THE CAPACITOR

A DEVICE FOR THE STORAGE OF ELECTRICAL CHARGE.

IN ALTERNATING CURRENT CIRCUITS; IT CAUSES CURRENT TO LEAD THE VOLTAGE BY 90° RATHER THAN BEING IN PHASE AS IN RESISTIVE OR 90° BEHIND AS IN A PURELY INDUCTIVE CIRCUIT.

IT CAN BE USED TO COMPENSATE FOR INDUCTANCE SO THAT CURRENT AND VOLTAGE CAN BE KEPT IN PHASE.

IT DOES NOT CONDUCT DIRECT CURRENT AFTER BEING CHARGED.

SOME CAPACITOR USES

POWER FACTOR CORRECTION

MOTOR START-RUN

FLUORESCENT LAMP BALLASTS

AUTOMOTIVE IGNITION CIRCUITS

ENERGY STORAGE

ELECTRONIC CIRCUITS

- FILTER CAPACITORS
- BLOCKING CAPACITORS
- BY-PASS CAPACITORS
- IN L-C OSCILLATORS
- IN R-C OSCILLATORS
- DIFFERENTIATING CIRCUITS
- INTEGRATING CIRCUITS

CAPACITOR FUNDAMENTALS

CHARGE STORED BY A CAPACITOR

$Q = CE$ ampere seconds or coulombs

C in farads, E in volts

CAPACITANCE OF A PARALLEL PLATE CAPACITOR

$$C = 8.85 \times 10^{-14} \frac{A}{t} \kappa$$

A in cm^2, t in cm, κ = dielectric constant

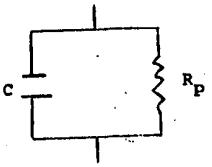
ENERGY STORED IN A CAPACITOR

$W = 1/2\ C\ E^2$ watt seconds

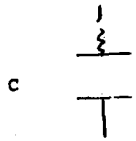
IMPEDANCE OF A CAPACITOR

$$X_c = \frac{1}{2\pi fc} \text{ ohms}$$

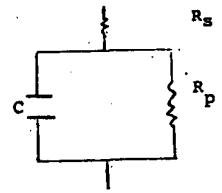
DISSIPATION FACTOR OF A CAPACITOR



$$D = \frac{X_c}{R_p} = \frac{1}{2\pi f c R_p}$$



$$D = \frac{R_s}{X} = 2\pi f c R_s$$



$$D = \frac{R_s + \dfrac{R_p X^2}{R_p^2 + X^2}}{\dfrac{R_p X}{R_p^2 + X^2}}$$

D = tan δ = cos θ or power factor
for value less than 0.1

MONS 033899

SOME KINDS OF CAPACITORS.

VACUUM DIELECTRIC

AIR DIELECTRIC

LIQUID DIELECTRIC

MICA DIELECTRIC

GLASS DIELECTRIC

CERAMIC DIELECTRIC

PLASTIC FILM DIELECTRIC

ELECTROLYTIC

IMPREGNATED PAPER

IMPREGNATED FILM

MONS 033900

WHY IMPREGNATE CAPACITORS?

TO ELIMINATE CORONA DISCHARGES

TO ACHIEVE GREATER CAPACITANCE IN A GIVEN VOLUME

TO PROMOTE HEAT TRANSFER

TO MINIMIZE FIRE HAZARD

TO MINIMIZE COST/PERFORMANCE

LAYER THEORY OF IMPREGNATED CAPACITORS

Impregnated paper capacitors behave as though they consist of two capacitors, one with cellulose and the other with the impregnating fluid as dielectric in series.

Capacitance of an Impregnated Capacitor

$$C = 8.85 \times 10^{-8} A \frac{\kappa_1 \kappa_2}{\kappa_1 t_2 + \kappa_2 t_1} \mu F$$

subscript 1 for paper, 2 for fluid

Dissipation Factor of an Impregnated Capacitor

$$D = \frac{D_1 C_2 + D_2 C_1}{C_1 + C_2} = \frac{D_1 \frac{\kappa_2}{t_2} + D_2 \frac{\kappa_1}{t_1}}{\frac{\kappa_1}{t_1} + \frac{\kappa_2}{t_2}}$$

Distribution of Electrical Stress in Impregnated Capacitors

$$\kappa_1 S_1 = \kappa_2 S_2 \quad \text{or} \quad \frac{\kappa_1}{\kappa_2} = \frac{S_2}{S_1}$$

S = dielectric strength volts/mil.

IMPREGNATED CAPACITOR DATA

Impregnant	κ-25°C	C	C*	D	D**
Air	1.00	.749μF	.744μF	.0016	.0012
Wemco C	2.13***	1 258	1.258	.0025	.0023
Aroclor 1242	5.95	1.978	2.04	.0034	.0034
96.5% Aroclor 1242 3.5% Diphenyl sulfone	6.45	2.109	2.13	.0036	.0036
2,2' dichloro diphenyl ether	12.4***	2.539	2.539	.0040	.0043

$$C^* = 8.85 \times 10^{-8} A \frac{\kappa_1 \kappa_2}{\kappa_1 t_2 + \kappa_2 t_1} \mu F$$

$$D^{**} = \frac{D_1 \frac{\kappa_2}{t_2} + D_2 \frac{\kappa_1}{t_1}}{\frac{\kappa_1}{t_1} + \frac{\kappa_2}{t_2}}$$

t_1 = .00103 cm paper

t_2 = .00187 fluid

A = 11328 cm^2

*** Used to calculate t_1 and t_2

ELECTRICAL PROPERTIES OF A DIELECTRIC FLUID

κ = dielectric constant - a measure of the ability of a dielectric to store electrical energy, relative to a perfect vacuum taken as 1.00

R = Resistivity in ohm cm

D = $\tan \delta = \frac{1}{2\pi fCR}$ - caused by ionic conduction at low frequencies, by restricted dipole rotation at high frequencies

S = Dielectric strength in volts/mil required to cause breakdown may be D.C., 60 Hz A.C. or impulse strength

Corona Inception Voltage

Corona Extinction Voltage

OTHER PHYSICAL PROPERTIES

Boiling Point

Freezing Point

Viscosity

Surface Tension

MONS 033904

Other Physical Properties (Cont'd.)

Solvent action on materials

Thermal Conductivity

Temperature coefficient of expansion

Density

CHEMICAL PROPERTIES

Non Ionic

Stability

a) Thermal
b) Oxidative
c) Hydrolytic
d) Under electrical stress

Flamability - Liquid - Arc Formed Gases

Biodegradability

Toxicity

ECONOMICS

Must give the most performance per dollar.

AROCLOR 1242

Biphenyl chlorinated to 42.5-43.5% Cl

Chlorine content corresponds to trichloro biphenyl

Contains about 60 homologs and isomers

Meets requirements for most capacitors better than any other available fluid.

Only serious flaw - It does not biodegrade in the environment rapidly enough to prevent build up to concentrations which cause problems.

Lipid solubility permits concentration through the marine food chain so that it affects reproduction cycle of marine birds.

Accumulates in larger fish - a potential hazard to man.

OUR FIRST RESPONSE TO THE PROBLEM

MCS 1016 produced by fractionating Aroclor 1142 in a 30 plate column to remove substantially all material with 5 or more chlorine atoms per molecule.

A FURTHER POSSIBLE MODIFICATION

MCS 1043 Fractionated Aroclor 1129

TABLE I

Sample Analyses Reported 11-15-70 Recalculated with Disc Integrator (to correct for errors in electronic integration of 5 & 6 chlorine isomers)	Weight % of Chlorinated Biphenyls — Number of Chlorine Atoms						
	0	1	2	3	4	5	6
1) Aroclor 1242, Made at WGK - 3/9/70	0.01	0.7	15.5	49.4	24.8	8.7	0.85
2) Aroclor 1242 E-18, made in Great Britain 7/21/70	0.01	0.04	13.0	56.4	22.8	7.4	0.34
3) MCS-1016*	0.02	1.0	19.7	57.3	21.2	0.8	<0.05
4) Kaneclor KC 300	0	0	10.8	58.0	23.9	7.0	0.30
5) Bayer Clophen (14057)	0	0.02	18.3	58.5	16.2	5.1	1.9
6) Prodelec Superad	0	0	12.1	58.8	21.5	7.1	0.45
New Analyses Completed 1-18-71 Calculated with Disc Integrator							
7) Pyralene 1499 (12/22/70)	0	0	12.0	59.1	22.4	5.9	0.6
8) Pyralene 1499 (N 70/729)	0	0.1	17.0	55.2	21.7	5.5	0.5
9) Pyralene 1500 (U.D.S.)	0	0.4	43.9	30.0	16.6	7.9	1.2
10) Pyralene 1500 (12/22/70)	0.02	0.4	34.6	44.1	16.3	4.1	0.5
11) Pyralene 1500 (N 70/728)	0.02	0.4	37.0	42.8	15.5	3.9	0.4
12) Bayer Clophen A.30	0.02	0	16.8	58.4	18.0	4.9	1.9
13) Bayer Clophen A.30 (20198)	0	0.02	17.7	57.7	19.8	4.3	0.45
14) Bayer Clophen A.30 (20200)	0	0	6.5	58.6	19.3	5.0	0.6
15) Caffaro Apirollo 1431C	0	0	14.3	59.5	20.1	5.5	0.69
16) Bayer Clophen (14057)(Repeat)	0	0.05	17.6	57.9	16.5	5.7	2.2

*Aroclor 1242 distilled to remove high boilers

ELECTRICAL PROPERTIES OF FLUIDS

FLUID 4	κ^K	tan δ *	Rs **	Remarks
Aroclor 1242	4.85	.0002	100	
MCS 1016	4.87	.0004	129	
MCS 1043	4.83	.0001	121	
HDK, Aroclor	5.46	.05	3	
dichloro 1,1,3,3 phenyl trimethyl indane	4.48	.0013	670	
2,4' dichlorobiphenyl	5.98	.00022	110	
o-dichlorbenzene	7.5	.00071	1	
trichlorodiphenyl oxide	3.63 4.2	.00024	110 .05	
2,2' dichloro diphenyl ether	9.48	.00096	10	
m trifluoromethyl diphenyl ether	6.18	.00030	54	
n-butyl 2,4,dichloro phenyl ether	6.61	.00066	34	C.P. = -9.4°C
n-butyl o chloro phenyl ether	6.07	.00078	26	C.P. <-20°C
3,4 dichloro diphenyl methane	5.84	.00096	6	
Veratrol	4.14	.088	0.26	
96.5% Aroclor 1242 3.5% diphenyl sulfone	5.47	.0004	13	
95% Aroclor 1242 5% benzophenone	5.14	.0009	38	
Wenco C Oil	2.13	.0005	65	

* At 100°C, 60 Hz
** x 10^{12} Ohm-cm, 500 volts for 1 min.

DIELECTRIC FLUIDS COMPARISON

FLUID	BIODEGRAD.*	FLAMMABILITY*	K	MFG. COST.
Aroclor 1242	1	1	4.85	.074
MCS 1016	2	2	4.87	.084
MCS 1043	3	3	4.83	.084
3,4 dichloro diphenyl methane	4	4	6.39	.39
Trichloro diphenyl ether	4	4	3.63	.13
2,2'dichlorodiphenyl ether	4	4	9.48	.32
ochloro, 2,4 dichloro phenyl n butyl ether mix	5	5	6.3	.29
Tolyl-xylyl sulfone	?	6	20.8	.30
Diphenyl sulfone ethyl diphenyl sulfone mix	?	6	22.6	.40
Benzophenone	7	7	8.6	.42
Anisole	7	7	3.66	.22
96.5% Aroclor 1242 3.5% diphenyl sulfone			5.47	.086
93% Aroclor 1242 7% tolylxylyl sulfone			5.98	.090
50% Aroclor 1242 50% 2,2'dichloro diphenyl ether			7.16	.20

* Biodegradability and flammability increase in numerical order.

MONS 033910

FLASH AND FIRE POINT DATA

Fluid	Pour Point	Flash Point	Fire Point
1. Aroclor 1254	10°C	None	None
2. Aroclor 1248	-7	193-96°C	None
3. Aroclor 1242	-19	176-180	None to B.P.
4. MCS 1016	-20	182	None to B.P. (327°)
5. Aroclor 1232	-35.5	152-154	238°C
6. MCS 1043	-30	160	288
7. Aroclor 1221	Crystals at 1°C	141-150	176

DATA SUMMARY

168 hr., 100°C G. E. Polypropylene Film (5N17 VH11 PB44) Stability Test

Fluid	Film Breaking Time in Hrs.	Avg.
Biphenyl	>168; >168; >144, <168	164 hrs.
Tolyl Xylyl Sulfone	>168; >168; >168	>168 hrs.
Aroclor 1221	>72, <96; >72, <96; >72, <144	92 hrs.
Aroclor 1232	>96, <168; >72, <96; >72, <144	108 hrs.
Aroclor 1242	>72, <96; >72, <96; >72, <144; >120, <168	105 hrs.
Aroclor 1248	>72, <96; >72, <96; >72, <144	92 hrs.
Aroclor 1254	>96, <168; >96, <168; >72, <144	124 hrs.
Tri Tetra Chloro Benzene	>24, <48; >48, <72; >48, <72	52 hrs.
Tri Chloro Benzene	>24, <48; >24, <48; >24, <48	36 hrs.
*PFA Fluid #9	>168; >168; >72, <144	148 hrs.
2,2' Dichloro Diphenyl Ether	>168; >168; >168	>168 hrs.
**N,N Dimethyl Formamide	>72;>72	> 72 hrs.
*** Dimethyl Sulfoxide	>168; >168	>168 hrs.
OS-59	>48, <168; >120, <168	132 hrs.

* fluid evaporated to 12-12.5 ml. during the test

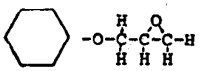
** fluid evaporated to 12 ml., test discontinued after 72 hrs.

*** fluid evaporated to 17-18 ml. during the test

MONS 033912

SCAVENGERS

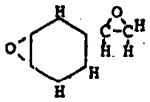
Phenoxy propene oxide



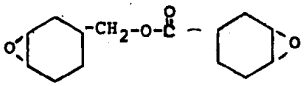
Tin tetraphenyl



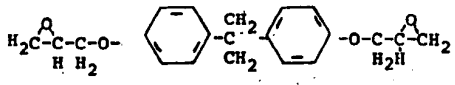
Unox 4206



Unox 221

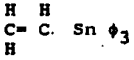


Diglycidyl ether of bisphenol A



NEW CANDIDATE

Triphenyl vinyl tin



USE OF THICKENERS AND GELING AGENTS

5% Polystyrene in Aroclor 1242

	C	tan δ @ 25°C 300V	600V
5% polystyrene 95% Aroclor 1242	1.955	.00357	.00349
Aroclor 1242	1.978	.00318	.00338
	1.966	.00336	.00371

Polyethylene forms a gel with Aroclor 1242.

Can a system with polymerization catalyst in the paper and monomer in the impregnation liquid be developed?

LIFE TESTING

Life $\frac{1}{E^n}$

where n = 5 to 7

E = test voltage

10°C temperature increase
cuts life to 1/2 or 1/3

Life $\frac{1}{f}$

f = frequency - Hz

Life Test Schedules

Room temperature, 1.75 x rated voltage, 24 hours

70°C, 1.5 x rated voltage, 750 hours

LIFE TEST DATA - PAPER CAPACITORS

Test Conditions, Tan δ, Capacitance, Failure Times

Started 9-16-70

Temp., °C		70°	70°	70°	70°	70°	70°	80°	90°	100°	100°
Voltage		870	900	900	930	965	1000	1000	1000	1000	1000
Time, Hrs.	0	750	168	1274	336	168	168	168	168	168	336
	a	a	a	a	b	b	b	b	b	b	
Aroclor 1242	.00338	.00344	.00348	.100360	.00303	.00304	.00301	.00309	.00341	.00472	
	1.979 ufd						112 hr.			12.75 hr.	183.83 hr.
										79.5	268.5
										136.0	
										2 OK	
MCS 1016	.00348	.00342	.00345	.00358	.00318	.00320	.00306	*.00316	.00350	.00434	
	1.996 ufd									8.5 hr.	269.5 hrs.
										15.0	270.0
										126.16	
										2 OK	

a) Measured at 600V, room temp.
b) Measured at test voltage and temp.
* Line fuse blew, measured time was 148 hrs.

MONS 033916

LIFE TEST DATA FOR PAPER CAPACITORS

	Time to Failure 70°C				Capacitor tan δ					Fluid tan δ 60 Hz, 100°C
					600V (RT)			930V (70°C)	965V (70°C)	1) Initial 2) Degassed 3) Impregnator
	750 hrs 870V	1274 hrs 900V	336 hrs 930V	168 hrs 965V	Initial	750 hrs 870V	1274 hrs 900V	336 hrs 930V	168 hrs 965V	
Aroclor 1242				All still OK	.00338	.00344	.00360	.00303	.00304	1) .00036 2) .00552 3) .04668
MCS 1016				All still OK	.00348	.00342	.00358	.00318	.00320	1) .00132 2) .00510 3) .06342
2,2'-Dichloro Diphenyl Ether				All still OK	.00422	.00526	.00544	.00475	.004995	1) .00114 2) .00474 3) .05268
96.5% 1242 3.5% DPS	56 hrs 130 364 689 2 ok				.00356	.00360				1) .0006 2) .0008 3) .0123
Wemco C	All OK				.00246	.00257				1) .00048 2) .00060 3) .0013

MONS 033917

LIFE TEST DATA FOR POLYPROPYLENE FILM AND POLYPROPYLENE FILM PLUS KRAFT PAPER CAPACITORS

	Time to Failure				Capacitor	Fluid tan δ 60 Hz, 100°C
	Room Temp.		70°C			1) Initial 2) Degassed
	24 hrs. 787V (1.75 x 440)	24 hrs. 1155V (1.75 x 660)	750 hrs. 660V	750 hrs. 1000V	tan δ 500V	3) Impregnator 4) Capacitor
6306 Aroclor 1242		22-1/2 hr.	1 hr.	94.8 hr. 151 2 ok	.00073	.00096 .00438 .1502 4.7
6306 Aroclor 1242 + 0.3% Unox 4206			83	1.3 8 27.5 38 183 all failed	.00062	.0274 .0174 --- ---
6306 Aroclor 1242 + 0.3% Unox 221			33	5.3 43.8 77 100 311 all failed	.00072	.0929 .0667 --- ---
6306 Aroclor 1242 + 0.005% Triphenyl vinyl tin			130 394	15 29 44.5 79 all failed	.00062	.0035 .0032 .61 ---
6307 Aroclor 1242	MONS 033918			All still ok	.0011	.0009 .0067

CAPACITOR LIFE TEST CONCLUSIONS

1) A scavenger such as:

   0.3% Unox 4206
   0.3% Unox 221.
   0.005% Triphenyl vinyl tin

   is required to pass the 24 hr. 1.75 rated voltage room temperature test in all film units.

2) Same capacitors without scavenger lasted longer than any with scavenger.

3) Paper capacitors impregnated with 96.5% Aroclor 1242 - 3.5% diphenyl sulfone will not pass 1.5 x rated voltage, 70°C, 750 hours life test.

4) With addition of 0.3% Unox 221 such units pass test with margin to spare.

5) No discernable difference among

   Aroclor 1242
   MCS 1016
   Aroclor 1242 MMK
   Kaneclor 300

   in paper capacitors through 750 hours @ 870V, 1274 hours @ 900V, 336 hours @ 930V, 168 hours @ 965V.

METALLIZED FILM OR PAPER CAPACITORS

CONCEPT:

THIN ELECTRODE FORMED BY EVAPORATION OF ZINC OR ALUMINUM ONTO FILM OR PAPER CLEARS THE SHORT CIRCUIT FORMED ON BREAKDOWN BY EVAPORATING BACK AWAY FROM THE POINT OF BREAKDOWN FAR ENOUGH TO WITHSTAND THE APPLIED VOLTAGE.

FLUID REQUIREMENTS:

NO ELEMENTS SUCH AS Cl WHICH FORM IONIZABLE COMPOUNDS DURING BREAKDOWN.

MINIMUM FORMATION OF CONDUCTING SOLIDS DURING BREAKDOWN.

OXYGEN IN MOLECULE CONSIDERED DESIRABLE.

HIGH DIELECTRIC CONSTANT IS NOT AS IMPORTANT AS FOR MOST IMPREGNATED CAPACITORS.

TABLE II

MCS No.	Product	tan (60 Hz) (After 30 mins. at 100°C)	R_s (500 volt)	DK	Pour Pt.	C.P. °C	Viscosity 100°F Cks.	Viscosity 210°F
MCS 1046	C_7-C_9 Adipate	.00240	28×10^{12}	3.55		-8.2	8.73	2.60
MCS 1050 =	C_7-C_9-C_{11} Phthalate	.01578	2×10^{12}	4.02	50°C			4.2
MCS 1047	Mixed Alkyl Mono and Polynuclear Aromatics	.00048	265×10^{12}	2.22	-50°F		30±3	
MCS 1045	Mono Isopropyl Biphenyl	.00108	138×10^{12}	2.49				1.6
MCS 1048	C_5-C_9 Acids Pentaerythritol Ester	.00228	44×10^{12}	3.27	-70°F		26	
MCS 1049	40% Hydrogenated Terphenyls 60% Diphenyl Ether	.00180	360×10^{12}	2.90	-40°C			
MCS 1054	C_{11} Phthalate	.01572	164×10^{10}	3.71	- 5°C	+2°C	54@25°C	
MCS 1055	C_8 Tri Mellitate	.01326	142×10^{10}	4.15	-50°F			59 (SUS
MCS 1054	Polymeric Adipate	.20460	21×10^{10}	4.84	- 5°F		280@25°C	

MDNS 033921

CAPACITOR FLUID CONSIDERATIONS

1) Biodegradability increases in the following order:

   Aroclor 1242
   MCS 1016
   MCS 1043
   Chlorodiphenyl ethers
   Alkyl chlorophenyl ether
   Fluids with only C, H and O

2) Flammability increases in roughly the same order.

3) Polypropylene film-paper type capacitors are very desirable because of low tan δ (0.001 vs. 0.004 for impregnated paper) and because the tan δ decreases with increasing temperature. Also give smaller volume and cost/KVAR.

4) All polypropylene film capacitors would be even better. Such capacitors are technically and probably economically feasible now and will very likely come into use.

5) Surfactants can probably be used to make impregnation of all film units easier.

6) Metallized film or metallized paper electrode, film dielectric capacitors offer advantages in size and cost/performance in small sizes.

7) Optimum fluid for use with such capacitors is not yet known. Must not contain halogens, sulfur, silicon, etc. Must form as little carbon on arcing as possible. Oxygenated compounds are believed to be desirable to promote this.

8) These developments may be counteracted by developing fluids with higher K and choosing all components of the capacitor to minimize ionic contamination.

9) Use of a high K fluid such as 2,2' dichlorobiphenyl would make possible a 25% reduction in capacitor foil area, paper thickness being kept constant.

10) Use of mixtures of 2,2' dichlorodiphenyl ether with MCS 1016 or 1043 might give better cost/performance than the pure 2,2' ether

11) Sulfones plus an additive in MCS 1016 or 43 might also give improved cost/performance to impregnated paper capacitors.

12) Fluids containing only C, H and O having a K $\sim$ 6 might offer the best all round compromise if flammability is not overriding. We can make such a fluid.

13) Scavengers are necessary to meet the 1.75X working voltage, 24 hour, room temperature test to detect capacitors subject to early failure.

14) Triphenylvinyl tin at 0.005% seems as good as 0.3% of Unox 4206 or 221 in film capacitors. Preparations for test in paper capacitors are being made.

15) There seems to be a very real possibility that epoxides would also be effective at concentrations in the 0.005% range. This would simplify epoxide purification, minimize power factor degradation and simplify reclamation of used fluid.

TRANSFORMER FLUIDS

WHY ARE THEY NEEDED?

- DIELECTRIC STRENGTH OF LIQUIDS IS OF THE ORDER OF 10 TIMES THAT OF A GAS AT 1 ATMOSPHERE PRESSURE.
- FOR HEAT TRANSFER. SPECIFIC HEAT AND HEAT CONDUCTIVITY OF LIQUIDS ARE GREATER THAN THOSE OF GASES.
- PROVIDE A QUIETER TRANSFORMER

DESIRABLE PROPERTIES

PROPERTIES OF INTEREST IN A TRANSFORMER FLUID ARE THE SAME AS THOSE OF INTEREST IN A CAPACITOR FLUID BUT THE RELATIVE IMPORTANCE OF THE DIFFERENT PROPERTIES IS CHANGED. THE MOST IMPORTANT ARE:

- HIGH DIELECTRIC STRENGTH - BOTH 60 Hz A.C. AND IMPULSE
- WIDE OPERATING TEMPERATURE RANGE
- GOOD HEAT TRANSFER PROPERTIES
- DIELECTRIC CONSTANT SHOULD BE LOW TO MEDIUM
- LONG TIME STABILITY 30-40 YEAR LIFE
- LOW POWER FACTOR AND HIGH RESISTIVITY REQUIREMENTS NOT AS GREAT AS FOR CAPACITORS
- NON FLAMMABLE - BOTH LIQUID AND ARC FORMED GASES
- PRICE/PERFORMANCE

MONS 033925

USUAL TRANSFORMER FLUIDS

MINERAL OIL

ASKARELS

PYRANOL A13B3B

45% AROCLOR 1260, 55% TRI-TETRA CHLOR BENZENE

INERTEEN PPO, PYROCHLOR

60% AROCLOR 1260, 40% TRICHLOROBENZENE

INERTEEN 54201KA

70% AROCLOR 1242, 30% TRICHLOROBENZENE

AROCLOR 1242

MONSANTO COMPETITION

MINERAL OIL

DRY TYPE

HIGH PRESSURE GAS FILLED - SF_6

VAPORIZING LIQUID - FREON

TABLE II

THE AVERAGE CHARACTERISTICS OF MINERAL INSULATING OIL

Property	For Use in solid Type Cables	For Use in Capacitors and Hollow Core Cables	For Use in Transformers, Switches and Circuit Breakers
Condition	Clear	Clear	Clear
Viscosity	100° (98.9°C)	100° (37.8°C)	38° SSU (37.8°C)
Specific Gravity	.930 (15.5/15.5°C)	.885	.885 (15.5/15.5°C)
Color	2-5 (NPA)	1 or less (NPA)	1 or less (NPA)
Neutralization Number	.02 (Mg KOH/gram)	.02(Mg KOH/gram)	02 (Mg KOH/gram)
Flash Point (open cup)	235°C	163°C	153°C
Burn Point (open cup)	280°C	185°C	178°C
Pour Point	-5°C	-45°C	-45°C
Free Sulfur	nil	nil.	nil
Total (fixed) Sulfur	.35%	.15%	.1% or less
Evaporation (8 hrs/100°C)	------	------	8%
Dielectric Strength	30 kv	30 kv	30 kv
Specific Heat (30-35°C)	------	.412	.4252
Power Factor (100°C)	.001	.001	.001
Chlorides and Sulfates	nil	nil	nil
Resistivity (100°C)	1-10 x 10^{13}(ohm-cm)	50-100 x 10^{13}(ohm-cm)	1-10 x 10^{13}(ohm-cm)
Coef. of Expansion	.00073		.00070
Specific Optical Dispersion	115-120	115-120	110-113
Thermal Conductivity	------	------	.39 cal/cm/sec/°C
Refractive Index (25°C)	------	------	1.4828
Aniline Point	------	------	169°F (76°C)

MONS 033927

STRATEGY

MAXIMIZE USE OF MONSANTO PRODUCTS BY PROMOTING USE OF AROCLOR 1242 IN PLACE OF MIXTURES.

SECURE A COMPETITIVE ADVANTAGE FOR ASKAREL TRANSFORMERS BY HELPING DESIGN LOWER COST UNITS BY MAKING USE OF THE HIGH OPERATING TEMPERATURE CAPABILITIES OF AROCLOR 1242.

PROBLEMS

LOW IMPULSE RATIO OF ASKARELS

FLAMMABILITY OF AROCLOR 1242 ARC FORMED GASES

NO ADEQUATE HIGH TEMPERATURE PAPER SUBSTITUTE

TABLE I

DEGRADATION OF DISSIPATION FACTOR
OF AROCLOR 1242 BY PROPOSED SHEET INSULATING MATERIALS

	Sample	Dissipation Factor at 100°C Hz 144 hrs. at 50°C	96 hrs. at 125°C
0	Aroclor 1242 Blank	.0002	.001
1	Cerex Spun Bonded Nylon .014"	.018	.121
2	(1) Washed with soap and water, dist H_2O, Acetone and dried	.019	.436
3	Cerex Spun Bonded Nylon .025"	.010	.102
4	(3) Washed same as (2)	.67	-
5	Webril SM 213.1	4.05 - 120 hrs	-
6	(5) Acetone extracted	.15	2.28
7	(5) Trichloro benzene extracted	.14	8.3
8	(5) Washed with soap and water, dist H_2O, acetone extracted, dried	.0034	.127
9	(5) Washed with soap and water, dist H_2O, acetone, dried	.298	-
10	(5) Boiled in 10% HCl 1 hr., 5X water washed acetone extracted, dired	.0052	.103
11	Wet Laid Acrylan paper	.0158	.0113
12	(11) Washed with soap and water, H_2O, Acetone, dried	.0022	.0040
13	Nomex Type 410 .003"	168 hrs. at 100°C .0204	168 hrs. at 150°C .0363
14	Nomex Type 411 .006"	.069	.134

TABLE II

BREAKDOWN VOLTAGES FOR
PRESENT AND PROPOSED SHEET INSULATING MATERIALS*

	Sample	Breakdown Voltage Dry	Breakdown Voltage Aroclor 1242 Impregnated
1	Kraft Layer Insulation .010"	4.3 KV	19 KV
2	Nomex 410 .010"	8.1	15.2
3	Cerex Spun Bonded Nylon .011"	5.1	6
4	Acrylan Wet Laid Paper 2 x .0055"	3.7	1.5
5	"Webril" Non woven sheeting SM-213.1 2 x .005"	2.3	4.3
6	Air .010"	2.2	
7	Aroclor 1242 after testing Cerex Samples .100"		39.5
8	Aroclor 1242 after testing Acrylan Paper .100"		33
9	Aroclor 1242 after testing Webril .100"		31

* Measurements were made in a standard ASTM dielectric strength cell with cylindrical electrodes 1.000" in diameter and flat faces. Dry measurements were made by placing a 2" x 2" piece of the sheet material between the electrodes, pressing them together firmly and clamping them in place. Measurements on Aroclor impregnated samples were made in the same manner placing the previously impregnated sheet sample in the cell filled with Aroclor 1242. All samples were dried in a vacuum <5μ. Samples were impregnated in vacuo with vacuum degassed Aroclor 1242 after vacuum drying.

ARC FORMED GAS INVESTIGATION

ESTABLISHED:

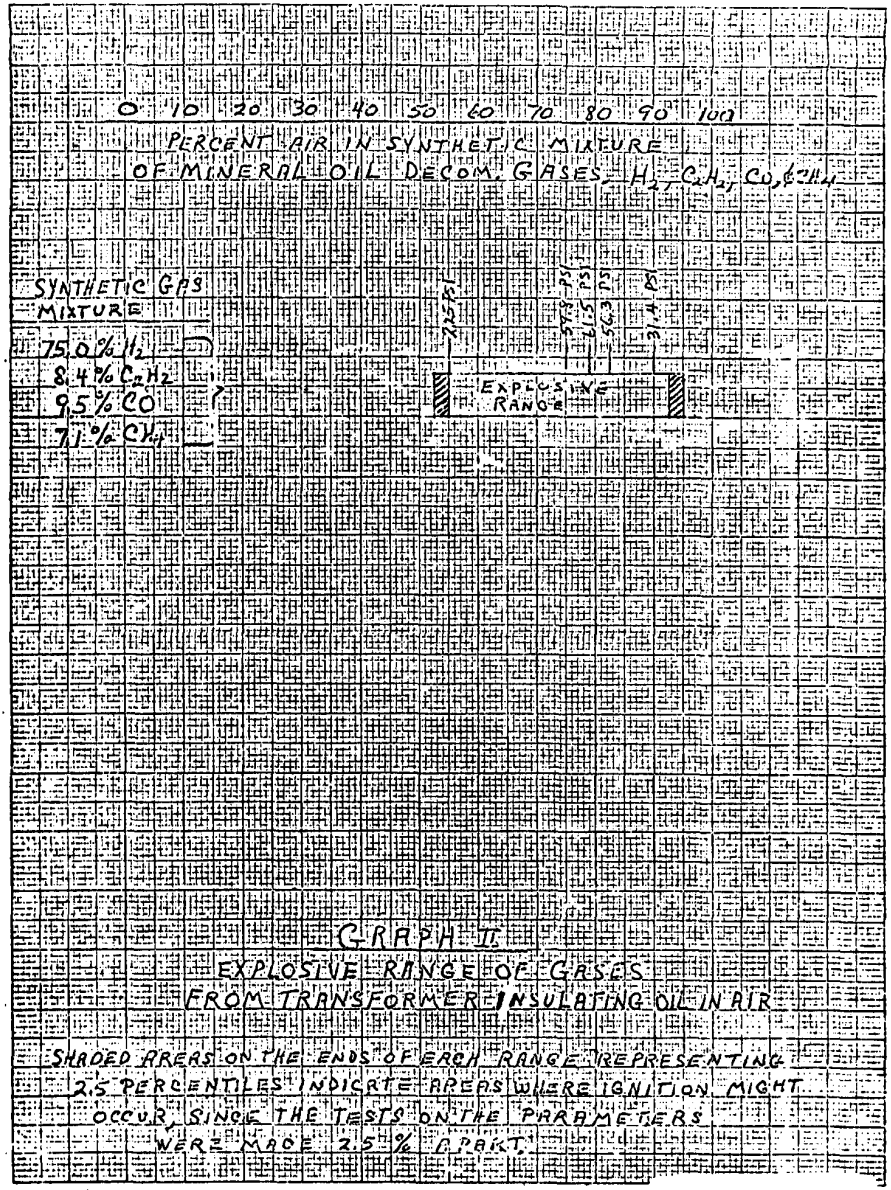
COMPOSITION OF THE ARC FORMED GASES

EXPLOSIVE RANGES WHEN THESE ARE MIXED WITH AIR

PEAK PRESSURES REACHED DURING EXPLOSION

TIME TO REACH PEAK PRESSURE

DATA WERE PRESENTED TO TRANSFORMER MANUFACTURERS FOR THEIR GUIDANCE.

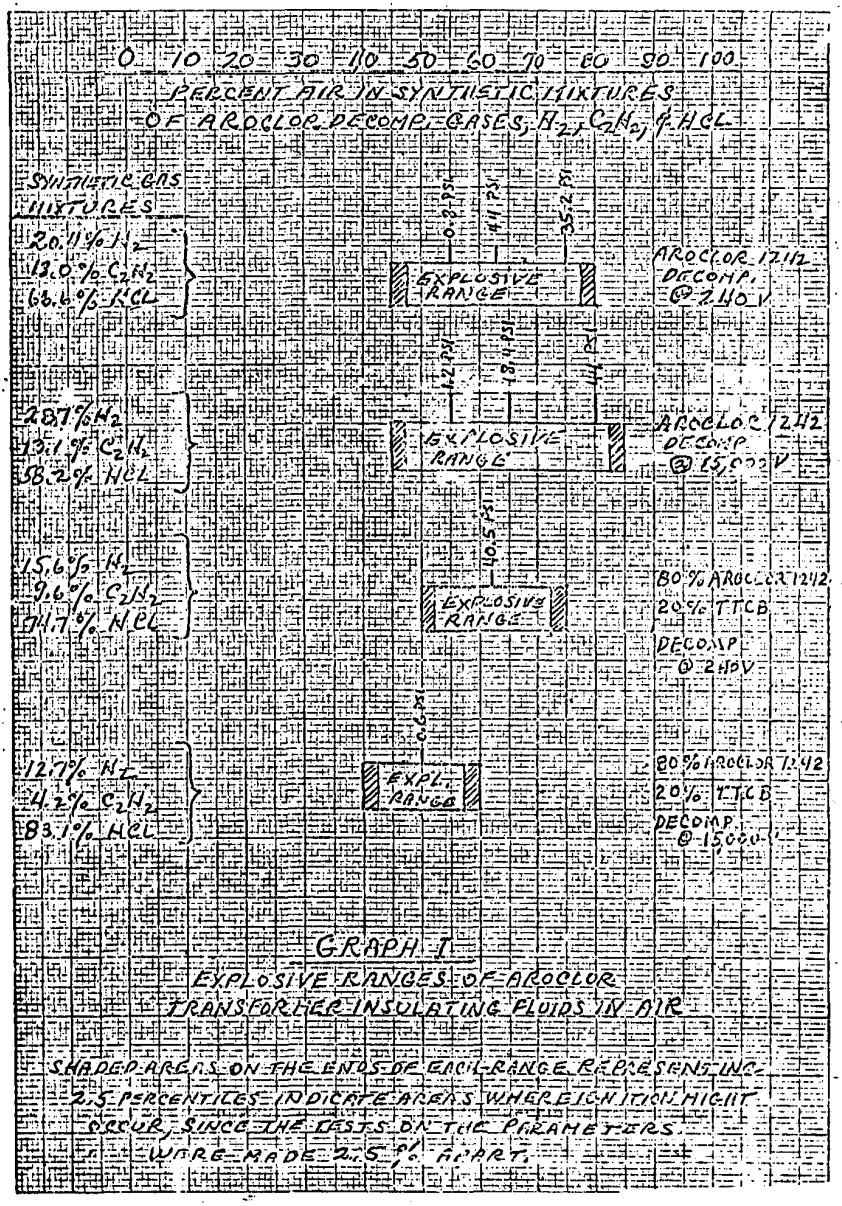


GRAPH II

EXPLOSIVE RANGE OF GASES FROM TRANSFORMER INSULATING OIL IN AIR

SHADED AREAS ON THE ENDS OF EACH RANGE REPRESENTING 2.5 PERCENTILES INDICATE AREAS WHERE IGNITION MIGHT OCCUR, SINCE THE TESTS ON THE PARAMETERS WERE MADE 2.5% APART.

KE 10 X 10 TO INCH 46 1470
KEUFFEL & ESSER CO.



GRAPH I

EXPLOSIVE RANGES OF AROCLOR TRANSFORMER INSULATING FLUIDS IN AIR

SHADED AREAS ON THE ENDS OF EACH RANGE REPRESENTING 2.5 PERCENTILES INDICATE AREAS WHERE IGNITION MIGHT OCCUR, SINCE THE TESTS ON THE PARAMETERS WERE MADE 2.5% APART.

K&E 10 X 10 TO THE INCH 40 1320 7 X 10 INCHES KEUFFEL & ESSER CO.

TRANSFORMER FLUIDS

1) Trichloro diphenyl ether (mixed isomers) has advantages for transformer use. These are: a) better low temperature properties, b) lower viscosity, c) lower K, d) probable better biodegradability, e) chlorinated to optimum level (probably pentachloro) and mixed with TCB or TTCB would make a true Askarel, non-flammable, no flammable arc formed gases.

2) Chlorinated diphenyl methane with substitution only on the phenyl groups might offer a similar opportunity.

CABLE FLUIDS

REQUIREMENTS ARE MUCH THE SAME

AS FOR TRANSFORMERS.

MAJOR DIFFERENCES:

- HIGHER VISCOSITY IS DESIRABLE
- FIRE RESISTANCE IS NOT AS IMPORTANT

CABLE FLUIDS

1) We can probably gain acceptance of MCS 1071-2 type of fluid. We must recognize that this will be a futile effort unless we insure that we have a continuing supply of material of uniformly high quality. Quality requirements for the delivered fluid are much higher than in the capacitor industry.

Properties	Low Visc. Polybutene Oil for Pipe Type Cable		Alkalate High Boiler - Light MCS 1071	Alkalate High Boiler - Heavy MCS 1072
Research Identification				
Flash Point°C		130° or higher	180	200
Pour Point°C ASTM D97		-45 or lower	<-55	<-60
Viscosity (SUS)				
@37.8°C		115 to 140	100 to 125	130-150
@100°C		38 to 44	39	40.5
ASTM D88				
Neutralization No. (MAX) ASTM D974 MgKOH/g sample		0.02	<0.05	
Free and Corrosive Sulfur ASTM D909 Except the copper strip shall be maintained in the oil @ test temp. for 16 hrs.		none	should not be a problem - no test data	should not be a problem - no test data
Dielectric Strength ASTM D877 (KV)		35	>50	>50
Power Factor (%) 60 Hz @ 100°C ASTM D924		0.1	0.005-0.14* *Values are not consistent with the resistivity values. Values actually much lower.	.22*
Resistivity (10^{12} ohm cm) @ 100°C ASTM D1169		100	500	500
Gas content Guaranteed Max. as shipped @ 760mm + 0°C ASTM D831	To be provided by the vendor		Must be determined but should be sufficiently low because of the process condition alone	
Color Number ASTM D155-45T	2 typical is actually water white or <1		1	1
Misc Properties				
Specific Gravity 60/60 (g/cc)			.893	.897
Cost			$0.014/lb.	$0.014/lb.
Availability			24M lbs/yr.	8M lbs/yr.
			Chocolate Bayou	Chocolate Bayou
Dist. Range °F				
Init. B.P.			560-620	640
20%			640-660	680
Water Content after refinement		30 ppm	10	10
Acceptance or rejection reasons			seems to meet the requirement	slightly heavy on viscosity; otherwise ok

HIGH VACUUM FLUIDS

SANTOVAC 5

- FIVE RING POLYPHENYL ETHER
- VACUUM CAPABILITY - 5×10^{-10} TORR WITH AMBIENT AIR COOLING
- TOO LOW FOR US TO MEASURE WITH LIQUID N_2 TRAPS

COMPETITION

DOW CORNING 705

COMPARISON

ULTIMATE VACUUM	EQUIVALENT
PUMPING SPEED	EQUIVALENT
VISCOSITY INCREASE	SANTOVAC 5 NONE DC705 QUITE LARGE
SURFACE MIGRATION	SANTOVAC 5 DC705
DECOMPOSITION PRODUCTS	DC705 - SiO_2 SANTOVAC 5 CARBON
CORROSION	SANTOVAC 5 PRODUCES PHENOLICS CORROSIVE TO ALUMINUM IF REFLUXED AT ATMOSPHERIC PRESSURE

MONS 033939

DIELECTRIC FLUIDS

I. IMPROVED ENVIRONMENTAL ACCEPTABILITY

A. MCS 1016
MCS 717 - IMPROVED DIV

B. 1130 PRODUCT AND DK COMPONENTS
(ENVIRONMENTAL IMPROVEMENT AND ANSWER TO PYRALINE 1500)

C. NEW TYPE OF CAPACITOR IMPREGNANTS - PAPER, PAPER FILM OR ALL FILM

1. ALKYL-CHLOROPHENYL ETHERS (DK-6)

2. o-DICHLOROBENZENE (DK-8)

3. ETHERS (ANISOLE)
(VERATROLE)

4. ESTERS FOR HIGH FREQUENCY

5. GEL SYSTEMS

D. NEW CAPACITOR IMPREGNANTS FOR METALLIZED FILM CAPACITORS

1. C7-9 TRIMELLITATE

2. SANTICIZER 79 C7-9 PHTHALATE

3. SANTICIZER 7-11 C7-11 PHTHALATE

4. SANTICIZER 412 POLYMERIC ADIPATE

5. SANTICIZER 97 C7-9 ADIPATE

6. ISOPROPYL BIPHENYL

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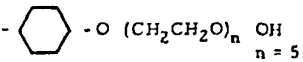
5. SANTICIZER 97 C7-9 ADIPATE

6. ISOPROPYL BIPHENYL

7. 40% HB40 - 60% DIPHENYL ETHER

8. HERCOLUBE J PENTAERITHRITOL ESTER $(RCOOCH_2)_4C$ $R=C_5$

9. STEROX NJ 

10. STEROX CD $C_{17}H_{35}COO(CH_2CH_2O)_n$ OH, $n = 4$

E. POWER FACTOR STABILITY PROBLEM

F. SCAVENGERS

II. IMPREGNATION

A. SURFACTANTS

B. PHYSICAL PROCESSING VARIABLES

C. PAPER, PAPER FILMS, FILM ONLY

D. IMPROVED CAPACITOR PAPER

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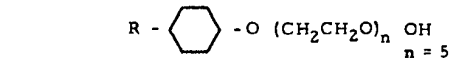
9. STEROX NJ 

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II. IMPREGNATION

A. SURFACTANTS

B. PHYSICAL PROCESSING VARIABLES

C. PAPER, PAPER FILMS, FILM ONLY

D. IMPROVED CAPACITOR PAPER

II. IMPREGNATIONS (CONTINUED)

E. TABLE

IMPREGNANT	DK-25°C	CAPACITANCE	TAN δ
AIR	1.00	.749	
WEMCO C	2.13	1.258	.0025
*AROCLOR 1242	5.95	1.915	.0033
AROCLOR 1242	5.95	1.978	.0034
A DPS	6.45	2.109	.0036
2,2'DICHLOR@-DIPHENYL ETHER	12.4	2.539	.0040

*COMMERCIALLY IMPREGNATED WEIGHT OF IMPREGNANT 37 GM (AROCLOR 1242)
COST OF COMMERCIAL CAPACITOR $.40

A COST OF AROCLOR 1242 $\frac{37 \times .15}{453} = .012$

B COST OF 2,2'DICHLORO DIPHENYL ETHER

@ .75 $\frac{36 \times .75}{453} = .060$

B - A = .048 COST OF B CAPACITOR .45

VALUE OF B = $\frac{2.5 \times .40}{1.98} = .51$

C COST OF ADPS @ .16 $\frac{37 \times .16}{453} = .013$

C - A = .0019 COST OF C CAPACITOR .401

VALUE OF C = $\frac{2.109 \times .40}{.198} = .425$

MONS 033944

II. IMPREGNATIONS (CONTINUED)

E. TABLE

IMPREGNANT	DK-25°C	CAPACITANCE	TAN δ
AIR	1.00	.749	
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II. IMPREGNATIONS (CONTINUED)

F. TABLE

6306 CAPACITOR (P.P. FILM) IMPREGNATION TEST

	Cap. ufd			D. f.		
	300V	500V	1000V	300V	500V	1000V
Aroclor 1242, Anniston Spl. (5-9-70)	2.182	2.182	2.182	.00077	.00073	.00064
Aroclor 1242 + .03% Unox 221	2.193	2.193	2.193	.00085	.00072	.00054
Aroclor 1242, + 0.3% Unox 206	2.187	2.187	2.188	.00064	.00062	.00056
Aroclor 1242, + 0.005% triphenyl vinyl tin	2.180	2.180	2.180	.00065	.00062	.00057

MONS 033946

II. IMPREGNATIONS (CONTINUED)

F. TABLE

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MONS 033947

III. TESTING PROGRAM

A. LIFE TESTING OF CAPACITORS

B. LIQUID

C. HIGH FREQUENCIES

D. HIGH VOLTAGE DIELECTRIC STRENGTHS

E. IMPULSE DIELECTRIC STRENGTHS

F. CORONA TESTING

IV. TRANSFORMER FLUIDS

ARC GENERATED GASES

HEXACHLORO BUTADIENE

VI. SOLID TRANSFORMER INSULATION

HIGH TEMPERATURE SYNTHETICS

HIGHER IMPULSE STRENGTH

AROCLOR IMPREGNATED PRESSBOARD

MONS 033948

III. TESTING PROGRAM

A. LIFE TESTING OF CAPACITORS

B. LIQUID

C. HIGH FREQUENCIES

D. HIGH VOLTAGE DIELECTRIC STRENGTHS

E. IMPULSE DIELECTRIC STRENGTHS

F. CORONA TESTING

IV. TRANSFORMER FLUIDS

ARC GENERATED GASES

HEXACHLORO BUTADIENE

VI. SOLID TRANSFORMER INSULATION

HIGH TEMPERATURE SYNTHETICS

HIGHER IMPULSE STRENGTH

AROCLOR IMPREGNATED PRESSBOARD

MONS 033949

DIELECTRIC FLUIDS

I. IMPROVED ENVIRONMENTAL ACCEPTABILITY

A. MCS 1016
MCS 717 - IMPROVED DIV

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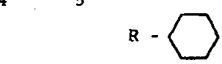
9. STEROX NJ  $n = 5$

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E. POWER FACTOR STABILITY PROBLEM

F. SCAVENGERS

II. IMPREGNATION

A. SURFACTANTS

B. PHYSICAL PROCESSING VARIABLES

C. PAPER, PAPER FILMS, FILM ONLY

D. IMPROVED CAPACITOR PAPER

II. IMPREGNATIONS (CONTINUED)

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MONS 033953

III. TESTING PROGRAM

A. LIFE TESTING OF CAPACITORS

B. LIQUID

C. HIGH FREQUENCIES

D. HIGH VOLTAGE DIELECTRIC STRENGTHS

E. IMPULSE DIELECTRIC STRENGTHS

F. CORONA TESTING

IV. TRANSFORMER FLUIDS

ARC GENERATED GASES

HEXACHLORO BUTADIENE

VI. SOLID TRANSFORMER INSULATION

HIGH TEMPERATURE SYNTHETICS

HIGHER IMPULSE STRENGTH

AROCLOR IMPREGNATED PRESSBOARD

MONS 033954