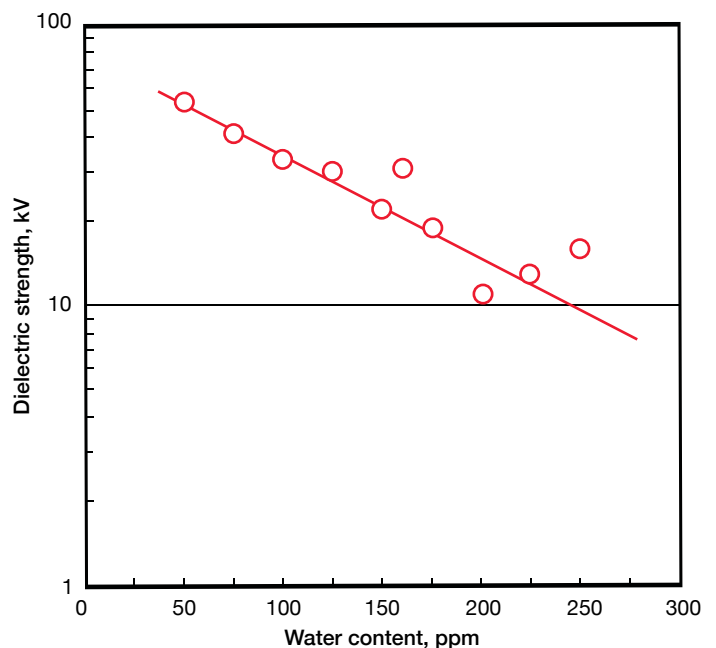
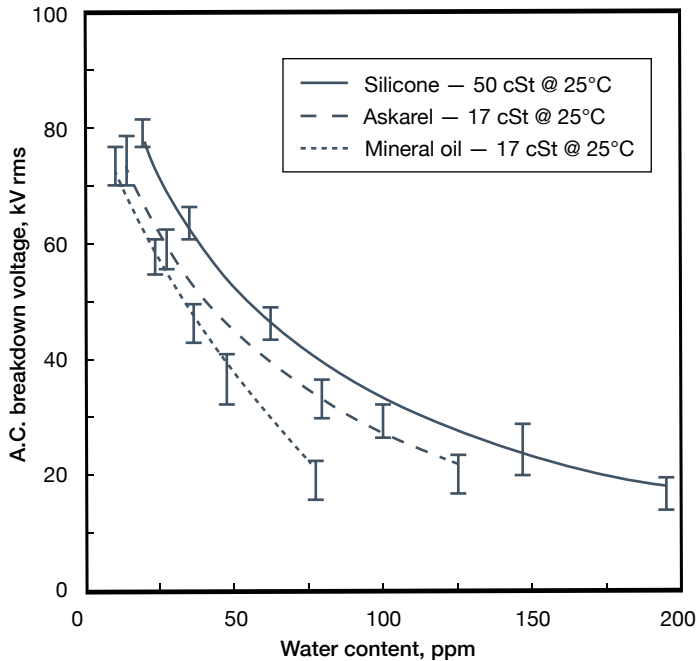


Figure 6.6 — Breakdown voltage changes with water content for transformer fluids—12.5 mm diameter sphere-to-sphere electrodes with 2.5 mm gap



Rates of water pickup and removal — Figure 6.8 shows the rate at which mineral oil and askarel pick up water when exposed to air of different humidities. In this work the fluids were exposed in a quiescent state under the following conditions:

Volume of fluid	7,500	cm ³
Surface area exposed	375	cm ²
Fluid depth	20	cm
Temperature	25	°C

Figure 6.8 shows that the sorptive ability of the fluid varies considerably. Askarel fluids pick up water more rapidly than mineral oil. A similar test on silicone transformer fluid (figure 6.9) is also shown. The data cannot be compared directly to the mineral-oil and askarel data since the fluid volume is smaller and the surface area to fluid depth ratio is much larger than in the tests above. The faster water pick up may be a result of these geometrical differences. However, if a linear relationship between sample dimensions and the time to reach equilibrium is assumed, the hygroscopic behavior of the silicone transformer fluid appears to be similar to askarel fluids.

Figure 6.9 also shows how rapidly water can be removed from the silicone fluid under mild drying conditions at 45°C. Experience with silicone transformer fluid during processing and manufacture has shown that silicone fluid can be dried to a low water content using either conventional or vacuum ovens. In the U.S., all large manufacturers of silicone-filled transformers use the same vacuum-temperature treatment of dry windings and fluid-saturated windings that has been established for mineral oil and askarel fluids. Practical work has suggested that drying of silicone fluid is best carried out in a conventional degasifier operating with vacuums of 1 to 2 torr and at temperatures between 20 and 80°C. Typical flow rates used in these degasifiers are 15 to 30 liters per minute.

Figure 6.7 — Relationship of volume resistivity of XIAMETER™ 561 Silicone Transformer Liquid to water content (15-min stress data, Keithley 610R)

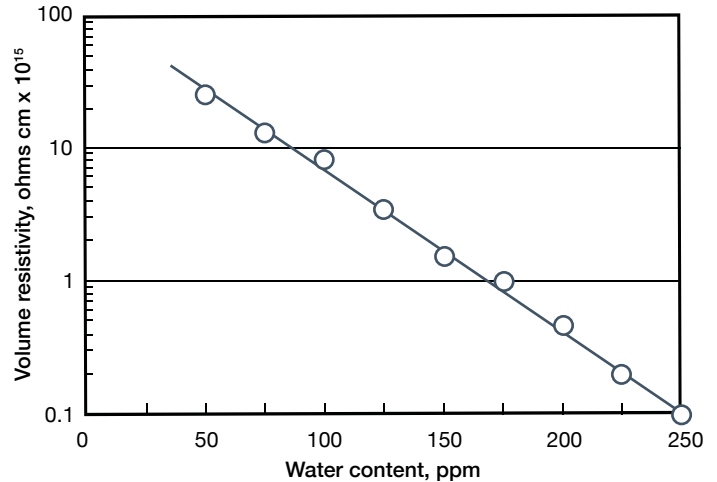


Figure 6.8 — Rate of water absorption for transformer fluids at various relative humidities

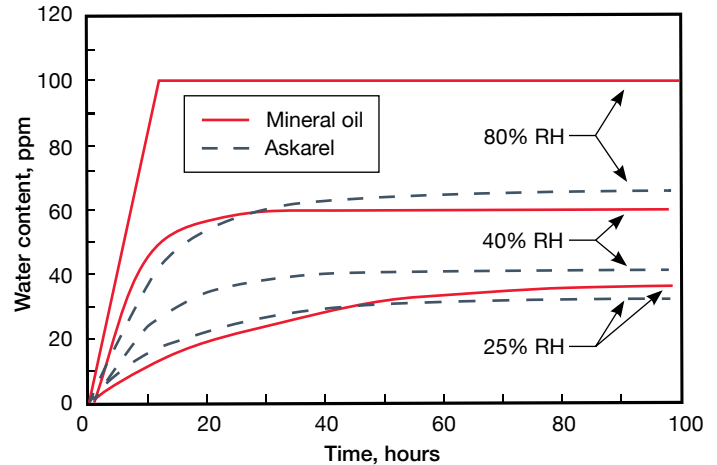
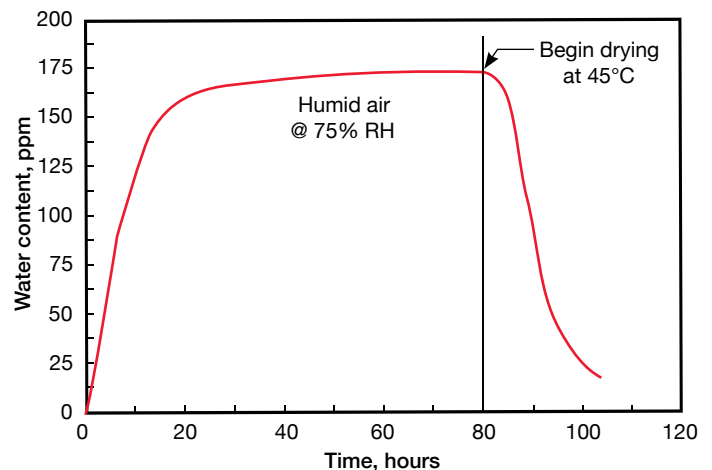
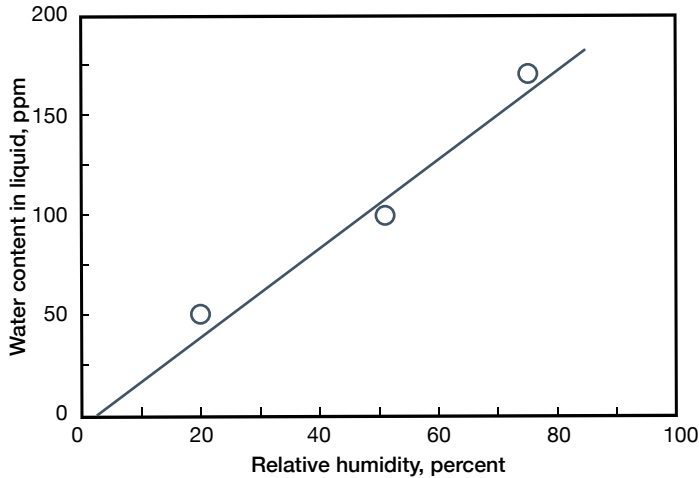


Figure 6.9 — Water absorption and drying curves for XIAMETER™ 561 Silicone Transformer Liquid



The equilibrium moisture balance between humid air and XIAMETER™ 561 Silicone Transformer Liquid depends on the humidity of the air and the water content of the fluid. Dry air will tend to dry wet fluid and wet air will add moisture to dry fluid. The rates at which this happens depend on such factors as surface area of fluid exposed to air, agitation, temperature, and the relative difference in the vapor pressures. A graph of the equilibrium water content of silicone transformer fluid at various relative humidities is shown in figure 6.10.

Figure 6.10 — Equilibrium between moisture in air and water content of XIAMETER™ 561 Silicone Transformer Liquid



6.2.2 Contamination with particulates

Refer to section 6.3, filtration, for removal of particulates.

6.2.3 Contamination with mineral oil

The solubility/miscibility of mineral oil in XIAMETER™ 561 Silicone Transformer Liquid can vary with temperature and the feedstock composition and purification methods used to produce the mineral oil. Mineral-oil contamination will reduce the flash and fire points of XIAMETER™ 561 Silicone Transformer Liquid (see table 3.26). Refer to section 6.5 for information and options for removing contaminants — including mineral oil — from silicone fluid.

6.3 Filtration

Silicone transformer fluids can be filtered to:

- Remove particulate (solid) contamination
- Reduce water content

6.3.1 Removal of particulates

The type, amount, and size of the particles to be removed are important to the effectiveness of various methods of filtration. Three basic filtration devices are available: cartridge, filter press, and bag. The cartridge filter is usually the most effective and convenient. Cartridges have absolute filtration ratings. The rating, expressed in microns (micrometers, μm), is equivalent to the largest particle that can be passed. Absolute ratings of five microns or less will generally be sufficient to filter dielectric fluids for power transformers.

A limiting factor in the use of cartridge filters is the amount of particulate material that can be removed before the cartridges fill and begin to plug off. If large amounts of particulates are

present, a filter press may be more effective. An example might be where adsorptive filter aids have been added to the dielectric fluid to aid in purification.

Bag filters can remove larger volumes of particulates. However, a 3-micron nominal rating for a bag filter, for example, compares more closely to a 15-micron absolute rating. Bag filters are more appropriate for crude filtration that is followed by a secondary filtration step with a finer filter element.

6.3.2 Filtration to reduce water content

For a discussion on the effect of water on the properties of XIAMETER™ 561 Silicone Transformer Liquid, see section 6.2, contamination.

Water is largely insoluble in silicone transformer fluid. Free, or undissolved, water will separate from the fluid and settle to the bottom of the container. Silicone transformer fluid will appear milky white if contaminated with dispersed free water. The silicone fluid should not be used if this condition occurs. As much as possible of the dispersed free water should be removed by allowing the suspension to break and settle. Placing the container in a cool, dry area may facilitate this. Free water can then be removed by siphoning, draining from the bottom, or carefully decanting. However, the fluid must be further dried to remove any dissolved water.

It is difficult to remove large amounts of free water by filtration. Rapid wetting and saturation of the filter medium occurs, and excess water becomes dispersed in the fluid. However, trace amounts of dissolved water can often be removed with filtration techniques. This process is not true filtration; rather, the dissolved water is adsorbed onto the hydrophilic filter medium.

Dissolved water is not visible and must be detected by dielectric measurements or by other appropriate analytical techniques. (See section 6.1, periodic inspection and testing.)

A common approach to removal of water in transformer fluids is to use a blotter press. Care must be taken to properly dry any filter media to be used in the operation. Filter paper or cartridges should be dried immediately before use. For good results, spread the paper for maximum surface exposure in a hot-air circulating oven for 4 to 6 hours at 110°C. Even better results can be obtained by drying the filter medium in a heated vacuum oven at 110°C for 4 to 6 hours.

An alternative to the filtration approach is to use a molecular-sieve bed to remove trace amounts of water. Molecular sieves can remove dissolved water from silicone fluid effectively and economically. Molecular sieves with a 10 to 13 Å pore size are recommended for water removal from silicone fluid. However, the most effective method of water removal is by vacuum degasification as described in section 5.6.

6.3.3 Filtration equipment

Table 6.5 is a list of companies that supply filtration equipment. It is strongly recommended that all apparatus used in sampling, filtering, storing, or transporting silicone transformer fluid be maintained for exclusive use with silicone fluid. It is extremely difficult to remove all traces of hydrocarbon oil or other contaminants from equipment of this type. In addition, care must be taken to protect all such equipment from the elements and from water or moisture contamination.

Table 6.5 — Filter equipment manufacturers

Manufacturer	Location	Phone	Types of equipment
Filterite Div. of Memtec America	Timonium, MD	(410) 560-3000	Filter tubes and housings
Filter Specialists Inc.	Michigan City, IN	(800) 879-3307	Bag filters, pressure vessel filter housings
Sethco Division	Hauppauge, NY	(516) 435-0530	Cartridge filters
Pall Corporation	East Hills, NY	(800) THE-PALL	Cartridge filters, filter housings
Carborundum Corp.	Various in U.S.		Cartridge filters, filter housings
Shutte & Koerting	Bensalem, PA	(215) 639-0900	Cartridge filters, filter housings
Alsop Engineering Corp.	Kingston, NY	(914) 338-0466	Cartridge filters for the electrical industry
Filtration Systems Div.	St. Louis, MO	(800) 444-4720	Filter presses
AquaCare Systems, Inc.	Angola, NY	(716) 549-2500	Filter presses
Patterson Industries	Scarborough, ON	(800) 336-1110	Filter presses

This is not intended to be a complete list of filter-equipment suppliers. Not all equipment supplied by these companies may be suitable for XIAMETER™ 561 Silicone Transformer Liquid. Consultation with the equipment manufacturer is recommended.

6.4 Leaks

Leaks may occur during the lifetime of a silicone-filled transformer. As part of any regular maintenance schedule, routine checks should be made to detect leaks. Areas to check and repair should include valves, bushings, gauges, tap changers, welds, sample ports, manhole covers, pipe fittings, pressure-relief valves, etc. In short, the entire surface of the tank and all devices connected to it should be inspected for leaks.

If the leak is at a gasket surface, the leak can be repaired by either installing new gaskets or, if the gasket is still serviceable, tightening down the nuts or bolts provided for that purpose.

If the leak does not involve a replaceable seal or simple retightening, welding and epoxy sealing kits are two commonly used techniques to repair the leak.

Silicone transformer fluid is an effective release agent; it prevents the formation of adhesive or cohesive bonds. As a result, most epoxy sealing kits used to patch mineral-oil or askarel leaks will not work on leaks involving silicone fluid. Proper surface preparation is difficult unless the silicone-fluid level is lowered below the leak. If the sealing kit is applied and fully cured before refilling the transformer to the normal fluid level, the seal will remain in place and stop the leak. Repair bonds formed before contacting silicone or bonds made on surfaces prepared in accordance with section 5.8, paint and paintability, are unaffected when exposed to silicone fluid.

If leak repair requires reducing the fluid level, proper care must be taken to protect the purity of the silicone transformer fluid. Dedicated equipment and clean, dry storage containers must be used. Testing of the fluid is necessary before returning the transformer to its normal fluid level. All sampling, testing, and filling of transformers should be in strict accordance with the recommendations presented in this manual.

A more recent development is a sealing kit specifically designed for sealing leaks in silicone-filled transformers. For more information on this kit, contact:

Lake Chemical
250 North Washtenaw Ave.
Chicago, Illinois 60612
(312-826-1700)

Ask for information on Epoxy Tab Type S.

6.5 Reuse, recycle, or disposal of silicone transformer fluid

Dow's commitment to the environment is demonstrated by its willingness to assist customers in understanding options for handling used and/or contaminated XIAMETER™ 561 Silicone Transformer Liquid. One of the strongest value points and least understood benefits of silicone fluid is the variety of options available to customers at end-of-use. Dow firmly believes that waste minimization and reuse or recycle are much preferred alternatives to product disposal.

For transformer manufacturers, service companies, and large utility customers, waste minimization can take many forms. These include:

- Purchasing the proper quantity of material to reduce excess
- Minimizing the length of transfer piping that may require cleaning
- Reviewing systems to ensure secure storage, transfer, and usage
- Protecting equipment against physical damage

In 1996 Dow established the XIAMETER™ 561 Silicone Transformer Liquid Registration and Recycling Program as a multi-benefit option for fluid nearing its end-of-use point or fluid contaminated with water, particulate matter, or mineral oil. The program is intended to reduce end-of-use handling concerns for prospective customers while at the same time providing 100% closed-loop life cycle for the fluid. Registration ensures that a transformer purchased today (or purchased in the past) containing XIAMETER™ 561 Silicone Transformer Liquid will be a candidate for recycle consideration at end-of-use. More information on this program is available in a separate literature piece from Dow (Literature No. 10-710-96).

6.5.1 Recycling

Recycling options include:

- Reusing the material in the same application
- Reprocessing of fluid contaminated with water, particulates, of mineral oil
- Special reprocessing of fluids contaminated with PCBs
- Fuel blending to recover energy

In some cases, fluid can be reused in the same application without reconditioning. XIAMETER™ 561 Silicone Transformer Liquid can also be reprocessed to remove contaminants and then reused in transformers in many cases.

Commonwealth Edison, a major Illinois utility, has a reprocessing system in place specifically designed for recycling silicone transformer fluids. Commonwealth Edison specializes in fluids contaminated with water and/or particulates.

Silicone transformer fluid can also be reprocessed by the transformer owner or by a reputable service company. Reprocessing procedures are discussed in sections 5.6 and 6.3 as well as in IEEE C57.111.

Dow's Registration and Recycling Program is designed to accept fluids contaminated with water or particulates and that also meet certain other recycling criteria. Additionally, the Dow program can reprocess fluid that has been contaminated with mineral oil. This contamination may have resulted from several scenarios, but the most common one occurs when transformers originally filled with mineral oil are retrofilled with silicone fluid to improve fire safety and reduce long-term maintenance. Silicone fluid used to flush the mineral oil transformer is also a candidate for the Dow program. Until this program began in 1996, the primary method for recycling this type of contaminated fluid was fuel blending or incineration.

Material returned to Dow as part of the Registration and Recycling Program is returned one-way. Returned fluid is completely restructured through chemical reprocessing and

then used to rebuild other specific silicone products. The Dow program cannot, under any circumstances, accept fluid contaminated with PCBs.

SunOhio specializes in PCB-contaminated materials and is an option for those transformers that may contain PCB-contaminated fluids resulting from prior use of PCB fluids.

Fuel blending is another recycling alternative. Most non-PCB-contaminated silicone fluids are considered nonhazardous waste when disposed and can be compatibly blended with many organic solvents or other fuels. However, oxidizers and other incompatible materials as spelled out in the safety data sheets should not be blended with silicones.

Silicones have two advantages when properly used in fuel-blending operations. Silicone fluids have a fuel value of approximately 8,000 Btu per pound, providing a favorable heat balance for fuel-use applications. Further, when silicone fluids are burned in silica-demanding processes such as cement kilns, the resulting silica becomes a valuable component of the product.

Silicone-containing materials should not be burned in internal combustion engines or other operations in which ash generation may interfere with the operation of the equipment. Always check equipment specifications and/or local regulations as appropriate prior to combusting silicone materials.

6.5.2 Incineration and landfill

If other reuse and recycle methods have been thoroughly investigated, and destruction is the only remaining alternative, incineration of XIAMETER™ 561 Silicone Transformer Liquid can be considered. As with fuel blending and other combustion activities, incineration must consider the heat content of silicones and the silica ash generated by the combustion process.

Absorbents or other solid materials contaminated with XIAMETER™ 561 Silicone Transformer Liquid that might have been generated during maintenance or clean up of minor leaks or spills (assuming no PCB contamination is present) can be landfilled if local regulations allow.

6.5.3 Reprocessing and disposal services

Table 6.6 provides an overview of the alternatives and qualified reprocessors and disposal services. The lists on the following pages provide names, addresses, telephone numbers, and websites those companies. For further information on recycle or disposal of XIAMETER™ 561 Silicone Transformer Liquid or other Dow silicone products, contact your Dow representative.

Table 6.6 – Reuse, recycle and disposal alternatives for XIAMETER™ 561 Silicone Transformer Liquid

	Fluid without PCB contamination				Fluid with PCB contamination	
	Used but not contaminated	Reprocessing to remove water or particulate contamination	Reprocessing to remove mineral oil contamination	Fuel blending	Reprocessing to remove PCB contamination	Services or incineration
Customer	●					
Commonwealth Edison		●				
S.D. Meyers		●				●
Dow		●	●			
Phillips Environmental				●		
Systech Environmental				●		
Safety-Kleen Corp.				●		
SunOhio, In.c					●	
Incinerators						●

Reprocessing of XIAMETER™ 561 Silicone Transformer Liquid contaminated with water and/or particulates (not PCBs) may be obtained from:

Commonwealth Edison
1319 South First Avenue
Maywood, IL 60153
(708) 410-5476

S.D. Myers
180 South Avenue
Tallmadge, OH 44278
(330) 630-7000
www.sdmyers.com

Dow
Midland, Michigan 48686-0994
(800) HELP-561

Reprocessing of XIAMETER™ 561 Silicone Transformer Liquid contaminated with mineral oil is available through Dow's Registration and Recycling Program

Dow
Midland, Michigan 48686-0994
(800) HELP-561

Reprocessing XIAMETER™ 561 Silicone Transformer Liquid contaminated with PCBs may be obtained from:

SunOhio
1515 Bank Place, S.W
Canton, Ohio
(888) SUNOHIO
www.sunohio.com

Removal and disposal of XIAMETER™ 561 Silicone Transformer Liquid contaminated with PCBs is available from:

S.D. Myers
180 South Avenue
Tallmadge, OH 44278
(330) 630-7000
www.sdmyers.com

The following companies offer waste fuel-blending services for energy recovery:

Phillips Environmental
515 Lyncaste
Detroit, MI 48214
(313) 824-5850

Systech Environmental
245 North Valley Road
Xenia, OH 45385-9354
(800) 333-8011

Safety-Kleen Corporation
1000 North Randall Road
Elgin, IL 60123
(800) 669-5740
www.safety-kleen.com

6.6 IEEE guide availability

The comprehensive *IEEE Guide for Acceptance of Silicone Insulating Fluid and Its Maintenance in Transformers* (IEEE C57.111-1989) can be obtained by writing:

Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street
New York, NY 10017
U.S.A.

About Dow

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S2D 91894/E26923

Form No. 10-453-01 B