

Application for LEED Innovation & Design Points

Transformer Technology: Liquid-Filled vs. Dry-Type

Summary:

Dry-type transformer technology has been traditionally specified for in- and near-building applications to minimize the impact of environmentally detrimental fluids and accompanying fire safety issues, while sacrificing environmental issues of energy efficiency, sound level, and ease of recycling. This application diverges from this historical trend and utilizes liquid-filled transformers with an environmentally preferred fluid that maximizes performance in all of these areas. Use of less-flammable dielectric fluids and installation guidelines according to a listing body such as FM Global or Underwriters Laboratories will result in a certified installation that optimizes the many advantages of the liquid-filled transformers.

Industry / Technical Foundation:

Excerpt from:

Barnes 1996. Barnes, P.R., J.W. Van Dyke, B.W. McConnell, and S. Das. *Determination Analysis of Energy Conservation Standards for Distribution Transformers*. Oak Ridge National Laboratory ORNL-6847, July 1996. (pages xix and 3-7) Developed for US Department of Energy
<http://cta.ornl.gov/cta/Publications/pdf/ORNL-6847.pdf>

“Purchases of transformers are often based on the first cost (without any consideration of long-term economics) when transformer evaluation and purchase decisions are not made by the end-user. This is particularly true when agents or electrical contractors make purchase decisions on the basis of temperature rise and low first cost for C&I (commercial and industrial) end-users buying dry-type, pad-mounted transformers. These agents or contractors may have little incentive to take into consideration any economic factors other than the transformer’s first cost. End-user concerns about higher first costs discourage OEMs and contractors from offering or recommending the more expensive, efficient options to customer who do not specifically request them”.

“Because air is the basic cooling and insulating system for dry-type transformers, all dry-type transformers will be larger than liquid-immersed units for the same voltage and capacity (kilovolt/kilovolt-ampere) rating. When operating at the same flux and current density, more material for core and coil implies higher losses and higher costs. These trade-offs are inherent in the design of dry-type units, but dry-type transformers have traditionally offered certain fire-resistant, environmental, and application advantages for industrial and commercial situations. Recent advances in liquid-filled units are reducing some of these (dry-type) advantages”

Recent Advances:

Developments in less-flammable transformer fluids have overcome the previous mineral oil-filled fire safety issues. Less-flammable fluid-filled transformers now have a 30+ year, 350,000 unit installation record of no reported fires – a fire safety record that dry-type and cast-coil transformers cannot claim.

Since the 1996 Oak Ridge National Laboratory citations, transformer fluid developments have also overcome the previous liquid-filled environmental issues. High fire point natural ester fluids are renewable, biodegradable, non-toxic, non-bioaccumulating, non-carcinogenic, and recyclable.

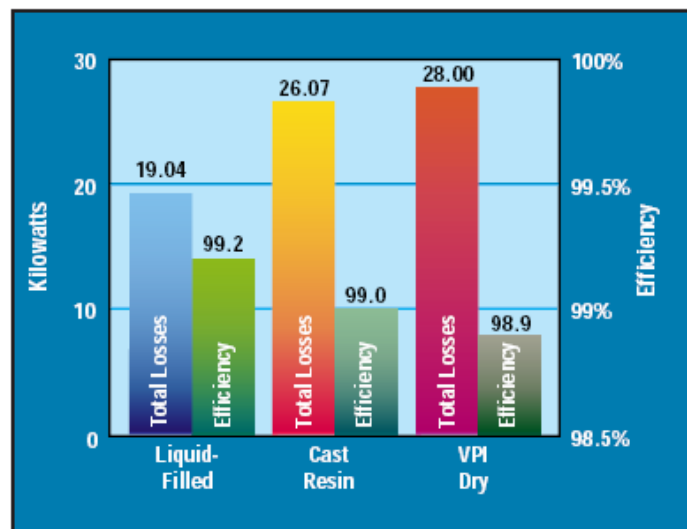
With these new fire safety and environmental advances in dielectric fluids, all of the other environmental performance advantages of liquid-filled transformers can now be exploited, including:

- Greater energy efficiency
- Lower sound level
- Smaller footprint
- Much longer operating life, ease of maintainability and repairability
- Ease of recycling

Feature: Liquid-filled transformers have higher standard energy efficiency
Energy/Environmental Benefit: Less transformer-related energy usage and air conditioning energy usage

When purchased on the basis of lowest first cost, dry type transformers typically have significantly higher operating losses than the more efficient liquid filled transformers. For this reason the major utilities seldom purchase dry type transformers.

“Because dry-type insulation systems lack the additional cooling and insulating properties of the oil-paper systems, for the same rating the dry-type transformers tend to be more costly, larger, and have greater losses than a corresponding liquid-immersed unit.” - ORNL-6847 pg 2-6



2500 kVA transformer.

Above graphic shows combined losses at 100% loading based on:

	<u>Liquid:</u>	<u>Cast:</u>	<u>Dry:</u>
Load Losses (kW):	16.38	21.00	18.52
No Load Losses (kW): +	<u>2.66</u>	<u>7.00</u>	<u>7.55</u>
Total Losses (kW): =	19.04	26.07	28.00

Above values are typical; additional similar values can be found in ORNL-6847, page 4-4.

At 50% loading, the no-load loss remains the same, and load loss is reduced by the inverse square:

	<u>Liquid:</u>	<u>Cast:</u>	<u>Dry:</u>
Load Losses (kW):	4.10	4.63	5.25
No Load Losses (kW): +	<u>2.66</u>	<u>7.00</u>	<u>7.55</u>
Total Losses (kW): =	6.76	12.18	12.25

Costs Of Transformer Losses - Transformer Energy Consumption:

Constants:

Energy Costs = \$0.06/kWh (Conservative Value)

8760 hours = 24hrs/day * 365 days per year

	<u>Liquid:</u>	<u>Cast:</u>	<u>Dry:</u>
Total Losses (kW):	6.76	12.18	12.25
KWH Billing Rate: x	\$0.06	\$0.06	\$0.06
Annual Hours: x	<u>8760</u>	<u>8760</u>	<u>8760</u>
Annual Cost of Energy due to Losses @ 50% Load: =	\$3,553	\$6,402	\$6,439
Excess Annual Energy Costs:	Base	\$2,849	\$2,886
10-Yr* Excess Energy Costs:	Base	\$28,490	\$28,860

*Simple costs, assumes no interest rate or escalating energy costs

Additional Cost Of Transformer Losses - Air Conditioning Energy Consumption:

Energy consumption by the transformer is not the only energy factor. Transformer losses are dissipated as heat, which must be removed from a controlled temperature environment by air conditioning. Illustrated below are calculations to convert transformer losses into increased air conditioning energy consumption.

Constants:

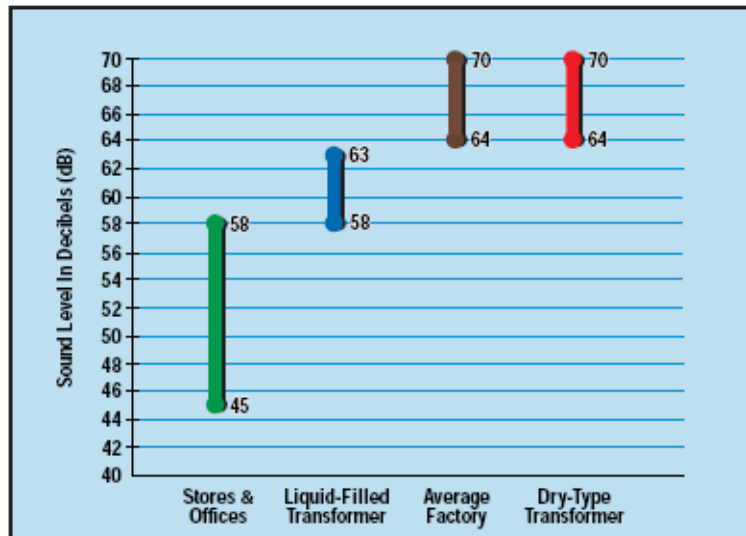
1kW = 3415BTU/Hr

1Ton Air Conditioning = 12000BTU/Hour

1Ton Air Conditioning = 1.7kW power use

	<u>Liquid:</u>	<u>Cast:</u>	<u>Dry:</u>
Total Losses (kW):	6.76	12.18	12.25
BTU/HR/KW: x	<u>3415</u>	<u>3415</u>	<u>3415</u>
BTU/HR: =	23085	41595	41834
BTU/HR per ton A/C: ÷	<u>12000</u>	<u>12000</u>	<u>12000</u>
A/C (tons): =	1.92	3.47	3.49
kW power usage per ton A/C: x	<u>1.7</u>	<u>1.7</u>	<u>1.7</u>
kW: =	3.27	5.89	5.93
Annual Hours of Operation(h): x	<u>8760</u>	<u>8760</u>	<u>8760</u>
Annual energy usage (kWh): =	28649	51619	51916
kWH billing rate: x	<u>\$ 0.06</u>	<u>\$ 0.06</u>	<u>\$ 0.06</u>
Annual Cooling Costs: =	\$1,718.94	\$ 3,097	\$ 3,115
Excess Annual Cooling Costs:	base	\$ 1,378	\$ 1,396
10-Yr Excess Energy Costs:	base	\$13,782	\$13,960

Feature: Liquid filled transformers have a lower operating sound level
Indoor Environmental Quality Benefit: Less noise pollution



Decibels is a logarithmic function, and sound pressure doubles for every three decibel increase. Research shows that decibel levels over 60 can reduce a person's attention span. A study by the American Society of Interior Designers showed that office productivity would increase if workspaces were less noisy.

References:

"Is There Too Much Noise in Your Office?", March 2002, The National Federation of Independent Business, <http://www.nfib.com/object/1584010.htm>

Green Buildings and Worker Productivity A Review of the Literature, Palmer et. al., SF Environment, undated.

Feature: Liquid filled transformers have a smaller footprint

Materials & Resources Benefit: Smaller equipment reduces building size demand

Constants:

Typical cost per square foot: \$25/SF

KVA		Liquid:	Dry:	Difference:	\$25/SF:
750kVA	Depth:	4.6 ft	5.5 ft		
	Width:	4.6ft	8.0 ft		
	Sq Ft:	21 ft ²	44 ft ²	23 ft ²	\$ 575
1000kVA	Depth:	5.2 ft	5.5 ft		
	Width:	4.8 ft	8.0 ft		
	Sq Ft:	25 ft ²	44 ft ²	19 ft ²	\$ 475
1500kVA	Depth:	6.3 ft	5.5 ft		
	Width:	4.4 ft	8.0 ft		
	Sq Ft:	28 ft ²	44 ft ²	16 ft ²	\$ 400

A smaller building also has the benefit of requiring less lighting and ventilation.

References:

Eaton VPI Ventilated Dry-Type:

<http://www.eatonelectrical.com/unsecure/cms1/TB00900002E.PDF> - pg 14.0-21

Cooper liquid-filled transformer dimensions:

<http://www.cooperpower.com/Library/pdf/21015.pdf> - pg 5

Feature: Liquid filled transformers have superior operating life, maintainability, and repairability

Materials & Resources Benefit: Less waste/disposal/replacement/labor

Operating Life:

Typical dry-type lifespan: 15-25 Years

Typical liquid-filled lifespan: 25-35 Years

“The retirement age of transformers removed from service for a variety of reasons ranges from 14 to 35 years; the average is 25 years. However, the average life of liquid-immersed transformers that remain in service is 30 years or more.”

-ORNL-6847 pg3-6

Because liquid-filled transformers last longer than dry-type, they save on material, labor to replace, and operational impact due to outage to replace.

Maintainability:

Recommended annual maintenance for a typical dry-type transformer consists of inspection, infrared examination of bolted connections, and vacuuming of grills and coils to maintain adequate cooling and prevent buildup of flammable material. Cleaning of the grill and coils may require the undesirable requirement of de-energizing the transformer, often leading to no cleaning. Omitting the cleaning decreases the transformer efficiency due to decreased airflow and creates a fire hazard.

Preventive maintenance for a liquid-filled transformer may consist of drawing and analyzing an oil sample. The oil analysis provides a very accurate assessment of the transformer condition – something not possible with dry-type transformers. Omitting the preventive maintenance does not decrease transformer efficiency or create a potential fire hazard.

Less-flammable liquid-filled transformers provide the best opportunity to enable maximum efficiency with the least maintenance, and provide the best diagnostics for repair/re-use rather than unforeseen failure/disposal.

Reference:

Enerwise Global Technologies, *Recommended Distribution System Maintenance*, <http://www.enerwise.com/pdfs/Dist%20System%20Maint.pdf>

Repairability:

“Coils in liquid-type units are much easier to repair than coils in dry-type transformers. Cast coils are not repairable; they must be replaced.” - Moran, Robert B. Guidelines for transformer application designs. Electrical Construction and Maintenance, May 1996 http://ecmweb.com/mag/electric_guidelines_transformer_application/index.html

When a transformer fails, a decision to repair or replace the transformer must be made. Liquid-filled transformers, in most situations, can be economically repaired at local independent service repair facilities.

Liquid-filled transformers provide the best opportunity to repair existing equipment rather than dispose and replace.

Example – 2500kVA Transformer – Purchase and Maintenance

	<u>Liquid</u>	<u>Cast</u>	<u>Dry</u>
Purchase Price:	\$35,000	\$60,000	\$38,000
Operating Life (years):	35	30	25
Annual Maintenance:	none	6 hours	6 hours
Annual Maintenance:	none	\$360	\$360
Outage Required for Maintenance:	N/A	Yes	Yes
Fire Hazard if not Maintained:	No	Yes	Yes
Repairable:	Yes	No	Yes
Annual cost to purchase and maintain:	\$902	\$1,693	\$1,376

Feature: Liquid filled transformers allow easier core/coil reclamation
Materials & Resources Benefit: Easier to recycle

Utility companies who use most of the liquidfilled transformers typically replace the coils on old transformers and continue to use them for a large percentage of their old substation transformers. The small distribution transformers are disposed/recycled when they reach an end of life.

When it comes time to decommission a transformer, recycling offsets the need for new material and provides a positive cash flow. Most components of liquid-filled and dry-type transformers can be recycled. Cast resin type transformers are an exception. Because of their construction, the materials in cast resin type transformers can be difficult and uneconomical to recycle. When a cast coil fails, the entire winding, encapsulated in epoxy resin, is rendered useless and typically ends up in a landfill. This wastes the resource and creates additional costs for disposal, plus long-term liability exposure to the original owner.

In contrast, liquid-filled transformers can be easily recycled after their useful life. The transformer fluid can be reconditioned and used again, and the steel, copper, and aluminum can be completely and economically recycled, providing a positive cash flow. The scrap values and disposal costs for a 2500 kVA transformer are shown below. Positive cash flows are shown in parentheses.

	VPI Dry	Cast Resin	Liquid-Filled
Dielectric Fluid	\$0	\$0	(\$500)
Core & Coil	(\$1,100)	(\$100)	(\$1,200)
Tank & Fitting	(\$400)	(\$100)	(\$400)
Disposal Costs	\$0	\$400	\$0
Total Cost or (Savings)	(\$1,500)	\$200	(\$2,100)

2500 kVA transformer.

CONCLUSION:

Envirotemp® FR3® natural-ester fluid-filled transformers are being used for this project in lieu of (more common) more noisy, hotter, less easily repaired, less recyclable, and less efficient dry-type or cast-resin transformers. Use of liquid-filled transformer(s) for commercial and industrial facilities is an innovative design practice. A dry-type transformer is the standard solution for providing power in this type of design. A total owning cost evaluation of both dry-type and liquid-filled transformers will show the lowest total owning cost choice is the installation of less-flammable liquid filled transformers. The natural ester Envirotemp FR3-filled transformer pays off in lower energy requirements, lower materials demand, better environmental quality, and lower cost of ownership.

Natural-ester fluid-filled transformers contribute to affordable, sustainable engineering/building practices.

Additional Supporting Documentation:

Comparison of Transformer Losses Calculator

<http://www.powersystems.ca/losses.asp>

Electrical Line Magazine, Jan/Feb 2005, “Natural Ester Based Transformer Fluids - The New Indoor Transformer”

http://www.electricalline.com/images/mag_archive/36.pdf

Cooper Power Systems, Bulletin 00006, “Rethinking Transformers for Safety, Performance, and Value – Transformer Selection Guide”

<http://www.cooperpower.com/Library/pdf/00006.pdf>

ABB Environmental Product Declaration, Large Distribution Transformer 10 MVA (ONAN), September 2003,

[http://library.abb.com/GLOBAL/SCOT/SCOT292.nsf/VerityDisplay/57C1D5721712C65FC1256DE9003D9401/\\$File/10%20MVA.pdf](http://library.abb.com/GLOBAL/SCOT/SCOT292.nsf/VerityDisplay/57C1D5721712C65FC1256DE9003D9401/$File/10%20MVA.pdf)

Electricity Today, Issue 8 2004, “Seed-Based Transformer Dielectric Fluids Provide Safety, Environmental Responsibility, and Longevity”

http://www.electricity-today.com/download/issue8_2004.pdf

Losses Between Dry Type Transformers And Oil Transformers

<http://www.powersystems.ca/dry.pdf>

Copper.Org – “High-Efficiency Utility Transformers Mean Lowest Total Owning Cost”

http://64.90.169.191/applications/electrical/energy/trans_ad.html