FRA-79-10

REPORT NO. FRA/ORD - 79/37

EVALUATION OF SILICONE FLUID FOR REPLACEMENT OF PCB COOLANTS IN RAILWAY INDUSTRY

E.J. Walsh
D.E. Voytik

Westinghouse Electric Corporation
469 Sharpsville Avenue
Sharon PA 16146

JUNE 1979

FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Research and Development
Washington DC 20590

Technical Report Documentation Page

1. Report No. FRA/ORD - 79/37	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle EVALUATION OF SILICONE FLUID FOR REPLACEMENT OF PCB COOLANTS IN RAILWAY INDUSTRY		5. Report Date June 1979 6. Performing Organization Code
7. Author(s) E.J. Walsh, D.E. Voytik		8. Performing Organization Report No. DOT-TSC-FRA-79-10
9. Performing Organization Name and Address Westinghouse Electric Corporation* 469 Sharpsville Avenue Sharon PA 16146		10. Work Unit No. (TRAIS) RR930/R9336 11. Contract or Grant No. DOT-TSC-1294
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Railroad Administration Office of Research and Development Washington DC 20590		13. Type of Report and Period Covered FINAL REPORT Nov. 1976 - July 1977 14. Sponsoring Agency Code
15. Supplementary Notes *Under contract to: U.S. Department of Transportation, Research and Special Programs Administration, Transportation Systems Center, Cambridge MA 02142		

16. Abstract

Electrical performance evaluations were made on a railway transformer which was retrofilled with 50 cs polydimethylsiloxane. Comparisons of the data from the PCB-filled transformer retrofilled with the silicone oil indicated no reduction in operating performance.

Analyses of the various flushing cycles and of the final silicone fluid showed that the most efficient flush method was to circulate solvent in the completely filled unit, followed by solvent removal and a subsequent silicone fill. Residual levels of PCB's were found to be stabilized at 3.47% two weeks after retrofilling.

Investigations were carried out to determine possible temperature changes which could occur with a silicone retrofilled transformer. A maximum rise of 2.7°C was observed with this type of retrofill. This small increase in temperature for a forced air cooled transformer could have a minimal effect on transformer performance.

17. Key Words Retrofilling PCB's Silicone Fluids Railway Transformers Solvent Flush, Electrical Performance	18. Distribution Statement DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 54	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

At present, polychlorinated biphenyls (PCB's) are used as a coolant in railroad transformers. PCB's are considered a pollutant, however; and the Environmental Protection Agency has indicated that it may prohibit them. Commercial production of PCB's has already stopped.

The purpose of this study was to determine whether PCB's could be replaced with silicone fluid. The study was made by the Westinghouse Electric Corporation under contract to the Electrical Power and Propulsion Branch of the Transportation Systems Center. The Silicone Evaluation Retrofill Program is sponsored by the Office of Research and Development of the Federal Railroad Administration. The Transportation Systems Center and the Federal Railroad Administration are both part of the Department of Transportation.

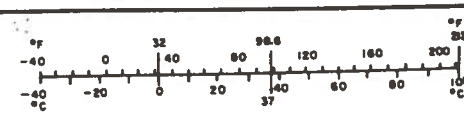
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. SUMMARY

Polychlorinated biphenyls (PCB's) are a class of compounds which have long been used as a liquid coolant and as an insulating medium in railway transformers. This class of compounds is very stable chemically, thus making PCB's a persistent contaminant in the environment.

The Enviromental Protection Agency (EPA) has identified PCB's as being environmentally hazardous, and therefore regulations have been promulgated which severely restrict the amount of PCB's which can be discharged into the environment. Monsanto, the sole producer of PCB's in the United States, has discontinued production of these materials, thus making it necessary to develop alternative fluids for use in railroad transformers.

The foremost candidate now available for consideration as a PCB retrofilling material is a polydimethysiloxane (silicone) fluid of 50 centistoke viscosity. Silicone fluid has been identified as a fluid with physical and chemical characteristics suitable for use in transformers; heat transfer, insulating capacity, and thermal stability all meet the criteria for the intended use. The chemical structure of silicone is markedly different from the PCB's and they are generally regarded as environmentally acceptable.

Silicone fluids have earned a reputation for low toxicity and physiological inertness. In fact, numerous toxicological studies have placed silicones among the least toxic of all industrial chemicals. As a result, specified grades of silicones conform to appropriate FDA regulations to permit direct and indirect food contact under specified conditions in such uses as defoaming, and are widely used in cosmetics, medical, and pharmaceutical applications.

The primary objective of this program was to evaluate silicone fluid as a potential replacement fluid for the PCB coolant presently used in transformers by the railway industry. To accomplish this objective, the following tasks were performed.

1.1 LITERATURE SEARCH AND DATA COMPILATION

A complete search utilizing all library and supplier information sources was carried out. The information from all these sources is listed as references 1 through 8. The information includes detailed physical property data as well as performance evaluation reports on silicone-filled transformers.

1.2 PCB REMOVAL AND RETROFILLING OF TRANSFORMER WITH SILICONE FLUID

A detailed, stepwise method for draining and flushing railway transformers was developed using a hydrocarbon solvent. Approximate efficiency data was collected and the final retrofilled transformer fluid tested to determine residual PCB levels which could be expected utilizing the methods discussed. It was found that using mineral spirits as a flushing material resulted in residual levels of 3.47% PCB. Suggestions were made in the text for possible methods by which the flushing efficiency could be increased.

1.3 ELECTRICAL TESTING TO DETERMINE RETROFILLED TRANSFORMER PERFORMANCE

The transformer which was used for these studies was tested before and after retrofill. The tests carried out were typical of those tests done on new transformers to establish satisfactory performance before shipping. In addition to the electrical performance tests, studies were also conducted to evaluate the effects of retrofilling on the temperature rise in the transformer and also to determine if retrofilling had any effect on the pressure in the head space of an operating unit.

All electrical tests showed very favorable results showing that the retrofill did not decrease the electrical performance of this transformer. A slight rise in termperature was observed in cooled type transformers. Therefore, this slight temperature rise observed should have very little effect on transformer life or capacity. Also, no significant pressure increases were noted in our studies which could have affected the overall performance of the transformer.

Note: Transformers discussed in this document refer to railway transformers.

2. INTRODUCTION

Polychlorinated biphenyls (PCB's), Figure 2-1, are a class of compounds which have long been used as a liquid coolant and as an insulating medium in railway transformers.

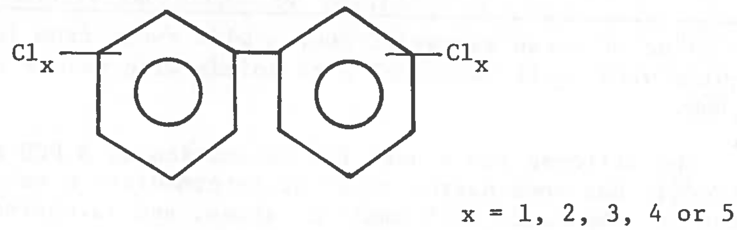


FIGURE 2-1. POLYCHLORINATED BIPHENYLS (PCB'S)

The various manufacturers of PCB-filled transformers have used many different types of PCB's in their products. Monsanto, which has been the major supplier of these materials in the United States, sold this material under the trade name of Aroclor with varying numerical designations. The numbers used to identify a specific PCB product are related to the average percent of chlorine to be found in the product. Those PCB materials most normally found in transformers would be Aroclor 1260, Aroclor 1254, Aroclor 1248, and Aroclor 1242 with 60%, 54%, 48%, and 42% chlorine respectively. The Aroclors with the higher percentages of chlorine are very viscous materials and are adpated for low temperature use in railway transformers by mixing with from 40% to 10% tri and tetrachlorobenzenes. As all of the PCB coolants are interchangeable, it is not unusual to find mixtures of the various types in a transformer which has seen considerable service.

Each of the Aroclors is a complex mixture of the various possible chemical isomers. The higher-numbered Aroclors have a greater degree of chlorination. X of Figure 2-1, for example, is predominately 2, 3, and 4 for Aroclor 1260, and thus it has greater chemical stability. It is the chemical stability which has made PCB's a persistant contaminant in the environment. The Environmental Protection Agency (EPA) has identified all PCB's as being environmentally hazardous; and consequently, regulations now exist that severely restrict the amount of PCB's that can be discharged into the environment. Monsanto, the sole producer of PCB's in the United States, has discontinued production of these materials, thus making it necessary to develop alternative liquids for use in transformers.

The foremost candidate now available for consideration as a PCB retrofilling material is a polydimethylsiloxane silicone fluid of 50 centistoke viscosity. Although retrofilling with silicone is relatively new, generally speaking, the Japanese have been retrofilling with silicone satisfactorily for the past twenty years. Figure 2-2 gives the backbone structure of this liquid which is just one of a large family of liquids, gums, and solids commonly call silicones.

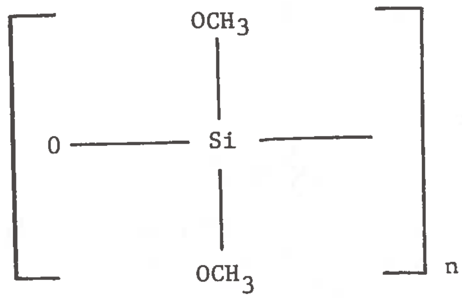


FIGURE 2-2. POLYDIMETHYLSILOXANE SILICONE FLUID OF 50 CENTISTOKE VISCOSITY

The value of n can be varied over a wide range from low-viscosity liquids with small values of n to solids with values of n greater than 15,000.

The silicone fluid used for evaluation as a PCB replacement in a retrofill has some narrow range of intermediate n values, contains no volatile components with small n values, and is characterized by a viscosity of approximately 50 centistokes.

This silicone fluid is not inflammable as were the PCB's, even though it does have a relatively high flash point of 545°F and fire point of 650°F. Silicone fluid also has many of the other physical and chemical characteristics necessary for its use in transformers; heat transfer, insulating capacity and thermal stability all meet the criteria for the intended use. Silicone does, however, have some differing characterisitcs from the PCB's. In an electrical arc, PCB's produce noncombustible gases, predominately HCL. Silicones produce hydrogen and methane, both combustible gases. Also, the chemical reactions which may occur between silicone fluid and some of the materials in the older transformer are still unknown factors. Silicones, however, are generally regarded as being environmentally acceptable and can function as both a coolant and an insulator comparable to PCB's in transformers.

The impact of silicone fluid in the environment will not be noticed for some time. Contact with soil and water may cause silicone fluid to slowly depolymerize to low molecular weight species. Known chemistry suggests that these species degrade in water and the atmosphere. Additional tests to further characterize the breakdown of silicone fluid in the environment are under way.

In order to collect and identify the pertinent information on the use of silicone fluids in transformers, a comprehensive literature search was undertaken. The compilation of this information was necessary to try to identify as many considerations as possible which should be investigated.

In order to evaluate the effects of retrofilling a drained and flushed PCB containing railway transformers with silicone fluid, the following project was undertaken. A Westinghouse railway transformer containing PCB liquid was obtained and shipped to a Westinghouse Apparatus Repair Plant. The unit was tested for electrical performance (Section V), drained, flushed with solvent, dried, flushed with silicone fluid, and then refilled with silicone fluid (Section IV). The retrofilled unit was then retested electrically (Section V). The results of the two sets of electrical tests were compared to determine if any changes in electrical performances could be detected due to the silicone fluid retrofill. There were no significant differences electrically between the two liquids, with the exception of the meggar readings. This difference, which represented an improvement in the insulation, was attributed to the insulation and the core being dried during the retrofilling process.

3. LITERATURE SEARCH AND DATA COMPILATION - TASK I

The first task undertaken as part of this project was to collect and organize as much data as available on the silicone liquid to be evaluated. The information can be roughly divided into two categories. The first set of data deals almost entirely with the physical and chemical charactistics of 50 centistoke polydimethylsiloxane. Data of this type, boiling point, flash and fire point, insulating characteristics, thermal conductivity and thermal expansion are necessary to provide criteria for the evaluation of the silicone fluid. Table 2-1 shows the comparison of silicone fluid with oil and PCB. Also covered in this category of information would be data on possible chemical interactions between silicones and transformer materials.

The second major category would be that of the performance of silicone fluid as a dielectric medium in transformers. The types of information collected dealt with areas such as: the effects that various levels of water contamination have on silicone performance; the changes in electrical performance with temperature; the ability of silicone to penetrate and replace PCB's in transformer insulation; and other published information on the use of silicones in transformers.

All the information collected is listed under the Bibliography section of the report on page 44.

It is apparent, however, from all the data available, that although silicones are now in use in some types of transformers, many unanswered questions and conflicting opinions exist concerning the use of this material for retrofilling. One of the major questions which was identified by the literature research was the consideration of the effects that residual PCB's would have on the silicone fluid performance. Also identified as possible factors influencing retrofilling were the possibilities of pressure increases and temperature rises in retrofilled units. The effect that residual PCB's would have in the solid insulation was also an unknown factor in retrofilled units.

TABLE 3-1. COMPARISON OF SILICONE FLUID WITH OIL AND PCB

OIL 55822AG	TEST	ASTM	DIMETHYL SILICONE	PCB 54201 CM
30 Min.	Dielectric Strength, KV	D877	37	30 Min.
0.05	Power Factor, % 60 HZ, 25°C	D924	-.01	1.0 Max.
40 Min.	Interfacial Tension, Dynes/CM	D971	20.8	40+
0.03	Neutralization No. MG KOH/GR	D974	.002	0.014 Max.
0.05 Max	Color	D1500	0.0	0.0
62 Max.	Saybolt Viscosity Sec. - 100°F	D88	185.2	62 Max.
0.898 Max.	Specific Gravity	D1298	0.960	1.381-1.392
-50 Max.	Pour Point, °F	D97	-67	+7 Max.
35 Max.	Moisture, PPM	D1533	50	35 Max.
293 Min.	Flash Point, °F	D92	600	390
315	Fire Point, °F	D92	650	NTB
.488	Specific Heat, Gal/gr. °C		.360	
.000725	Coefficient of Expansion cc/cc °C		.00104	
2.2	Dielectric Constant		2.5	
7.5	Weight Per Gallon, pounds		8.0	

4. SOLVENT CLEANING AND SILICONE FILLING OF UNIT - TASK II

After the initial electrical tests were made on the PCB-filled unit as received to establish the reference values for later comparison, the head space in the unit was determined. This was accomplished by adding mineral spirits until the unit was completely filled and then draining the unit as much as possible. It was found that a completely drained unit yielded a total of 147 gallons of liquid and that the unit as received required 13 gallons additional mineral spirits to fill the head space. Therefore it was determined that the unit contained 134 gallons of PCB's which could be removed by draining. The draining unit was then set on end as shown in Figure 4-1. 55 gallons of mineral spirits were introduced and then circulated through the unit for one hour using an external pump. Mineral spirits were chosen as the solvent for the cleaning because it is very economical and effective. Table 4-1 lists the identification number of the solvent along with its properties. Mineral spirits would not affect the insulation or the materials in the transformer. The cost of this material is relatively low when compared to other solvents and also low enough in viscosity to penetrate the insulation to speed up PCB removal. Finally, it has less toxicity than most other PCB solvents commonly used. It was intended that a solvent such as mineral spirits could be reclaimed after use as a cleaning agent by a simple distillation. The small amount of PCB residuals after distillation could then be disposed of by incinceration.

After the initial flush solution was drained out of this unit, an additional 40 gallons of mineral spirits were circulated for another hour using an external pump, and then drained again.

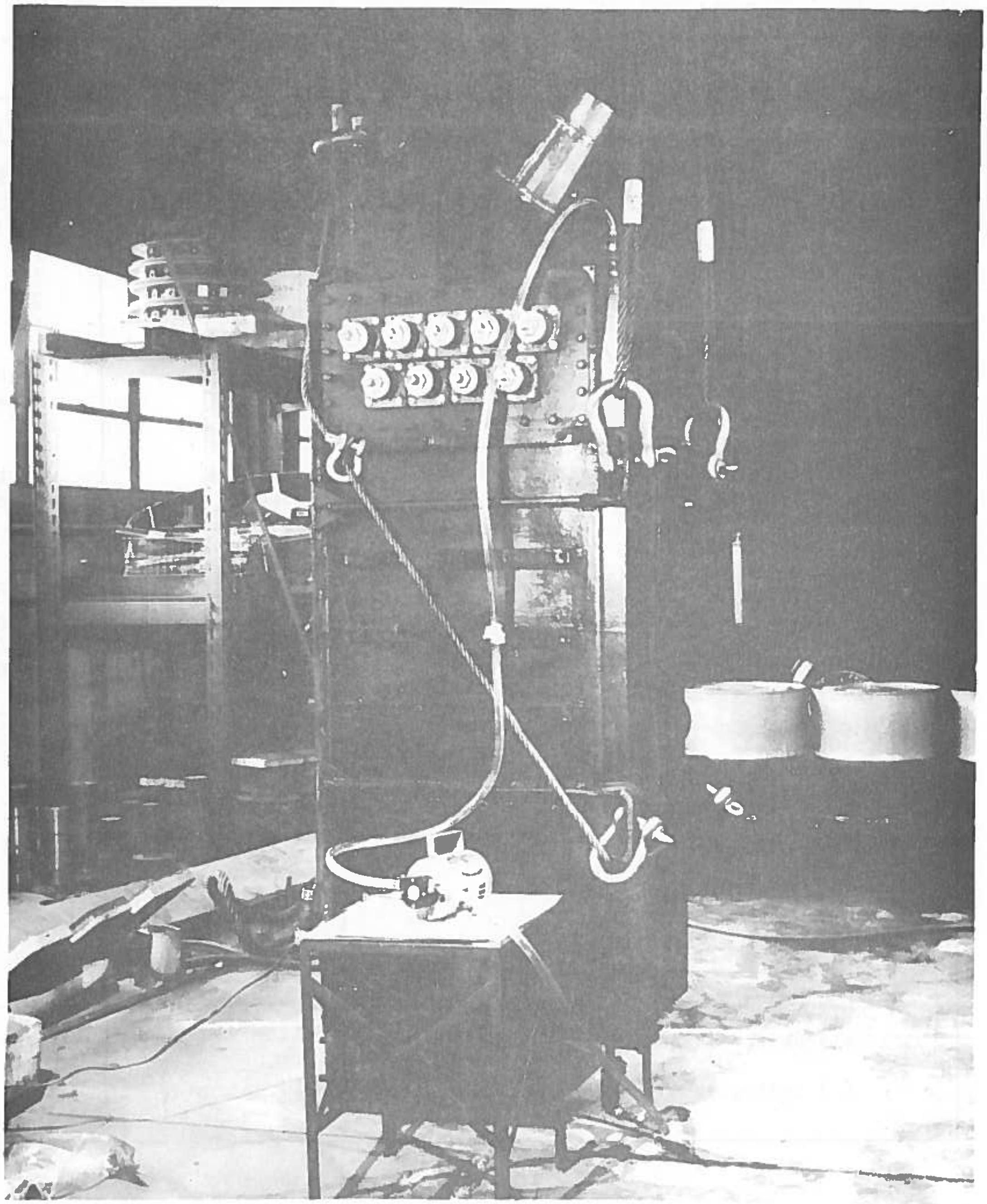


FIGURE 4-1. TRANSFORMER POSITIONED ON END DURING FLUSHING OPERATIONS

TABLE 4-1. PROPERTIES OF THE MINERAL SPIRITS USED IN FLUSHING PROCESS (#55812FA)

	SPECIFICATION	TYPICAL
Gravity	47-51	49.2
Specific Gravity @ 60°F	.7927-.7753	.7831
Pounds per Gallon	6.60-6.455	6.519
Color (D-156)	30 min.	+30
Flash (D-56) °F	100 min.	105
Kauri - Butanol Value (D-1133)	33 min.	35
Aniline Point (D-1012) °F	150 max.	142
Refractive Index (D-1218)		
Odor	Mild	Mild
Residual Odor	None	None
Bromine Number (D-1159)		.8
Sulfuric Acid Absorption (D-484)		1
Acidity of Distillation Residue (D1093)	Neutral	Neutral
Sulfur H_2S/Doctor (D484)	Sweet	Sweet
Corrosion (D-130)	1B	1A
During Distillation	2B	1A
Composition Volume %		
Paraffins		32.5
Olefins		.6
Naphthenes		59.9
Aromatics	7.5 max.	7.0
Distillations (D-86) °F		
IBP	310-320	315
10%	320-335	325
20%		330
30%		334
40%		338
50%	335-350	342
60%		346
70%		350
80%		355
90%	360-375	365
Dry Point		385
End Point	380-401	390
Viscosity Saybolt - 100°F		30
Viscosity - Kinematic - 104°F		1.03

( ) Indicates ASTM Test Procedure.

The unit was then completely filled with 147 gallons of mineral spirits, which were circulated for 14 hours using an external pump. In Figure 4-2, the unit was then placed in the normal operating position with an additional two hours of solvent circulation, using the transformer pump. The unit was raised slightly on one end for draining. Dry air was then blown through the unit for three hours followed by sixteen hours of vacuum drying. After the vacuum drying, it was still possible to detect a slight odor of the mineral spirits. Therefore, the unit was again reblown with dry air for one hour and vacuum-dried for an additional two hours. After this treatment no odor of mineral spirits could be detected.

Each of the solvent flush solutions were tested to determine the amount of PCB content and thus the efficiency of each individual flushing step. This data is summarized in Table 4-2. The analyses were performed using a gas chromatographic technique, which requires an electron capture detector and an XE-60, six foot silicone gum column.

TABLE 4-2. GALLONS OF PCB'S REMOVED DURING CLEANING AND FLUSHING OPERATIONS

CLEANING STEP	% PPM 1242	% PPM 1260	% PCB RESIDUAL	GALLONS PCB REMOVED
1. Draining of Unit	-	-	-	134.0
2. 55 Gallon Solvent Flush	2.80	2.50	5.30	2.91
3. 40 Gallon Solvent Flush	0.85	0.77	1.62	0.62
4. 147 Gallon Flush (14 Hour Circulation)	6.68	5.61	12.3	14.48
			Total	152.0

This data shows that the mineral spirits did indeed remove much of the PCB's from the unit. The most efficient method of flushing would appear to be that of completely filling the unit and circulating the solvent for extended periods of time.

The data in Table 4-2 also indicate that the PCB's in the unit were a mixture of the heavier aroclor 1260 and the lighter aroclor 1242. The significance of this data is that the 1242 does not require tri- and tetrachlorabenzene for use in transformers. Thus, the quantity of PCB's in this unit would probably be greater than in a unit filled with straight 1260 which has considerable tri- and tetra-chlorobenzene present.

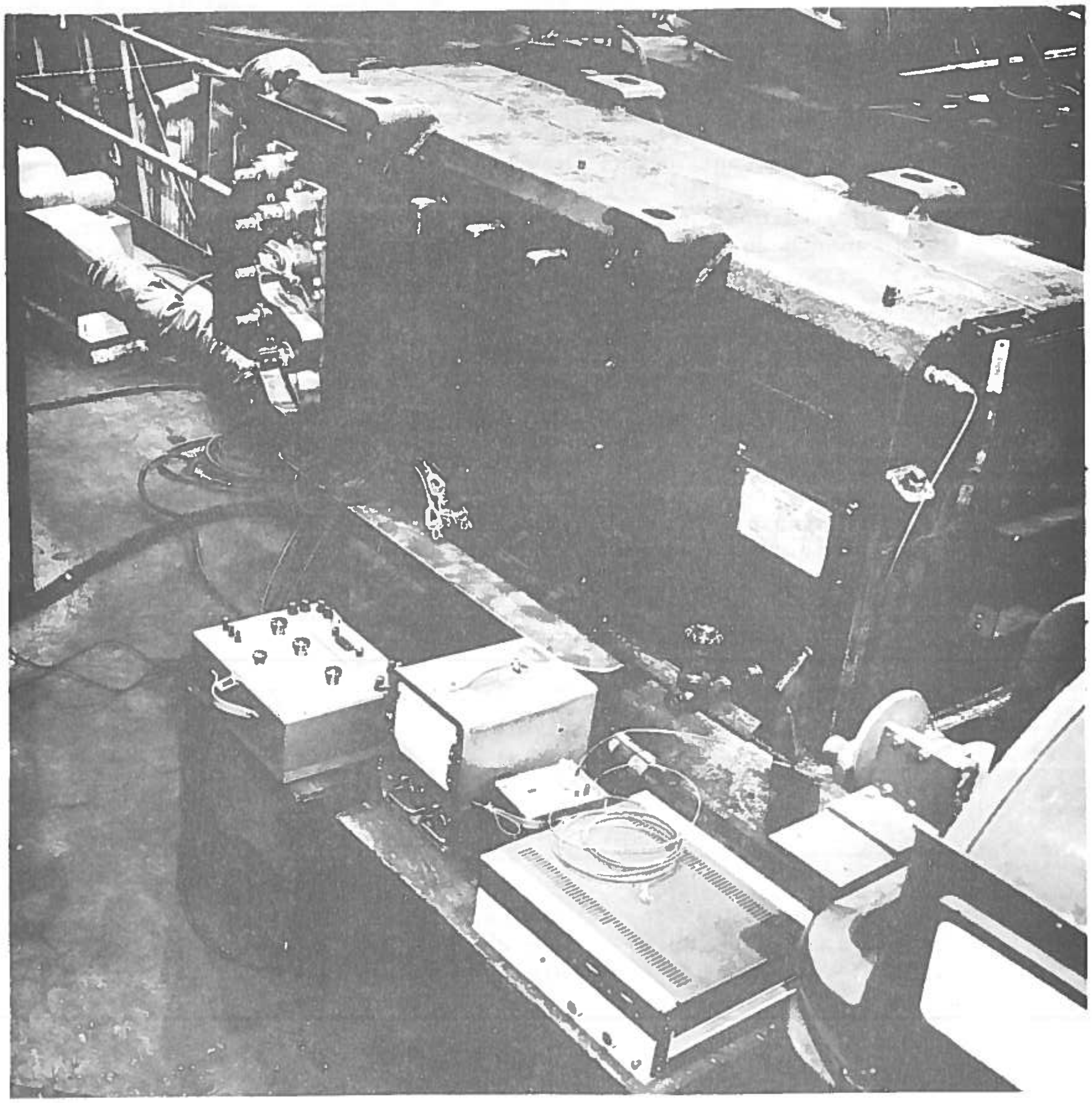


FIGURE 4-2. EQUIPMENT USED IN PERFORMING ELECTRICAL TESTING OF TRANSFORMER

The original data for this unit indicated that it was originally filled with 168 gallons of PCB liquid. Using this value and the data from the last column in Table 4-2, it can be estimated that a minimum of 87% of the PCB's were removed by these operations. This value would increase if considerable chlorobenzenes were present in the transformer or if there were less than 168 gallons of material in the unit when it was received at our repair plant. Because the quantity of PCB absorbed into the insulation, core, and coils is an unknown factor, the determination of a more accurate figure is not possible.

Fifty-five gallons of silicone fluid were introduced into the dried unit with the external pump circulating the fluid for three (3) hours. A sample of the liquid was taken. The transformer was drained; and by using a slight pressure of dry air, all possible liquid was drained from the bottom of the unit. Vacuum was again applied to the transformer for one (1) hour. The transformer was now filled under vacuum with 137 gallons of silicone fluid to bring the fluid level to approximately the minimum level on the sight gauge. The fluid was circulated overnight, using the transformer pump, for approximately fourteen (14) hours. A sample of fluid was taken and tested for the amount of PCB residual in the fluid. Three additional gallons were required to bring the fluid level to the 25°C mark on the sight gauge (normal operating fluid level), three weeks after the original filling. The additional fluid was added before the electrical tests were done on the retrofilled transformer. This additional fluid was due to the fact that the unit was stored outside after the original filling, causing some thermal contraction of the fluid to take place. Table 4-3 shows the amount of PCB's that was removed by the initial silicone rinse and also the % PCB residual in the silicone fluid after the final fill.

TABLE 4-3. POUNDS OF PCB REMOVED WITH INITIAL SILICONE RINSE AND % PCB RESIDUAL AFTER FINAL FILL

STEPS-INITIAL AND FINAL FILL WITH SILICONE	% 1242	% 1260	% PCB RESIDUAL IN SILICONE	POUNDS PCB REMOVED	POUNDS PCB RESIDUAL
55 Gallon silicone flush - 3 hour circulation (2-16-77)	0.26	0.30	0.56	2.5	
137 Gallon silcone final fill - 14 hour circulation (2-17-77)	0.26	0.38	0.64		7.0
140 Gallon silicone final fill - 2 hour circulation (3-4-77)	1.62	1.85	3.47		38.86

	TABLE 4-3. (Cont.)				
Silicone sample taken before and after 3-hour temp run (3-30-77)	1.61	1.79	3.40		38.08
Silicone sample taken after pump circulated overnight and unit idle for 3-months (7-7-77)	1.90	2.47	4.37		48.94
Total PCB's in unit were found to be 1023.1 + 51.44 lb. = 1074.54 PCB (Approximately 162.8 gallons)					

In the first silicone rinse, test analyses showed 0.56% residual PCB content which is equivalent to 2.5 pounds PCB removed by the initial silicone rinse. The low level of residual PCB indicates that the flushing procedure removed most of the unbound PCB's. The liquid sample taken from the 137 gallon fill showed 0.64% PCB residual which is equivalent to 7.0 pounds of PCB present in the silicone fluid. After approximately a 3-week period has elapsed, the anaylses showed that the % PCB residual rose from 0.64% to 3.47%, which is an increase to 38.86 pounds residual PCB's. After a final temp run was made, another sample was taken three weeks later. Analyses showed 3.40% PCB residual which is equivalent to 38.08 pounds PCB. This result confirmed the previous result of 3.47% residual PCB in the transformer and established the fact that apparently equilibrium was attained. A later sample taken in July, after four months of setting, showed a slight increase to 4.37% PCB's probably due to the new equilibrium level attributed to the hotter summer temperatures.

Analyses were made to determine the % residuals of mineral spirits and trichlorobenzene (TCB) in the silicone fluid after retrofilling. The samples were analyzed by gas chromatograph using a Hewlett-Packard 5750 gas chromatograph with a thermal conductivity detector and a 1/8"-10% Apiezon L, 80/100 mesh column - 6 feet in length. Table 4-4 gives the various concentrations of residuals in the silcone.

TABLE 4-4. CONCENTRATION OF RESIDUALS IN SILICONE

SAMPLE IDENTIFICATION	MINERAL SPIRITS	TRICHLOROBENZENE
I. Silicone sample taken after transformer pump circulated for 14 hours overnight (2-17-77)	2%	0.635%
II. Silicone sample taken before and after 3-hour temp run	3.12%	3.14%

Table 4-5 gives some data on the fire characteristics of the silicone fill solutions which resulted from the flushing procedure used.

TABLE 4-5. FLASH AND FIRE POINTS OF SILICONE FLUID AFTER RETROFILLING		
SAMPLE IDENTIFICATION	FLASH POINT	FIRE POINT
I. Silicone sample after transformer pump circulated for 14 hours (2-17-77)	Initial flash 235°C ceases flashing @ 575°F reflash @ 590°F	None to ignition by wicking of gelling material @ 625°F
II. Silicone sample taken after three (3) hour temp run (3-30-77)	Initial flash 195°F flashes to boiling point @ 635°F	640°F

The data from Tables 4-4 and 4-5 indicate that there were tri and tetrachlorobenzenes as part of the original solution in the transformer. As these materials are not considered in the same toxicity class as PCB's, the residual percentages were not deemed excessive.

Also, the fire characteristics of the silicone fluid as a function of the residual mineral spirits indicates that a more effective means of removing the residual solvent before introduction of the silicone fluid should be developed. Possibilities would be increasing the time of vacuum drying and also heating the unit while under vacuum. It may be possible to use other lower molecular weight solvents other than mineral spirits, making it easier to remove the solvent by vacuum following the flushing operations, and also making the solvent less expensive to recover.

Our experiences during these studies showed that a hydrocarbon flush was effective in removing the "free" or unbound PCB's from the unit if carried out in a solvent-filled unit for 12-24 hours. The remaining PCB's which are bound in the insulation and core require much longer periods to be displaced, and no information is available as to how long it would take for complete removal of all residual PCB's.

Table 4-6 lists a recommended procedure to follow when flushing and retrofilling a PCB unit with mineral spirits and silicone fluid.

TABLE 4-6. RECOMMENDED FLUSHING PROCEDURE

1. Set the unit on the end with the drain valve at the bottom and the top valve at the upper end. Introduce 55 gallons of mineral spirits into the transformer. Figure 4-1 shows the transformer up on end. (Refer to Page 9.)

2. Using an external pump and heavy wall tygon tubing, circulate the solvent through the transformer for one (1) hour.

3. Drain the solvent and take a liquid sample of the first rinse.

4. With the unit in the vertical position, fill the transformer completely with mineral spirits.

5. Circulate the liquid for a minimum of sixteen (16) hours using an external pump.

6. Drain liquid from transformer until level is below the top valve and purge dry air (minimal pressure) through the transformer while solvent rinse is being drained from the unit. Take a sample of the second solvent rinse.

7. Lower the transformer to its normal horizontal position and fill completely with mineral spirits. Circulate the liquid for twenty-four (24) hours using the transformer circulating pump.

8. Drain liquid from the transformer until level is below the top valve and purge dry air through the transformer while final solvent rinse is being drained from the unit. Take a liquid sample of the final solvent rinse. Lift the transformer up on one end to drain all possible liquid from the unit.

9. Purge dry air through the transformer for additional six (6) hours.

10. Pull vacuum of at least 27" of mercury for a minimum of sixteen (16) hours and record the vacuum reading. Heat if possible.

11. Crack bottom valve of transformer to detect the presence of mineral spirit vapors. If an odor still exists, repeat step 10 above until no mineral spirits are detected.

12. Introduce fifty-five (55) gallons of silicone fluid into the transformer and circulate for four (4) hours using an external pump.

13. Raise the transformer up on one end during the draining process so that all possible liquid is drained from the bottom of the transformer. Take a sample of the liquid during the draining.

14. Fill the transformer to the required level; i.e. - 25°C level on sight gauge.

15. Circulate the liquid for sixteen (16) hours and take a sample.

16. Analyze for % residual of PCB in the rinse samples and the final silicone liquid samples.

5. ELECTRICAL TESTS ON THE TRANSFORMER BEFORE AND AFTER RETROFILL - TASK III

Table 5-1 lists the name plate data for the transformer tested. Figure 5-1 is a winding diagram for this unit and Table 5-2 lists the voltage reading for the various terminals on the transformer.

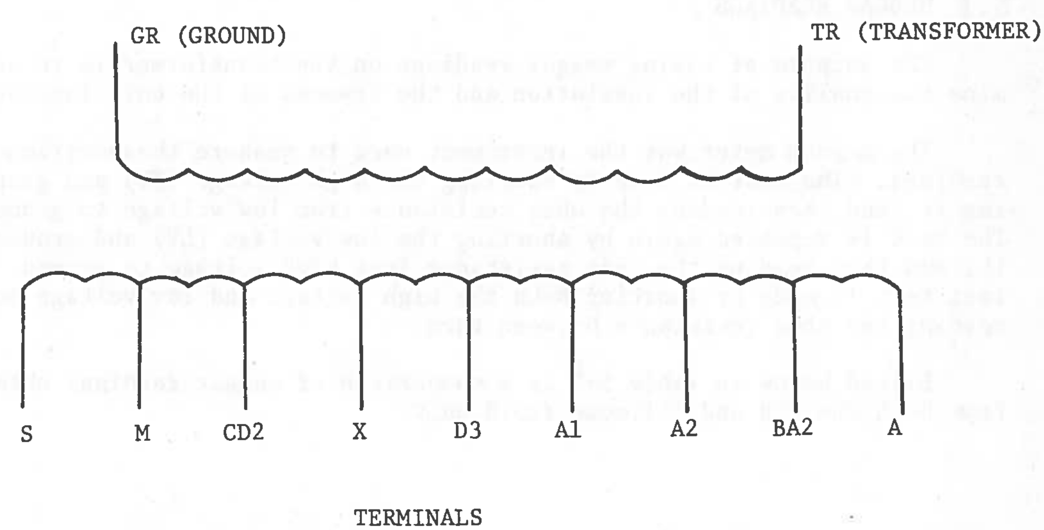
The following tests were carried out to evaluate the electrical performance of the transformer before and after retrofilling.

TABLE 5-1. UNIT CHARACTERIZATION

A description and rating of Westinghouse Manufactured Railway Transformer C-955 is given below:

1.	Serial Number	3164786
2.	L Spec. Number	338205
3.	KVA	418
4.	Hertz	25
5.	Rise	60°C
6.	Cooling Air	1400 cubic ft./minute @ 2 ounces pressure

FIGURE 5-1. WINDING DIAGRAM OF RAILWAY TRANSFORMER C-955



The voltage and ampere readings available with the various connections on the transformer are given in Table 5-2.

TABLE 5-2. VOLTAGE AND AMPERE READINGS OF HIGH AND LOW VOLTAGE WINDING			
CONNECTIONS			
WINDING	VOLTS	AMPERES	LEADS ON
HIGH VOLTAGE	1100	38	TR and GR
LOW VOLTAGE	1002	350	S and A3
	915	350	S and BA2
	830	350	S and A2
	657	600	S and A1
	549	600	S and D3
	420	600	S and X
	334	600	S and CD2
	75.5	600	S and M

5.1 MEGGAR READINGS

The purpose of taking meggar readings on the transformer is to determine the quality of the insulation and the dryness of the unit insulation.

The megohm meter was the instrument used to measure these various readings. The test is made by shorting the high voltage (HV) and grounding it, and then reading the ohms resistance from low voltage to ground. The test is repeated again by shorting the low voltage (LV) and grounding it, and then reading the ohms resistance from high voltage to ground. The last test is made by shorting both the high voltage and low voltage and reading the ohms resistance between them.

Listed below in Table 5-3 is a comparison of meggar readings obtained from both the PCB and silicone fluid unit.

TABLE 5-3. COMPARISON OF MEGGAR READINGS OF PCB AND SILICONE-FILLED UNITS		
TERMINAL CONNECTIONS	PCB FILLED UNIT	SILICONE RETROFILLED UNIT
HV to LV & GR	300 Megohms	2000 Megohms
LV to HV & GR	125 Megohms	2000 Megohms
HV to LV (Floating GR)	300 Megohms	2000 Megohms

Although the insulation in the PCB medium was satisfactory, the resistance readings with the silicone fluid were much higher than with the PCB liquid, which is attributed to the insulation and core being dried further and thus improved by the retrofilling process.

5.2 RATIO TESTS

The purpose of the ratio tests is to determine the voltage and ampere readings on the high and low voltage windings and to see if they correspond to the readings given on the nameplate, which are shown in Table 5-2. Two methods were used for performing the ratio tests depending on the various equipment and electrical supply available. First, using the switchboard at Glassport, where the various testing was performed, 1100 volts were applied to the high voltage terminal (TR & GR) and the low voltage readings shown in Table 5-4 were obtained. Because the voltage applied was approximately one-tenth of the normal high voltage, the measured low voltage should be approximately one-tenth of the rated (actual) voltage. The following readings were obtained for the PCB liquid and silicone fluid.

TABLE 5-4. RATIO TEST COMPARISON OF PCB AND SILICONE-FILLED UNITS				
INTERCONNECTED LV TERMINAL	ACTUAL VOLTAGE THAT SHOULD HAVE BEEN OBTAINED	CALCULATED VOLTAGE	MEASURED VOLTAGE	
			PCB	SILICONE FLUID
S-A_3	1002.0	100.3	100.0	100.0
S-BA_2	915.0	91.6	91.2	91.5
S-A_2	830.0	83.0	82.8	83.0
S-A_1	657.0	65.8	65.7	65.7
S-D_3	549.0	55.0	54.8	54.9
S-X	420.0	42.1	42.0	42.0
S-CD_2	334.0	33.4	33.4	33.4
S-M	75.5	7.5	7.5	7.6

The second method utilized was a transformer turns ratio tester (TTR) which reads the ratio of the two voltages. The following data (listed in Table 5-5) was obtained for the PCB liquid and silicone fluid.

TABLE 5-5. COMPARISON OF CALCULATED AND ACTUAL TTR READINGS OF PCB AND SILICONE-FILLED UNITS

LV TERMINAL	CALCULATED TTR	PCB	SILICONE FLUID
S-A_3	10.96	10.948	10.945
S-BA_2	12.00	11.978	11.975
S-A_2	13.24	13.223	13.220
S-A_1	16.72	16.692	16.668
S-D_3	20.00	19.969	19.996
S-X	26.15	26.113	26.109
S-CD_2	32.90	32.883	32.819
S-M	145.70	Exceeded TTR Ratio	Exceeded TTR Ratio

The data shows no difference from the TTR readings on the various low-voltage terminals between the PCB-filled unit and the silicone-filled unit. It can be concluded that the voltages measured with both liquids corresponded to those indicated in Table 5-2 and that no shorted turns existed in the transformer.

5.3 RESISTANCE TESTS

The purpose of this test is to measure the resistance of the winding to determine if the conductor size is correct and also if any shorted turns existed. These measurements are made with a Kelvin Bridge.

The Kelvin Bridge was connected across the high and low terminals of the transformer and the resistance of the winding was measured. The winding temperature was also the fluid temperature. Because the electrical resistance of copper is a function of its temperature, it is expressed by the resistivity constant. The resistance readings were corrected to 75°C to compare with C5712 ANSI Standards for transformers. The following resistance measurements (listed in Table 5-6) were taken on both the PCB liquid and silicone fluid.

TABLE 5-6. RESISTANCE TEST COMPARISON OF PCB AND SILICONE-FILLED UNITS						
	PCB			SILCONE FLUID		
TERMINAL	°C	OHMS READ	OHMS CORRECTED TO 75°C	°C	OHMS READ	OHMS CORRECTED To 75°C
TR-GR	18°	4.02000	4.9200	21°	4.0300	4.8830
S-A_3	18°	.02824	.03460	21°	.02868	.03475
S-A_1	18°	.01346	.01650	21°	.01367	.01656
S-X	18°	.009035	.01108	21°	.009190	.01140

The resistance test indicated that the conductor size was correct and also confirmed that no shorted turns existed in the transformer.

5.4 IRON LOSS TEST

The purpose of this test is to determine if the proper amount of iron is present in the transformer. A higher iron loss value above the calculated value would indicate that some shorted turns were possible in the transformer.

The equipment used to perform these tests consisted of a potential transformer, current transformer, Yew Digital AC Power Meter and a test set (60 hertz). Figure 5-2 shows the test set-up, and the results are listed in Table 5-7.

The data shows that the unit had the proper amount of iron present, and the iron loss value indicated that no shorted turns existed while unit was energized.

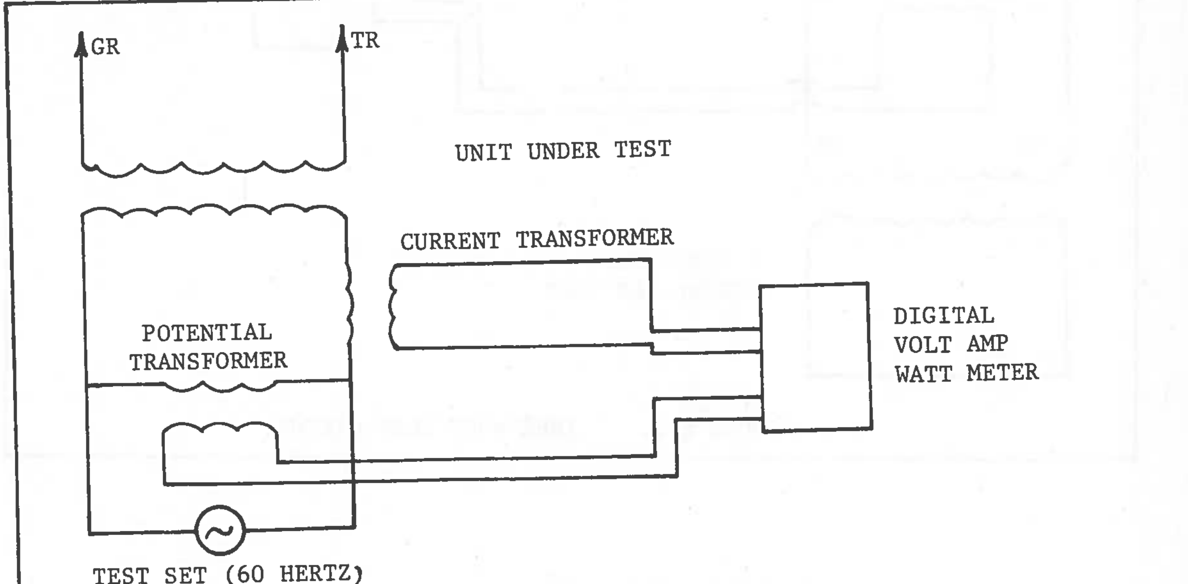


FIGURE 5-2. IRON LOSS TEST CIRCUIT

TABLE 5-7. IRON LOSS OF PCB AND SILICONE FLUID						
PCB RESULTS:						
	METER READINGS			ACTUAL READINGS		
TERMINAL	AMPS	WATTS	VOLTS	AMPS	WATTS	VOLTS
$S-A_3$	.5428	19.2	50.2	1.0856	768	1004
$S-A_3$	1.7930	46.7	82.5	3.586	1868	1650
SILICONE RESULTS:						
$S-A_3$	.5686	18.9	50.2	1.1372	756	1004
$S-A_3$	1.8600	46.0	82.5	3.7200	1840	1650

5.5 IMPEDANCE AND LOAD LOSS TESTS

The purpose of impedance and load loss tests is to determine the % impedance and load loss of the unit.

The equipment used to make these various tests was a potential transformer, current transformer, YEW Digital AC Power Meter and test set (60 hertz). Figure 5-3 gives a diagram of the test circuit.

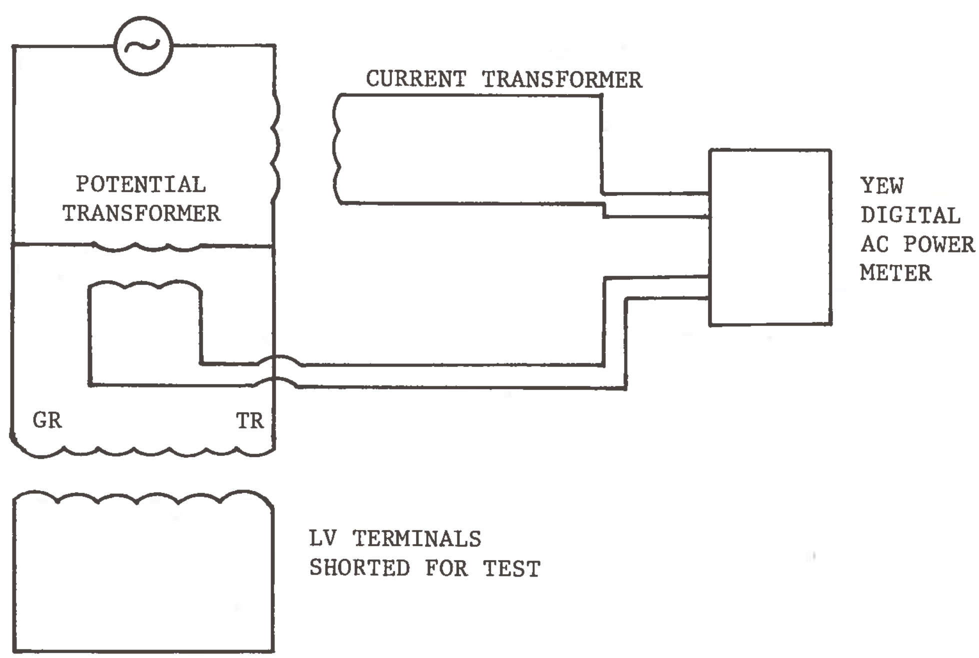


FIGURE 5-3. IMPEDANCE TEST CIRCUIT

The low voltage terminals of the unit were shorted and voltage applied to HV terminals GR-TR. The voltage was raised until rated current was reached in the HV winding. The YEW Digital AC Power Meter was used to measure the volts, amps, and watts with the various terminals shorted. A current transformer with a 50/5 ratio and potential transformer with a 20/1 ratio were also used. The tests were run at 60 hertz. A comparison was made on both PCB liquid and silicone fluid. The results are listed in Tables 5-8 through 5-11.

TABLE 5-8. METER READINGS WITH PCB FOR IMPEDANCE AND LOAD LOSS CALCULATIONS

TERMINAL SHORTED	VOLTS	AMPS	WATTS	°C
S-A$_3$	54.8	3.18	42.4	18.5
S-A$_1$	63.7	3.55	56.4	18.5
S-X$_1$	34.2	2.29	30.1	18.5

TABLE 5-9. CALCULATED TEST RESULTS WITH PCB

TERMINAL SHORTED	VOLTS	AMPS	% IZ @ 75°C	Watts 18.5°C	Watts 75°C	I^2R 75°C
S-A$_3$	1096	31.8	9.96	8,480	10,000	9,239
S-A$_1$	1274	35.5	11.58	11,280	13,231	12,078
S-X$_1$	684	22.9	6.20	6,020	7,102	6,568

TABLE 5-10. METER READINGS WITH SILICONE FOR IMPEDANCE CALCULATIONS

TERMINAL SHORTED	VOLTS	AMPS	WATTS	°C
S-A$_3$	54.8	3.17	42.5	25°
S-A$_1$	63.8	3.55	57.0	25°
S-X$_1$	34.3	2.29	30.6	25°

TABLE 5-11. CALCULATED TEST RESULTS WITH SILICONE

TERMINAL SHORTED	VOLTS	AMPS	% IZ @ 75°C	Watts 25°C	Watts 75°C	I^2R 75°C
S-A$_3$	1095	31.7	9.96	8,500	9,867	9,220
S-A$_1$	1275	35.5	11.59	11,400	13,193	12,223
S-X$_1$	686	22.9	6.24	6,120	7,084	6,572

The impedance and load measurements on both liquids were in line with the calculated values and with previous test data made after the unit was built.

5.6 CONCLUSIONS OF ELECTRIC TESTS

Meggar, ratio, resistance, iron loss, insulation, impedance and load loss tests were performed on the unit when it was first shipped from the factory 33 years ago. These tests were repeated with the PCB-filled unit when received in our repair shop before the retrofill, with essentially the same results as when shipped, and later with silicone after the retrofill. It can be concluded from the test results that the replacement of the PCB with the silicone fluid had no effect on the integrity of the unit.

One of the items identified in Task I as a potential problem in a retrofilled unit was what would occur at a PCB-silicone interface in the insulation. In an effort to examine this problem, a test cell, which consisted of two disc electrodes 0.3 inches apart, was filled with PCB and silicone fluid so that the interface of the two immiscible liquids was between the electrodes. The dielectric breakdown of the interface was then measured. It was found that the dielectric breakdown was the same for the interfaced liquid as for the PCB liquid. Thus no decrease in dielectric strength results from having a liquid interface in the insulation.

An Engineering Memorandum, No. 1722, was written on FOA Temperature Tests with Polychlorinated Biphenyl (PCB) and Silicone Fluid in a railway transformer. (FOA denotes forced oil to forced air heat exchanger.) This memorandum, written in its entirety, is included at the end of this section.

The purpose of these tests was to compare the heat transfer characteristics of PCB and silicone fluid when used in a railway transformer. These tests were made at the Westinghouse Repair Plant in Glassport, Pa.

Tests were made on both liquids under identical conditions. Figures 1 and 2 of the memorandum show the test setup used on both liquids.

The transformer was excited with 60 hertz and the pump operated with a 25 hertz supply. Following the standard ANSI procedure, three ambient thermometers were thermally lagged to measure the temperature. The fan used was not able to deliver the rated 1400 CFM, but did deliver approximately 667 CFM. Even though the oil temperature rise was considerably higher than if a transformer had been in service, it was not high enough to cause damage. The coil thermocouple temperature was read by a Thermo-Electric Minimite II in test 1 and a Doric DS-350 digital thermocouple indicator in test 2. Both instruments were calibrated before being used.

The tests showed no change in winding-to-fluid-temperature difference and 2.7°C higher fluid rise with the silicone fluid. See Table 2-1, 4-1, 4-2, and 4-3.

The small temperature rise should not cause any increased deterioration of the insulation or any significant pressure increase in the unit.

6. SUMMARY OF ENGINEERING MEMORANDUM ON FOA TEMPERATURE TESTS WITH PCB AND SILICONE FLUID

TRANSFORMER ENGINEERING MEMORANDUM NO. 1722

Title: FOA Temperature Tests - Inerteen vs Silicone Fluid

Purpose: The objective of these tests is to compare the heat transfer characteristics of Inerteen vs Dow Corning #561 Silicone Fluid when used in a force-cooled type FOA Transformer. The work was done on SO #QBS0101.

Summary: FOA temperature rise tests were made on a railway transformer with Inerteen and with Dow Corning #561 Silicone Fluid. The tests showed no change in winding - to - fluid temperature difference, and a 2.7°C higher fluid rise with silicone fluid.

Test Equipment: The transformer used for these tests is a Westinghouse Railway transformer, 418 KVA, 11000/1002 volts, 25 Hz, L-338205, Ser. #3164780 or 3164786 (not legible). A standard Temperature Rise run was made at the Westinghouse Repair Shop at Glassport, Pa., following standard ANSI procedures & supervised by the writer. Figure 6-1 shows the arrangement of equipment and the test transformer. Figure 6-2 shows the electrical connections. Test #1 was made with Inerteen in the transformer on 1/26/77. Test #2 was made on 3/10/77 under identical conditions except the transformer was filled with Silicone Fluid.

The transformer was excited with 60 Hz. The pump was supplied by a 25 Hz M-G set.

Ambient thermometers 1, 2, and 3 were supplied by Sharon; these are thermally lagged to have a thermal time constant of approximately 2-1/4 hours, roughly equivalent to the time constant of the transformer.

The fan used was not able to deliver the rated 1400 CFM; air flow was only approx. 667 CFM. Therefore the oil rise was considerably higher than in service. It was not too high, however, and would not damage the windings. For the purpose of this test, the fan is adequate.

The oil thermocouple was read by a Thermo-Electric Minimite II for test #1. For test #2 it was read by a Doric DS-350 digital thermocouple indicator. This would have no effect on the results because both instruments had been calibrated.

Test Results: The readings taken during Test #1 are shown in Table 6-1. The HV winding resistance was measured at the end of the fluid rise run. HV current was 33.2 amperes. The run was then continued for 1 hour with HV current held at 35.2 amperes (LV = 589 amperes) and the LV winding resistance was measured at the end of that hour.

The readings of winding resistance and the calculations of winding temperatures are shown on Table 6-2. These values of winding-to-oil difference

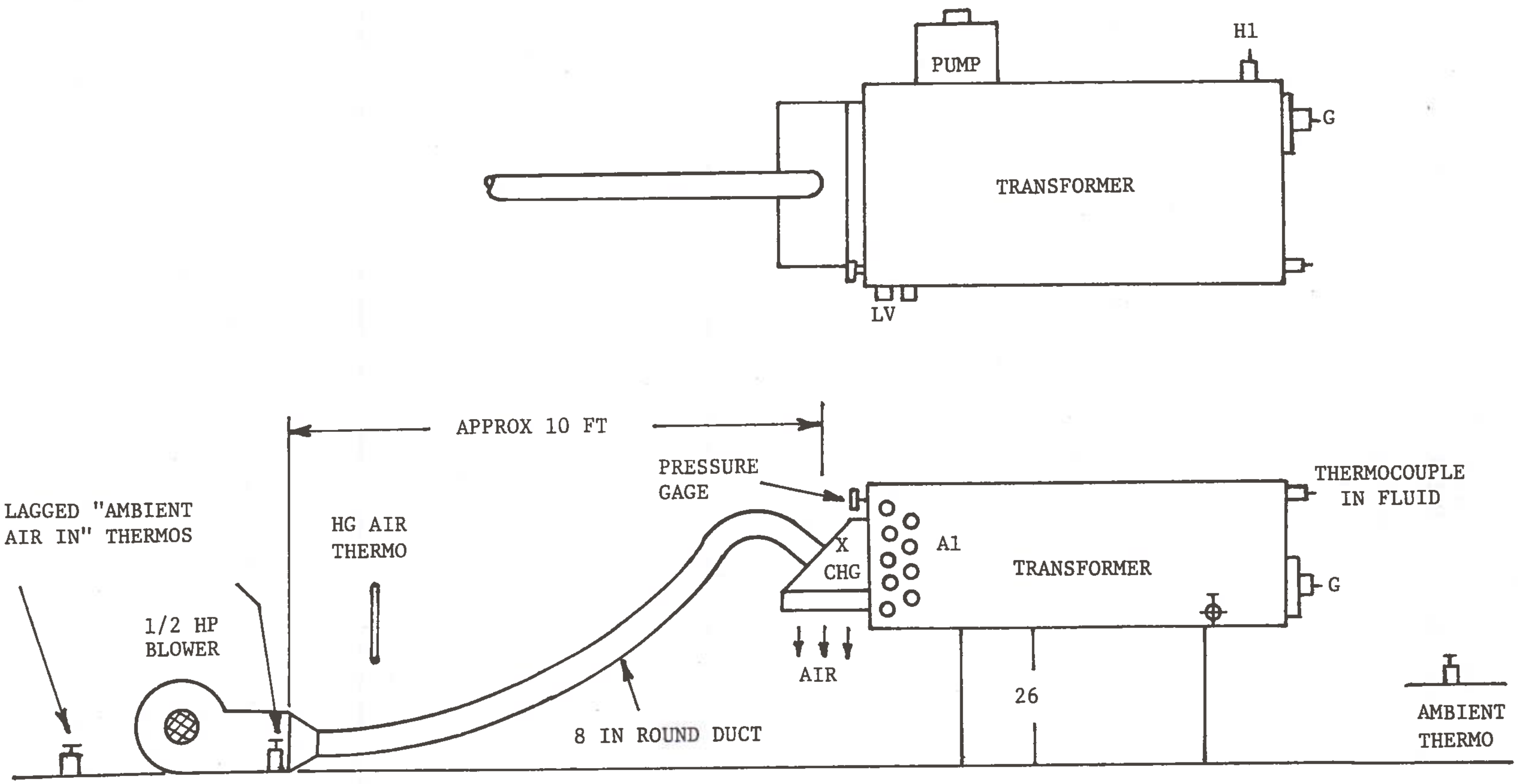


FIGURE 6-1. SKETCH OF TEMPERATURE RISE TEST SETUP QBS 0101

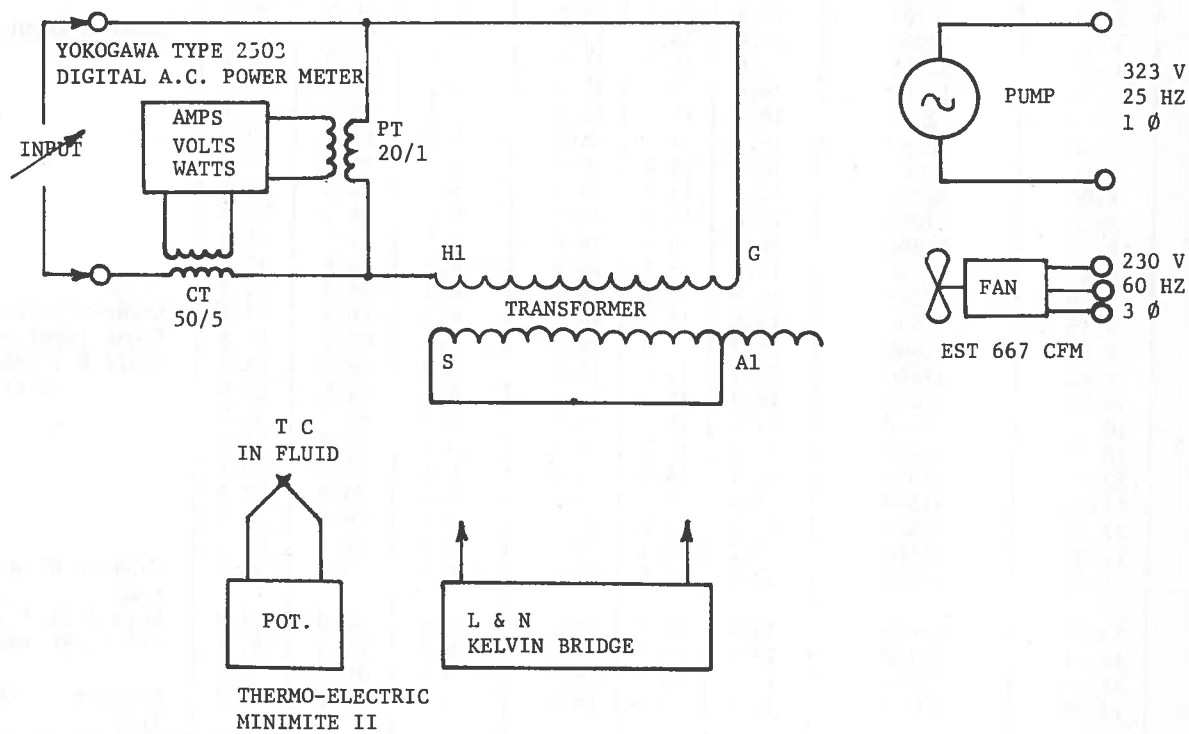


FIGURE 6-2. SCHEMATIC SKETCH OF TEST SETUP TEMPERATURE RISE TESTS ON QBS 0101

Test #1 - Inerteen

TABLE 6-1. TEMPERATURE RISE TEST SUMMARY ON RAILWAY TRANSFORMER C-955

1/26/77 TIME	WATTS MEAS. INPUT	AMBIENT #1	#2	Ave.	PRESS. PSI	OIL T.C.	OIL RISE °C	COMMENTS
5:00 PM	15340	15.2	15.5	15.4	2.5	45.0	29.6	
5:15	15460	15.2	15.5	15.4	3.1	48.5	33.1	
5:30	15460	15.5	15.6	15.6	3.7	52.5	36.9	
5:45	15520	15.5	15.6	15.6	4.2	55.5	39.9	
6:00	13080	15.7	15.7	15.7	4.6	58.5	42.8	Lowered input
6:15	13100	15.8	15.7	15.8	4.8	60.0	44.2	
6:30	12000	15.9	15.7	15.8	5.1	61.5	45.7	Lowered input
6:45	12000	15.9	15.7	15.8	5.2	63.0	47.2	
7:00	12200	16.0	15.7	15.8	5.3	63.5	47.7	
7:15	12200	16.1	15.7	15.9	5.7	65.0	49.1	
7:30	12240	16.1	15.7	15.9	5.8	64.8	49.9	
7:45	12200	16.2	15.8	16.0	5.8	66.0	50.0	
8:00	12200	16.2	15.8	16.0	5.9	66.5	50.5	
8:15	12200	16.2	15.8	16.0	6.0	66.5	50.5	
8:30	12200	16.3	15.8	16.0	6.1	67.5	51.5	
8:45	12280	16.3	15.8	16.0	6.2	68.0	52.0	
9:00	12300	16.5	15.8	16.2	6.3	68.5	52.3	
9:15	11900	16.6	15.8	16.2	6.3	68.5	52.3	Lowered input
9:30	11600	16.7	15.8	16.2	6.4	69.5	53.3	Final input adjust
9:45	11640	16.8	15.8	16.3	6.3	69.0	52.7	(Hold @ 11600 watts)
10:00	11640	16.9	16.3	16.6	6.4	69.5	52.9	
10:15	11660	17.0	16.3	16.6	6.4	69.5	52.9	
10:30	11660	17.0	16.3	16.6	6.4	70.0	53.4	
10:45	11620	17.1	16.6	16.8	6.4	70.0	53.2	
11:00	11540	17.2	16.6	16.9	6.4	70.0	53.1	
11:15	11600	17.2	16.5	16.8	6.3	70.0	53.2	
11:30	11600	17.2	16.7	17.0	6.3	70.0	53.0	
11:45	11620	17.2	16.5	16.8	6.3	70.0	53.2	Measure HV winding temp.
12:00	13040	17.2	16.7	17.0	5.9	68.0	51.0	Hold @ 35.2 amps
12:15	13100	17.2	16.7	17.0	6.0	68.5	51.5	(LV - 589 amps)
12:30	13060	17.1	16.6	16.8	6.0	70.0	53.2	
12:45	13100	17.1	16.6	16.8	6.1	70.5	53.7	Measure LV winding Temp.

Pump input measured after 1 hour run:
324 volts, 1 phase, 25 Hz = 5.3 amps, 1680 watts with Inerteen 2/12/77
324 volts, 1 phase, 25 Hz = 4.5 amps, 1360 watts with Silicone 2/16/77

Test #1

TABLE 6-2. WINDING-TO-OIL DIFFERENCE MEASUREMENT #C-955
L & N KELVIN BRIDGE NO. 4285 #423171

H-G Cold Res. 4.048 Ω @ 234.5 + 22.5°C = 257.0

Time (Min.)	3:10	3:40	4:10	4:40	5:10	5:40	6:10
Res.	4.990	4.880	4.876	4.868	4.864	4.858	4.852
Cold Res.	-4.048	4.048	4.048	4.048	4.048	4.048	4.048
Δ R	.942	.832	.828	.820	.816	.810	.804
Δθ	59.8	52.8	52.6	52.1	51.8	51.4	51.0
Cold θ	+22.5	22.5	22.5	22.5	22.5	22.5	22.5
Hot θ	82.3	75.3	75.1	74.6	74.3	73.9	73.5
Top Oil	-70.0						
Grad.	X	5.3	5.1	4.6	4.3	3.9	3.5

11.0° @ t = 0 @ 33.2 amps $\left(\frac{38}{33.2}\right)^2$ X 11.0° = 14.4° @ 38 amps
Per Fig. 3

vs 15.3° = 43.3
-28
15.3 *

S-X1 Cold res. .01372 Ω @ 22.5°C

Time (Min.)	1:30	2:00	2:30	3:00	3:30	4:00	4:30	5:00
Res.	.01672	1667	1664	1659	1657	1655	1653	1651
Cold Res.	-.01372	1372	1372	1372	1372	1372	1372	1372
Δ R	.00300	295	292	287	285	283	281	279
Δθ	56.2	55.3	54.7	53.8	53.4	53.0	52.6	52.3
Cold θ	+22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5
Hot θ	78.7	77.8	77.2	76.3	75.9	75.5	75.1	74.8
Top Oil	-70.5							
	8.2	7.3	6.7	5.8	5.4	5.0	4.6	4.3

11.0° @ t = 0 @ 35.2 amps $\left(\frac{35.8}{35.2}\right)^2$ x 11.0° = 11.4° @ 35.8 amps
Per Fig. 3

vs 17.2° @ 38 amps*
(= 15.3° @ 35.8 amps)

*Per Test Report 11/20/44 on S.O. 74-RS-924 Ser. #3060808 are plotted against time-after-shutdown on log-log coordinates on Figure 6-3. The straight line drawn through these points and extrapolated to time - 0 defines the steady-state winding rise above fluid at the current measured before shutdown.

Readings taken during Test #2 are shown in Table 6-3. Input was held constant at 11600 watts until fluid rise levelled off. One-hour runs were made with HV current of 33.2 amperes, and with LV current of 589 amperes. Readings of winding resistance and the calculations of winding temperatures are shown on Table 6-4. These points are also plotted on Figure 6-3.

Pump input watts were measured some time after Test #1 was completed. That data ia also shown in Table 6-1.

The input measured when the fluid rise levelled off, in Test #1, was 11600 watts. During Test #2 the input was held constant at 11600 watts in order to get a direct comparison of fluid rise. The readings of input watts in Test #2 are readings at the end of the 15-minute interval between readings. That input was readjusted to 11600 watts after each reading, if it exceeded ±50 watts from nominal. The input was therefore held constant by frequent adjustment.

Discussion: The plan was to load the transformer at full load, HV to S-A1, with 14909 watts input. After Test #1 got underway, however, it became obvious that the fan used for this test could not deliver 1400 CFM through the heat exchanger, and the input was reduced to 11600 watts so that the unit would not be run too high above normal fluid rise. This should be acceptable for the direct-comparison objective of these tests.

The fluid rise above cooling air is the sum of two temperature drops: fluid-to-heat exchanger and heat changer-to-air. The fluid side drop is typically about a third of the total drop, roughly 10° to 15°C at full load.

In these tests the air side efficiency is lower than normal, so the air side drop is high. Since the same air-side conditions were used in both tests, the difference in fluid rise must be in the fluid-to-surface drop. The measured difference in fluid rise was 2.1°C with 11600 watts input. At the maximum loss connection, rated KVA, loss would be 14909 watts. For forced-cooled systems the fluid-to-surface drop is directly proportional to the heat flux. Therefore with 14909 watts, the increase in fluid rise would be $\frac{14909}{11600} \times 2.1° = 2.7°C$

Conclusions:

(1) With 11600 watts input, fluid rise was 53.2°C with Inerteen and 55.3°C with Silicone. At the maximum loss connection, rated KVA, in service, the fluid rise would be approximately 2.7°C higher with Silicone fluid.

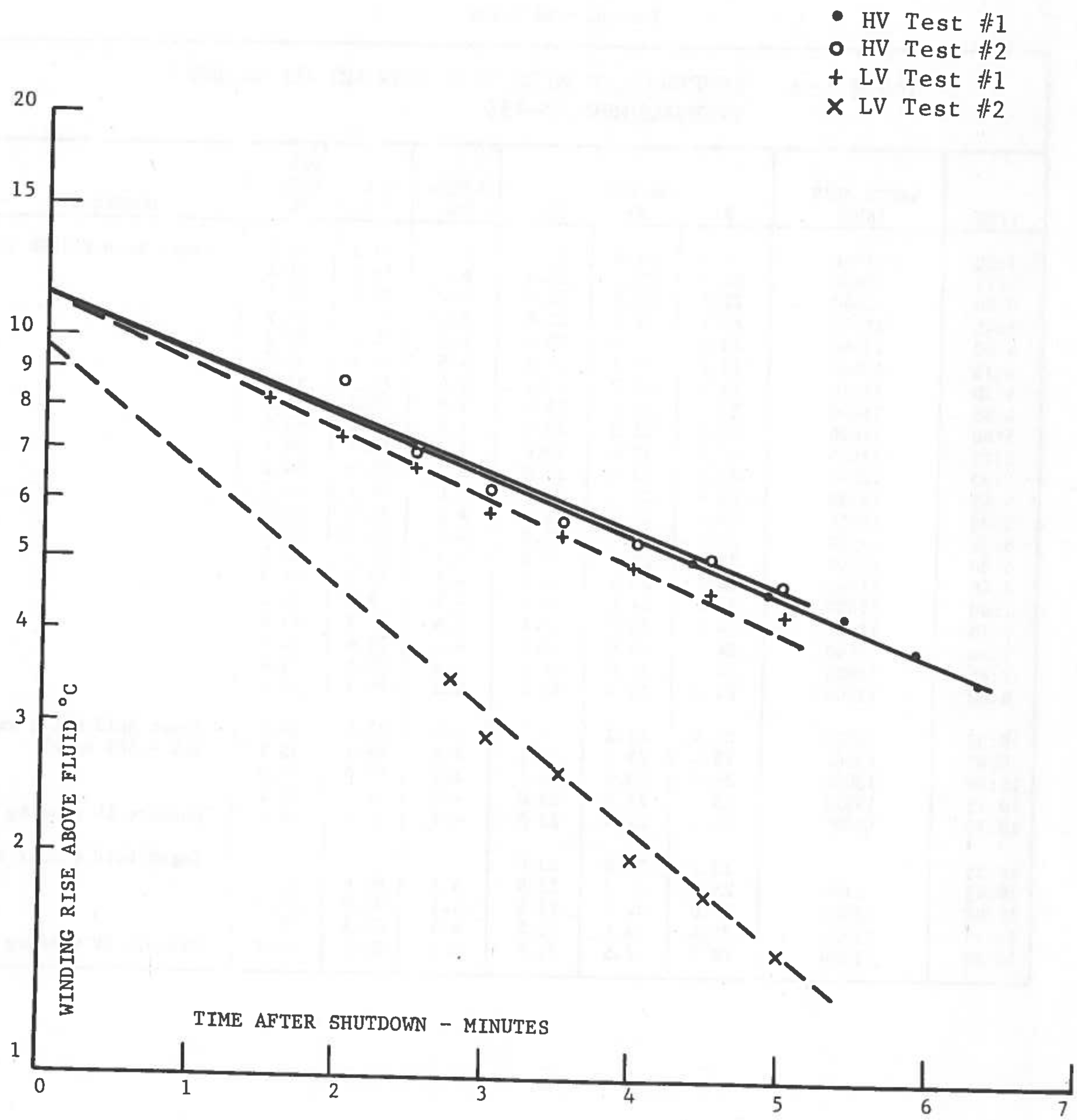


FIGURE 6-3. COOLING CURVES, AVERAGE WINDING RISE ABOVE FLUID VS TIME AFTER SHUTDOWN

Test #2 - Silicone

TABLE 6-3. TEMPERATURE RISE TEST SUMMARY ON RAILWAY TRANSFORMER #C-955

TIME	WATTS MEAS. INPUT	AMBIENT #1	AMBIENT #2	AMBIENT AVE.	PRESS. PSI	OIL T.C.	OIL RISE °C	COMMENTS
3:00	11580	21.8	21.9	21.8	6.4	73.1	51.3	Input held @11600 w.
3:15	11600	22.0	22.1	22.0	6.2	73.4	51.4	
3:30	11640	22.5	22.5	22.5	6.2	73.9	51.4	
3:45	11700	22.7	22.8	22.8	6.0	74.7	51.9	
4:00	11640	23.0	23.0	23.0	6.0	75.2	52.2	
4:15	11660	23.2	23.3	23.2	5.8	75.9	52.7	
4:30	11620	23.4	23.4	23.4	5.6	76.3	52.9	
4:45	11620	23.5	23.5	23.5	5.5	77.0	53.5	
5:00	11620	23.7	23.5	23.6	5.4	77.1	53.5	
5:15	11620	23.7	23.6	23.6	5.3	77.7	54.1	
5:30	11560	23.8	23.7	23.8	5.1	78.0	54.2	
5:45	11580	23.9	23.7	23.8	5.0	78.5	54.7	
6:00	11580	23.9	23.7	23.8	4.9	79.0	55.2	
6:15	11560	23.9	23.7	23.8	4.8	79.1	55.3	
6:30	11500	23.9	23.8	23.8	4.7	79.3	55.5	
6:45	11540	24.1	23.9	24.0	4.6	79.3	55.3	
7:00	11600	24.2	24.0	24.1	4.5	79.3	55.2	
7:15	11600	24.2	24.0	24.1	4.4	79.3	55.2	
7:30	11640	24.2	24.0	24.1	4.4	79.4	55.3	
7:45	11620	24.3	24.0	24.2	4.3	79.6	55.4	
8:00	11700	24.3	24.0	24.2	4.2	79.5	55.3	
9:30	13320	23.4	23.2	23.3	3.5	77.8	54.5	Input held @35.2 amps (LV - 589 amps)
9:45	13660	23.4	23.1	23.2	3.6	79.1	55.9	
10:00	13600	23.2	23.0	23.1	3.8	80.0	57.0	
10:15	13520	23.1	22.9	23.0	4.0	80.9	57.9	
10:25	13600	23.2	22.8	23.0	4.1	81.2	58.2	Measure LV winding temp
10:35		23.2	22.8	23.0				Input held @ 33.2 amps
10:45	12100	23.1	22.7	22.9	4.1	80.6	57.7	
11:00	12020	23.0	22.7	22.8	4.1	80.8	58.0	
11:15	12120	23.0	22.6	22.8	4.1	80.8	58.0	
11:30	12180	22.8	22.5	22.6	4.1	80.8	58.2	Measure HV winding temp

Test #2

TABLE 6-4. WINDING-TO-FLUID DIFFERENCE MEASUREMENT #C-955
L & N KELVIN BRIDGE NO. 4285 #423171

H-G Cold Resistance 4.086 Ω @ 24.7°C (234.5 + 24.7 = 259.2)

Time (mine.)	1:40	2:00	2:30	3:00	3:30	4:00	4:30	5:00
Res. Ω	5.120	5.094	5.080	5.070	5.060	5.056	5.050	5.044
Cold Res.	-4.086	4.086	4.086	4.086	4.086	4.086	4.086	4.086
Δ R	1.034	1.008	.994	.984	.974	.970	.964	.958
Δθ	65.6	63.9	63.1	62.4	61.8	61.5	61.2	60.8
Cold θ	+ 24.7	24.7	24.7	24.7	24.7	24.7	24.7	24.7
Hot θ	90.3	88.6	87.8	87.1	86.5	86.2	85.9	85.5
Top Oil	- 80.8							
Grad.	X	7.8	7.0	6.3	5.7	5.4	5.1	4.7

11.0° @ t = 0 @ 33.2 amps
Per Fig. 3

S-A1 Cold Resistance .01394 Ω @ 24.5° (234.5 + 24.5 = 259.0)

Time (Min.)	2:40	3:00	3:30	4:00	4:30	5:00
Res. Ω	.01718	.01715	.01713	.01710	.01709	.01707
Cold. Res.	-.01394	.01394	.01394	.01394	.01394	.01394
Δ R	.00324	.00321	.00319	.00316	.00315	.00313
Δθ	60.2	59.6	59.3	58.7	58.5	58.2
Cold θ	+24.5	24.5	24.5	24.5	24.5	24.5
Hot θ	84.7	84.1	83.8	83.2	83.0	82.7
Top Oil	-81.2					
Grad.	3.5	2.9	2.6	2.0	1.8	1.5

9.3° @ t = 0 @ 35.2 amps
Per Fig. 3

(2) The reduction in KVA which would lower the fluid rise to the old value for Inerteen can be calculated as follows:

Fluid rise is directly proportional to total loss for force-cooled transformers. If normal fluid rise is 28°C at rated load, Fe = 1420 watts, WM = 13489 watts, the fluid rise with silicone would be 28° + 2.7° = 30.7°C. Total loss must be reduced by 28/30.7 = .912 to 13598 watts.

$$13598 \text{ watts} = 1420 + P^2\ 13489$$

Solving: P = .95 load

This is a reduction of 5% in load, with silicone, for the same fluid rise as with Inerteen.

(3) HV winding-to-fluid difference was the same for both tests. LV winding-to-fluid difference was 1.7°C lower with silicone fluid than with Inerteen. The measurement of winding temperature by resistance is difficult and repeatability within 2°C is good. We can conclude that the winding-to-fluid temperature drop will be the same for both fluids under forced-flow conditions.

(4) The effect of changing fluid would be expected to be the same in the heat exchanger as in the transformer windings. Our tests did not show this; they showed slightly lower efficiency in the heat exchanger.

(5) Pressure readings showed a slight gas leak during the test with Inerteen. They showed a larger gas leak during the test with silicone; in addition, gasket leaks were obvious around the G bushing and at the glass diaphragm seal on the LV end. The flushing with mineral spirits, or the silicone fluid, caused leaks to appear.

7. CONCLUSIONS AND RECOMMENDATIONS

The results of this study indicate that at least for short periods of time a replacement of PCB's by silicone fluid was possible. The testing under this contract was, however, limited to determining the effectiveness of a flush and subsequent refilling with silicone in maintaining the short-term electrical performance of a railway transformer. Although very encouraging, the project did not address itself to the question of long-term effects of the retrofilling process.

Some problems were identified by Tasks II and III. We still lack complete data on the effects of the silicone on the gaskets and seals in the units. During the testing some leaks of the silicone were noted, but the cause of these leaks could not be identified. We lack information on the effect that the silicone will have on pump life, but indications are that pumps different from those now in use may be needed. We have no information on how the silicone fluid will affect the life expectancy of this unit. It can either increase or decrease depending on many factors. Also questions as to flammability of the retrofilled units and also the levels of residual PCB content still exist.

At the conclusion of our studies, many questions remain to be resolved. Therefore, the following recommendations are made for further studies:

I. To determine any structual or material changes which would be necessary for replacing PCB's with silicone fluids in railway transformers.

To accomplish the above objective, it is proposed that the following projects be undertaken:

a - Conduct compatibility studies of gasket and insulation materials.

b - Determine the penetration of silicone fluid into PCB saturated insulation .

c - Evaluate the lubricity of silicone fluid and its effect on existing pumps.

d - Determine solubility of gases in silicone fluid and the effects the gases have on bubble evolution while pumping.

e - Conduct long-term life testing of representative units filled with silicone fluid.

f - Investigate the need for increased cooling to maintain maximum electrical performance.

II. To develop an effective and economical method for cleaning PCB-filled units and to develop means of insuring that residual PCB content remains below the government-stipulated limits .

a - A survey of solvents which can be utilized for flushing units.

b - An investigation of conditions necessary to most effectively remove PCB's from the insulation.

c - Determine conditions most beneficial for silicone impregnation in the insulation materials.

d - Study the rate of PCB leaching from the core and coil into the silicone fluid.

8. GLOSSARY OF TERMS

1. ambient - temperature of air or liquid surroundings.

2. ampere - unit of electrical current or rate of flow of electrons. One volt across 1 ohm of resistance causes a current flow of 1 ampere.

3. aniline point - specific volumes of aniline and sample are placed in a tube and mixed mechanically. The mixture is heated at a controlled rate until the two phases become miscible. The mixture is then cooled at a controlled rate, and the temperature at which the two phases separate is recorded as the aniline point.

4. ANSI Standards - American National Standards Institute.

5. Aroclor - trademark for a series of polychlorinated polyphenyls available as liquids, resins or solids.

6. ASTM - American Society for Testing and Materials.

7. boiling point - the temperature at which the vapor pressure of a liquid is just slightly greater than the total pressures of the surroundings.

8. centistoke - (CS), one one-hundredth of a stoke. Stoke, the kinematic unit of viscosity, is equal to the viscosity in poises divided by the density of the fluid in grams per cubic centimeter, both measured at the same temperature.

9. centrifugal - a force which impels a liquid or parts of a liquid outward from the center of rotation.

10. CFM - cubic feet per minute.

11. chlorination - to treat or cause to combine with chlorine.

12. chlorobenzenes - clear, colorless, flammable liquid with flash point of 85°F, which is derived by passing dry chlorine into benzene with a catalyst present.

13. coefficient of expansion - the ratio of the increase of length, area, or volume of a body for a given rise in temperature, usually from 0 to 1°C to the original length, area or volume respectively. (Dow Corning 561-.00104 cc/cc°C, PCB liquids - .0007 cc/cc/°C)

14. compatible materials - materials which are capable of coexisting in harmony.

15. concentration - the amount of a given substance in a stated unit of mixture or solution.

16. current - movement of electrons through a conductor, measured in amperes. An electric current results from a difference of potential between two points just as current of water results from a difference of level or head.

17. degradation - reduction or state of being reduced in condition and physical strength. Chemically, changing a compound by splitting off one or more groups will eventually degrade the compound.

18. deterioration - condition which grows worse and becomes impaired in quality.

19. dielectric breakdown - an abrupt increase in the flow of electric current through a dielectric material as the applied electric field strength exceeds a critical value.

20. dielectric constant - the ratio of the capacitance of a capacitor with the given dielectric to the capacitance of a capacitor having air for its dielectric but otherwise identical.

21. dielectric medium - liquids of relatively high dielectric constant used in electrical capacitors, cables, switches, transformers and circuit breakers to replace air and increase dielectric strength, and often to improve heat dissipation.

22. Dow Corning 561 - a dimethyl silicone insulating material and a heat stable dielectric coolant with a much greater fire resistance than mineral oils, without the environmental hazards of PCB - containing liquids.

23. electron capture detector - a system, using Nickel 63 foil, which operates at high temperatures (360°C) and can analyze high-boiling components. The EC detector signal is generated by sample component molecular absorbing (capturing) electrons. The amount of response to a given quantity of sample is proportioned to the ability of the sample to capture these electrons.

24. energized - to apply the rated voltage to a circuit, such as to the coil of a relay, in order to activate it.

25. equilibrium - a state of balance or even adjustment between opposing forces.

26. equivalent - something that is equal in value or significant with respect to another.

27. excited - condition in which after current passes through it, the system is energized or activated.

28. external pump - a small self-priming, heavy-duty type, 1/6 HP, and capable of pumping six gallons of liquid per minute, which was used in addition to the transformer pump in the retrofilling process.

29. fire point - the lowest temperature at which a liquid evolves vapors fast enough to support continuous combustion and is usually close to the flash point.

30. flammability - conditions necessary to cause a liquid or other material to burn.

31. flash point - the lowest temperature at which a combustible liquid will give off a flammable vapor which can be ignited and will burn momentarily.

32. FOA - forced-cooled type transformer, which means forced oil to forced air in the heat exchanger.

33. gas chromatograph - an instrument which analyzes liquid or gas components. Basically, the components move through a packed column at different rates and so appear one after another at the effluent end, where they are detected and measured by thermal conductivity changes or density differences.

34. gravimetric analysis - analysis in which the amounts of the constituents are determined by weighing.

35. HCL - colorless, fuming, corrosive gas with a suffocating odor, which is very soluble in water and also soluble in alcohol and ether. A noncombustible gas formed from arcing PCB containing liquids.

36. head space - refers to the gas space above the liquid level in the transformer.

37. heat transfer - the ability of a liquid to dissipate heat from its source.

38. hertz - (Hz), a unit of frequency equal to one cycle per second.

39. immiscible liquids - liquids which are not capable of being mixed.

40. impedance - the total opposition (resistance and reactance) a circuit offers to the flow of alternating current at a given frequency; the ratio of the potential difference across a circuit or element of a circuit to the current through the circuit or element.

41. impregnation - a process of PCB liquid leaking out of the core and coil and being replaced with silicone liquid.

42. Inerteen - Westinghouse Electric Corporation's trade name for various types of PCB-containing liquids.

43. integrity - state or condition where the original quality remains unchaged or undivided.

44. interface - boundary between two phases when two liquids are mixed together.

45. interfacial tension - ASTM Method of test for measuring, under non-equilibrium conditions, the interfacial tension of mineral oils against water, which gives a reliable indication of the presence of hydrophilic compounds. IFT is determined by measuring the force necessary to detach a planar ring of platinum wire from the surface of the liquid of higher surface tension; that is, upward from the water-oil interface.

46. KVA - abbreviation for kilovolt-ampere.

47. Kelvin bridge - a seven-arm bridge for comparing the resistances of two 4 - terminal resistors or networks. Their adjacent potential terminals are spanned by a pair of auxiliary resistance arms of known ratio, and they are connected in series by a conductor joining their adjacent current terminals.

48. leaching - slow process whereby a liquid is percolated from the insulation and replaced by another liquid.

49. low voltage - refers to the low voltage winding on C-955 transformer which varies from 1002 to 75.5 volts.

59. lubricity - property of a liquid that diminishes friction.

51. meggar - a high range ohmmeter having a built-in, hand-driven generator as a direct voltage source, used for measuring insulation resistance values and other high resistances.

52. megohms - equivalent to one million ohms.

53. microsecond - one millionth of a second.

54. mil - one thousandth of an inch.

55. mineral oil - a refined insulating oil obtained from the fractional distillation of crude petroleum.

56. mineral spirits - a volatile petroleum product, intermediate between gasoline and kerosene, used extensively as a thinner for paints and varnishes. It is also a good and effective flushing solvent.

57. molecular weight - the weight of any molecule, being the same of the weights of its constitutent atoms.

58. neutralization - ASTM method D664 which determines the acidic or basic constituents in petroleum products and lubricants.

59. ohms (Ω) - a unit of resistance. One ohm is the value of resistance across which a potential difference of one volt will maintain a current of one ampere.

60. OSHA - Occupational Safety and Health Act.

61. plasticizers - materials added to a plastic to facilitate compounding and improve flexilibity and other properties of the finished product.

62. polychlorinated biphenyl (PCB) - a class of chlorinated, aromatic compounds which have found widespread applications because of their general stability and inertness as well as their excellent dielectric properties.

63. polydimethylsiloxane - refers to the dimethyl siloxane type polymer for Dow Corning 561 Silicone liquid.

64. polymer - a substance, often synthetic, composed of giant molecules that have been formed by the union of a considerable number of simple molecules with one another.

65. potential transformer - an instrument transformer in which the primary winding is connected in parallel with the circuit whose voltage is to be measured or controlled.

66. pour point - the lowest temperature at which a liquid will flow when a test container is inverted.

67. power factor - ratio of the actual power of an alternating or plusating current, as measured by a wattmeter, to the apparent power, as indicated by an ammeter and voltmeter. Also, it is the ratio of resistance to impedance - therefore, a measure of the loss in an inductor, capacitor, or insulator.

68. pressure/vacuum relief valve - relief valve consists of a diaphragm which will be ruptured when either the pressure or vacuum exceeds the limits of the transformer tank.

69. pyrolysis - chemical decomposition of complex materials into simpler units by use of heat.

70. rated voltage - the voltage at which a device or component is designed to operate under normal conditions.

71. residual - amount of material remaining, after a solvent flush process has been completed, to remove all possible amounts of this material from the transformer.

72. retrofilling - replacing one liquid or material with another.

73. saturated - state of a solution when it holds the maximum equilibrium quantity of dissolved matter at a given temperature.

74. shorted turns - transformer winding is a spiral loop and thus if two of these loops are connected in some way, a shorted turn results.

75. sight gauge - a visual gauge, located on the transformer side, to check and see if the liquid level is at the proper recommended level before the transformer is energized.

76. silica ash - formed when silicone liquids are burned. The silica ash blankets the surface, closing off the combustion-supporting oxygen source, thus making the silicone flame self-extinguishing.

77. solubility - the amount of a substance or liquid that will dissolve in a given amount of another substance or liquid. Solubility is expressed as the number of parts (by weight) dissolved by 100 parts of solvent, as percent by weight or by volume.

78. specific gravity - the weight of a particular volume of any substance, compared with the weight of an equal volume of water at the same temperature.

79. specific heat - the capacity of a material to be heated at a given temperature (expressed as calories per degree C per gram), compared to water, which has a specific heat of 1.

80. tetrachlorobenzene - this material, along with trichlorobenzene, was added to the heavier-viscosity types of PCB containing liquids, such as 1260.

81. thermal conductivity detector - gas chromatographic cell, which contains a filament inside a metal cavity and is heated by passing a current through it. The temperature rise increases the electrical resistance of the filament and this change can be displayed on a recorder. The circuitry of a thermal conductivity detector is similar to a wheatstone bridge circuit.

82. thermal expansion - physical expansion resulting from an increase in temperature; it may be linear and volumetric.

83. thermal stability - silicone transformer liquids exhibit a high degree of thermal stability; their low volatility and resistance to thermal oxidation enables them to maintain their insulating and other functional properties for extended periods of time at high temperatures.

84. thermal time constant - time required to reach 63% of the steady state value.

85. toxicity - quality, state or degree of being poisonous and environomentally unsuited.

86. trichlorobenzene - colorless, stable, refractive liquid which is miscible with most organic solvents and oils. It is used in chemical manufacturing, dyes and intermediates, dielectric fluid, synthetic transformer oils, lubricants, heat transfer medium and insecticides.

87. TTR - Transformer turns ratio instrument which reads the ratio of the voltages taken from the primary and secondary winding in the transformer.

88. twenty-five (25°C) mark - recommended liquid level to be filled before transformer is energized, thus making sure no part of core or coil is exposed.

89. Underwriters Laboratory - an independent laboratory that tests equipment to determine whether it meets certain safety standards when properly used.

90. viscosity - the internal resistance to flow exhibited by a fluid. Viscosity in centipoises divided by the liquid density at the same temperature gives kinematic viscosity in centistokes (CS). (100 centistokes equals 1 stoke). To determine kinematic viscosity, the time is measured for an exact quantity of liquid to flow by gravity through a standard capillary.

91. volatility - in general, the tendency of a solid or liquid material to pass into the vapor state at ordinary temperature. Specifically, the vapor pressure of a component divided by its mole fraction in the liquid or solid.

92. voltage - electrical pressure or force which causes current to flow through an electrical conductor; the greatest effective difference of potential between any two conductors of a circuit.

93. volume resistivity - ratio of the potential gradient parallel to the current in a material, to the current density. The electrical resistance between opposite faces of a 1 - cm cube of insulating material, commonly expressed in ohm-centimeters.

94. watts - a unit of the electric power required to do work at the rate of 1 joule per second. It is the power expended when one ampere of direct current flows through a resistance of one ohm.

95. winding temperature - calculated from resistance measurements taken on the high and low voltage windings of the transformer.

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APPENDIX

REPORT OF NEW TECHNOLOGY

Although there were no subject inventions generated during the performance of this work, new technology was developed for draining, flushing and retrofilling PCB-filled railroad transformers with silicone fluid and reducing residual PCB levels below 4%. Descriptions of the materials and procedures used in the draining and flushing operations are given on pages 8 through 16 of the report.

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