DIELECTRIC FLUIDS FOR TRANSFORMER COOLING
History and Types

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This discussion is intended to provide the reader with some level of insight into the appropriate selection and application of dielectric fluids used in transformer cooling. We will attempt to provide both a historical perspective as well as a discussion on the various types of fluids available today by most if not all manufactures of liquid filled transformers.

Before we begin to compare the relative merits of different fluid types, it would first seem appropriate to discuss the purpose of dielectric fluids in transformers as a baseline for discussion.

In liquid filled transformers, dielectric fluid is used to cool the windings and provide optimal performance in the following manner. From the bottom of the tank where the dielectric fluid is at it's lowest or "bottom" temperature, the fluid flows vertically up the winding ducts and is heated by the windings. At the top of the tank, where the fluid is at its highest or "top oil temperature", it exits the main tank and enters a series of radiators or cooling fins. It then flows downward through the radiators, where it is cooled, and reenters the main tank at the bottom. In self cooled transformers this cycle is governed naturally by convection. Natural convection can also be assisted by a series of fans directing air against the radiators increasing the rate of heat transfer and subsequent rate of cooling in the windings. In some large power transformers it is also possible to have a level of forced oil circulation where a pump assists in the circulation of the fluid. This generally provides a lower top oil temperature and more uniform temperatures within the windings.

From a historical perspective there have been several fluid types offered by a variety of different manufactures that have come and gone with the winds of time. Even though discontinued, it is important to have a basic understanding of these fluids and any special treatment that they may command should you encounter them in the field.

Mixtures of polychlorinated biphenyls (PCBs) were manufactured commercially in the United States until 1977 and used as a transformer

dielectric fluid because of their non-flammable nature and chemical stability. PCBs were widely used for about fifty years and produced under a variety of trade names, the most common of which were Askarel® and Pyranol®. Although chemically stable, PCBs would only slowly biodegrade. That is that they tended to persist in nature as opposed to decomposing into basic elements. There were numerous health studies conducted that documented their potential effects on both humans and wildlife. As a result of increasing public concern Congress reacted and passed the Toxic Substances Control Act. This act singled out PCBs for regulation and directed the U.S. Environmental Protection Agency to implement controls. These regulations were published in the Federal Register in 1979. During much of the 80's and 90's a great deal of time, money, and effort was expended in complying with federal mandates. The great majority of transformers containing PCBs were either retro-filled with more acceptable fluids, or disposed of under federal guidelines. It should be noted that it is still common to discover PCB filled or PCB contaminated transformers in limited service today.

In 1978 General Electric began marketing a new transformer design called "Vaportran®". This transformer used R-113 as the dielectric coolant and was very effective as a replacement for PCB units because of its relatively small footprint, non-flammable nature, and excellent performance. R-113 was a form of Freon that was in liquid state in the transformer tank, evaporated and turned into a gaseous state as it entered the cooling radiators, and then recondensed as it heated and reentered the tank. As most of you may know, with global concerns about damage to the ozone layer, it didn't take long before government regulation set in again and the design was conscientiously withdrawn from production. There are still respectable numbers of Vaportran® units in service today, and it should be noted that there are more environmentally friendly fluid substitutes available. 3M manufactures a fluid called PF-5060 that is generally used as a replacement, but the cost may be a bit burdensome.

In the early 1980's Westinghouse began marketing and promoting a new fluid called "Wecosol®". Wecosol® was the Westinghouse trade name for tetrachloroethylene, also called perchloroethylene, (PCE). This type of fluid was widely used in dry cleaning processes. The major advantages of this fluid as a transformer dielectric coolant were its nonflammability and low cost. The scientific data on tetrachloroethylene with regards to both health and environmental issues was far to similar to those that led to the regulatory

status of PCBs. Transformer manufacturers and their customers had and continued to carry a heavy burden in complying with Government regulations over PCBs, and would continue to do so for many years. The possibility of future restrictions of use and the danger of accidental misuse was simply more than most customers were willing to buy into.

R-Temp® was manufactured by Cooper Power Systems for a number of years. It was a blend of petroleum oils, and was considered to be a "Less-Flammable" dielectric fluid by both Factory Mutual and UL. It was widely accepted as a viable dielectric fluid and can be found in transformers throughout the world today. It was withdrawn as a fluid offering by Cooper in recent years when they began to produce Envirotemp®, FR3™, which offers superior performance.

Now that we have done a postmortem on some of the industries more notable stories, it would seem appropriate to take a look at some of the industries current dielectric fluid offerings.

Today there are four generally accepted fluid types offered in the market, Mineral Oil, Silicone, Beta fluid®, and Envirotemp®. While each has good properties as a dielectric fluid, there are attributes unique to each that may make one a better choice over the others depending on the users needs.

Mineral Oil has been used as a dielectric fluid in generations of transformers. There is a longstanding, proven, track record of good performance and low costs. Mineral Oil is generally considered as a top choice in outdoor installations where its low first cost is of prime concern, and its flammable nature is understood and accepted. Mineral Oil is considered to be a "Flammable" fluid by Factory Mutual, and as such has certain restrictions imposed on its use and containment that will be discussed later in this document.

Silicone was for several decades the fluid of choice when a Factory Mutual approved "Less-flammable" dielectric fluid was desired. It has a relatively high fire point and is generally considered to self extinguish when the source of a fire is removed. However, Silicone does contain Methylpolysiloxanes which can generate Formaldehyde at around 300 degrees Fahrenheit. Formaldehyde can be a skin and respiratory sensitizer, eye and throat irritant, and is believed to be a potential cancer hazard. Silicone has been used for many years in both

outdoor applications and indoor areas. When used indoors, it has been my experience that transformers are generally in vaulted, contained areas. Silicone is not miscible with conventional mineral oils and should not be mixed with other fluids.

Beta fluid® meets NEC and Factory Mutual requirements for a "Less-Flammable" dielectric fluid. It is a blend of petroleum oils and is 100% hydrocarbon. Beta fluid® is fully miscible with conventional mineral oil and may be used to retrofill or top off these units. Beta fluid® has high dielectric strength, stability, and is non-toxic. While it does meet NEC requirements for a "Less-Flammable fluid", its fire point is significantly lower than either Silicone or FR3™.

Cooper Power Systems offers a dielectric fluid called Envirotemp® or FR3™ which is available in transformers produced by most manufactures today. The product is a soy-based, fire-resistant fluid that meets NEC requirements for a "Less–flammable" fluid, and is listed by Factory Mutual and UL as such. "Because Envirotemp® FR3™ fluid is derived from 100% edible seed oils and uses food grade additives, its environmental and health profile is unmatched by other dielectric coolants. Its biodegradation rate and completeness meets the U.S. Environmental Protection Agency (EPA) criteria for "Ultimate Biodegradability" classification." Cooper also claims "Envirotemp® FR3™ fluid extends insulation life by a factor of as much as 5-8 times because it has the unique ability to draw out retained moisture and absorb water driven off by aging paper. It also helps prevent paper molecules from severing when exposed to heat. These properties can result in an increase of overloadability and/or longer transformer insulation life, resulting in both lower life cycle costs and delayed asset replacement." (www.cooperpower.com/FR3/) FR3™ is fully miscible with conventional mineral oil or R-Temp®, and may be used to retrofill or top off units filled with these fluid types. It appears the only negative that can be attributed to this fluid is the fact that it has a relatively high first cost relative to Mineral Oil and could easily add 15-30% to the transformer first cost.

The following chart is intended to outline some of the key thermal properties of the various fluids discussed. It should be noted there is a large amount of additional data that can be viewed and compared. You should

request a Material Data Sheet for full descriptive information on each of the fluids presented.

Key Thermal properties

	Mineral Oil	Beta Fluid®	Silicone	Envirotemp®
Fire Point	**165 Deg C**	**308 Deg C**	**371 Deg C**	**360 Deg C**
Flash Point	**145 Deg C**	**285 Deg C**	**268 Deg C**	**330 Deg C**

When it comes to selecting a dielectric fluid that best meets the needs of a particular installation and customer, there are several factors that need to be considered. Not the lease of these would be first cost. The following table is intended to provide the reader with an approximation of the relative first cost of transformers filled with each of the four dielectric fluids previously discussed. Please note that these are only approximations and the relative costs can vary depending on the volume of liquid contained in the transformer.

Fluid Type	Relative First Cost
Mineral Oil	1.00
Beta Fluid®	1.20
Silicone	1.30
Envirotemp®, FR3™	1.30

In determining first cost there is more to consider than just the initial equipment cost. There are installation requirements specific to different fluid types that can add a significant burden to project costs. It is generally considered that Factory Mutual is the ruling authority when it comes to standards and requirements for the installation of any liquid filled transformer. Factory Mutual has published data sheets that define separation distances

between transformers and buildings, fire barrier requirements, and liquid containment systems specific to the various fluid types and ratings. These requirements are very specific and should be consulted along with local building codes when determining the requirements specific to any installation.

The following tables published by Factory Mutual are used in determining separation distances between transformers, buildings, and other equipment.

Table 2a. Separation Distance Between Outdoor Liquid Insulated Transformers and Buildings

Liquid	FM Approved Transformer or Equivalent	Liquid Volume, gal (m^3)	Horizontal Distance (1)			Vertical Distance ft (m)
			Two Hour Fire Resistant Construction, ft (m)	Non-combustible Construction, ft (m)	Combustible Construction, ft (m)	
Less Flammable (FM Approved Fluid)	Yes	N/A	3 (0.9)			5 (1.5)
	No	≤10,000 (38) >10,000 (38)	5 (1.5) 15 (4.6)		25 (7.6) 50 (15.2)	25 (7.6) 50 (15.2)
Mineral Oil or (unapproved fluid)	N/A	<500 (1.9) 500-5,000(1.9-19) >5,000 (19)	5 (1.5) 15 (4.6) 25 (7.6)	15 (4.6) 25 (7.6) 50 (15.2)	25 (7.6) 50 (15.2) 100 (30.5)	25 (7.6) 50 (15.2) 100 (30.5)

(1) All transformer components must be accessible for inspection and maintenance.

Table 2b. Outdoor Fluid Insulated Transformers Equipment Separation Distance (1)

Liquid	FM Approved Transformer or Equivalent	Fluid Volume, gal (m^3)	Distance, ft (m)
Less Flammable (FM Approved Fluid)	Yes	N/A	3 (0.9)
	No	≤10,000 (38) >10,000 (38)	5 (1.5) 25 (7.6)
Mineral Oil or (unapproved fluid)	N/A	<500 (1.9) 500-5,000 (1.9-19) >5,000 (19)	5 (1.5) 25 (7.6) 50 (15.2)

(1) All transformer components must be accessible for inspection and maintenance.

As outlined by Factory mutual, containment systems are required when:

1) "A release of Mineral Oil would expose buildings."
2) "More than 500 gallons of Mineral Oil could be released."
3) "More than 1320 gallons of FM approved less flammable fluid could be released."
4) "More than 2640 gallons of biodegradable FM approved less flammable fluid could be released. The fluid must be certified as a biodegradable fluid by the environmental protection agency. A release of this fluid must not expose navigable waterways. The transformer must be properly labeled.

You should refer to Factory Mutual and local codes for complete definitions and requirements for compliance.

While the determination as to which fluid constitutes an individual users "fluid of choice" can vary greatly, it would seem clear that the industry is migrating in the direction of environmental awareness. Perhaps, unlike many of mans other decisions, we are not determined to repeat the mistakes of the past.

I hope this article provides you with a better understanding of the history, current offerings, and practices concerning dielectric fluids. It is ultimately the users decision based on design, cost, location, and potential environmental impact that should define the fluid type to be used.

Reference Material

www.cooperpower.com/FR3/
www.dsifluids.com/Beta%20Fluid%20Page.htm
"Envirotemp® FR3™ Fluid", Cooper Power Systems, Bulletin B900-00092
"Three-Phase Padmounted Transformers", GE publication #JVB-005
"Material Safety Data Sheet", GE Silicones
"Factory Mutual Global Property Loss Prevention Data Sheets", Factory Mutual Insurance Company, 2005.
"Cost Comparison - Cooling Options". GE Prolec
"Beta Fluid – Fire Resistant Insulating Oil", DSI Ventures, Inc.
"Material Safety Data Sheet – Beta Fluid", DSI Ventures, Inc., David Sundin, Ph. D., Effective Date 12/01/05
"SPQR – Westinghouse "Wescosol" Transformer", 11/15/1982, GE publication #GIZ-1768A
"Meeting Federal PCB Regulations for the Food and Feed Industry", by Edward W. Feuerstein and William K. Mallon, 8/84, GE Publication #GER-3381A