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IMPROVED PROCESS FOR IMPREGNATING
HIGH VOLTAGE TRANSFORMERS

PDO 6989282, Final Report

L. A. Wolfe, Project Leader

Published September 1976

MASTER

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Project Leader:
L. A. Wolfe
Department 845

PDO 6989282
Final Report

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IMPROVED PROCESS FOR IMPREGNATING HIGH VOLTAGE TRANSFORMERS

BDX-613-1650, UNCLASSIFIED Final Report, Published September 1976

Prepared by L. A. Wolfe, D/845, under PDO 6989282

High voltage transformers typically exhibit a 5 to 10 percent reject rate during corona and voltage breakdown tests because of incomplete impregnation. Sample coil assemblies were fabricated to provide data on the quality of four encapsulation processes: Bench Pour (pouring at atmospheric pressure and then deaerating), Vacuum Pour (placing units and material in a heated chamber and manually pouring under a vacuum), Vacuum-Pour-With-Positive-Pressure-Cure (same as Vacuum Pour except a positive pressure curing was used), and an Automated Encapsulation System (impregnating materials are stored in vacuum containers located in a heated chamber and then metered through static mixers). Results showed that an Automated Encapsulation System is equal to or better than the Vacuum Pour, Vacuum-Pour-With-Positive-Pressure-Cure, and Bench Pour processes.

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SUMMARY

High voltage transformers typically exhibit a 5 to 10 percent reject rate during corona and voltage breakdown tests. Almost all of these are the result of incomplete impregnation of the encapsulated assembly. Impregnation of encapsulated transformers is affected by transformer design, encapsulation process, and encapsulation material. This endeavor was designed to investigate the effects on impregnation of the most commonly used insulations, material, and processes.

Sample coil assemblies were fabricated for each of four encapsulation processes: Bench Pour, Vacuum Pour, Vacuum-Pour-With-Positive-Pressure-Cure, and an Automated Encapsulation System (AES). The sample coils were wound using various thickness of different insulations between winding layers (four layers per coil). Each coil was impregnated by one of the above processes using mica-filled epoxy, and then tested for corona starting voltage and breakdown voltage.

The Bench Pour Process consists of pouring a warm deaerated mixture of mica-filled epoxy into heated molds under atmospheric pressure and then again deaerating the mixture in a vacuum chamber. The parts are cured at a high temperature and at atmospheric pressure.

The Vacuum Pour Process consists of placing units in a vacuum and temperature controlled environment (Hull Chamber) after being heated. The warm mixture of mica-filled epoxy is also placed in the controlled environment. The mixture and the parts are then deaerated. The amount and actual pouring of the mixture is manually controlled by levers on the outside of the chamber. The parts are cured at a high temperature and at atmospheric pressure.

Vacuum-Pour-With-Positive-Pressure-Cure follows the same procedures as the Vacuum Pour Process except in the curing of the material. The Vacuum-Pour-Pressure-Cure Process utilizes a positive pressure along with a high temperature during the curing.

An Automated Encapsulation System is a semi-automatic method of encapsulation and impregnation using a vacuum controlled environment. The coils to be impregnated are placed in the controlled environment after being heated and are mechanically poured after the automatic controller has been properly set. The epoxy components are kept in material storage containers which are located in a heated chamber. The containers are designed to keep the material mixed and under a vacuum. A metering system controls the flow of the material. Static mixers are used to thoroughly mix the epoxy components before dispensing them into the heated vacuum chamber. After being poured, the parts are cured at a high temperature and at atmospheric pressure.

Results from voltage breakdown tests show that an Automated Encapsulation System is equal to or better than the other processes. Vacuum Pour and Vacuum-Pour-With-Positive-Pressure-Cure were fairly consistent with AES results but generally not as good.

The average breakdown voltage for insulation between 0.127 and 0.0254 mm (0.005 and 0.001 in.) was approximately 78.7 MV/mm (2000 V/mil) for each process except Bench Pour.

DISCUSSION

SCOPE AND PURPOSE

This study was undertaken to evaluate four processes for impregnating high voltage transformers, including three presently in use (Vacuum Pour, AES, and Bench Pour), and one possible new process--Vacuum-Pour-With-Positive-Pressure-Cure. The project was also designed to obtain realistic voltage breakdown values for different types of insulation.

ACTIVITY

The coils used in this project were assembled as shown in Figures 1 and 2. A rectangular 50 mm (2 in.) coil form was used with bare 35 AWG wire. The 175 turns per layer were centered on the coil using the highest acceptable tension. The coils have four layers of wire with a lead made available on each layer for testing. Corona starting voltage and voltage breakdown values were taken between each layer of wire--resulting in three pieces of data per coil. A total of 88 coils was assembled for this project. The eleven different types of thin insulation most commonly used in assembling transformers were used (Table 1). Because differences in voltage breakdown values for different types of Kraft paper insulation were not distinguishable, only insulation thickness was used for later comparisons.

The corona starting voltage tests were inconclusive because of a tester which produced inconsistent results. The test results are provided for reference (Appendix A), but no conclusions are drawn from the results.

Impregnation

The Automated Encapsulation System (AES) followed procedures similar to those described in *Development of an Automated Encapsulation System* (BDX-613-1493). The other impregnation processes followed standard encapsulation procedures (Engineering Process Standard 9927020) except where indicated in the following descriptions. These descriptions give a detailed account of what occurred during the impregnation processes for better evaluation of the data obtained.

Bench Pour

The Bench Pour Process consists of pouring a warm deaerated mixture of mica-filled epoxy into heated molds under atmospheric pressure and then again deaerating the mixture in a vacuum chamber. The parts are cured at a high temperature and at atmospheric pressure.

Table 1. Insulation Used in Transformers

Insulation	Thickness mm (mil)	Dielectric Breakdown Voltage Per Sheet Minimum Average Vrms*
7007145-01-009 Kraft Paper (Type I)	0.127 (5)	900
7007130-01-009 Kraft Paper (Type IV)	0.127 (5)	1200
7007123-01-003 Kraft Paper (Type IV)	0.025 (1)	430
7007155-003 Kraft Paper (Type II)	0.025 (1)	360
7007105-01-006 Kraft Paper (Type III)	0.076 (3)	800
7007128-01-006 Kraft Paper (Type IV)	0.076 (3)	800
7007143-01-800 Kraft Paper (Type I)	0.076 (3)	650
7007141-01-800 Kraft Paper (Type I)	0.051 (2)	495
MS-9508271-01-801 Fiberglass Tape Half Wrapped (Close Weave)	0.076 (3)	
229004-02-868 Polyethylene Terephthalate Electrical Insulation (Type G)	0.025 (1)	
606869-5 Mylar	0.051 (2)	

*ASTM D-1305-73a (Electrical Insulating Paper and Paperboard,
Sulfate or Kraft Layer Type)

Figure 1. Cutaway View of Potted Transformer

The 22 coils used for this process were divided into two groups to be poured at two different times because of a limit on the amount of material mixed at one time. Because of a bad vacuum seal, the parts and the resin used in Group 1 were at ambient temperature for 10 minutes before being processed. The resultant mixture temperature after evacuation (58°C or 136°F) is below minimum requirements of the standard encapsulation procedure (Engineering Process Standard 9927020) and therefore the Group 1 results are not included in the data. Group 2 did not have this problem and the mixture after evacuation was 70°C (158°F). The lower mixture temperature of Group 1 resulted in a lower $\bar{X}$ value for voltage breakdown as compared to Group 2. The processing differences between pours are illustrated in Figure 3.

Vacuum Pour

The coils to be encapsulated using the Vacuum Pour Process are placed in a vacuum and temperature controlled environment (Hull Chamber) after being heated. The amount of impregnant and the actual pouring of each coil is manually controlled.

Figure 2. Attachment of Test Leads

The 22 coils used in this process were divided into two groups to be poured successively in the Hull Chamber. There were no significant differences between the first and second pours. Some minor differences were in the length of time to pour and the amount of time a vacuum was applied to the poured units. These process differences did not affect the voltage breakdown or corona starting voltage values. Mixture temperature for both pours was kept at 71°C (160°F) by the Hull Chamber. The processing differences between pours are illustrated in Figure 4.

Vacuum-Pour-With-Positive-Pressure-Cure

The 11 coils used in this process were poured at the same time using the regular vacuum pour process but with a positive pressure during the cure cycle. The Hull Chamber, which obtained a 28.9 MPa (42 psi) pressure, was used for the two-hour cure. A higher pressure was desired but the facilities needed to obtain a higher pressure were not available for use. Figure 5 illustrates the process.

Automated Encapsulation

An Automated Encapsulation System is a semi-automatic method of encapsulation and impregnation using a vacuum controlled environment. The coils to be impregnated are placed in the controlled

GROUP 1 (TIME IS IN MINUTES)

0-----MATERIAL MIXED
 1
 2
 3
 4
 5
 6
 7
 8
 9
 10-----
 11 EVACUATION OF MATERIAL
 12-----MATERIAL TEMP 58°C (136°F)
 13
 14 POUR
 15
 16-----
 17
 18 EVACUATION OF PARTS
 19
 20-----
 21 TOP OFF
 22
 23-----
 24 EVACUATION OF TOP OFF
 25-----

GROUP 2 (TIME IS IN MINUTES)

0-----
 1 MIXING
 2
 3 EVACUATION OF MATERIAL
 4-----
 5-----MATERIAL TEMP 70°C (158°F)
 6
 7 POUR
 8-----
 9
 10 EVACUATION OF PARTS
 11
 12-----
 13-----
 14 TOP OFF
 15
 16 EVACUATE TOP OFF
 17
 18
 19 FINAL TOP OFF
 20
 21 PLACED IN OVEN TO CURE
 22 WITH SIX MINUTES LEFT ON
 23 POT LIFE
 24
 25

Figure 3. Bench Pour Process Mixture Differences

environment after being heated and are mechanically poured after the automatic controller has been properly set. The amount of impregnant poured per part is controlled by the settings. After being poured, the parts are cured at a high temperature and at atmospheric pressure.

The 19 coils used in Groups 1, 2, and 3 were processed the same way. The 14 coils used in Group 4 had one significant change: Groups 1 through 3 had a vacuum between 530 Pa (4 mm Hg) and 1332 Pa (10 mm Hg) during pouring; on Group 4 a vacuum of 66.7 Pa (0.5 mm Hg) was obtained. The greater vacuum typically resulted in slightly higher voltage breakdown values.

Encapsulation Versus Insulation Thickness

Table 2 shows a comparison of the $\bar{X}$ voltage breakdown values of each thickness of Kraft paper related to each process. Figure 6 is a graph of the Table 1 values and shows conclusively that the

FIRST 12 UNITS (TIME IS IN MINUTES)

0 _____
 1 _____
 2 MIXING
 3 _____
 4 _____
 5 EVACUATE TO 400 Pa
 6 (3 mm Hg)
 7 _____
 8 _____
 9 HOLD VACUUM $\leq$ 400 Pa
 10 _____
 11 _____
 12 _____
 13 _____
 14 _____
 15 _____
 16 POUR UNITS
 17 VACUUM DURING POUR WAS
 18 233 Pa (1.75 mm Hg)
 19 _____
 20 _____
 21 _____
 22 _____
 23 _____
 24 HOLD VACUUM TO END OF POT LIFE
 25 _____

SECOND 10 UNITS (TIME IS IN MINUTES)

0 _____
 1 _____
 2 MIXING
 3 _____
 4 _____
 5 EVACUATION OF MATERIAL
 6 _____
 7 _____
 8 _____
 9 POUR UNITS
 10 VACUUM DURING POUR WAS
 11 233 Pa
 12 _____
 13 _____
 14 _____
 15 CONTINUED VACUUM UNTIL END
 16 OF POT LIFE WITH PERIODIC
 17 TOP OFFS AS NEEDED
 18 _____
 19 _____
 20 _____
 21 _____
 22 _____
 23 _____
 24 _____
 25 _____

Figure 4. Vacuum Pour Process Mixture Differences

Bench Pour Process should not be used for impregnating high voltage transformers. The graph also provides an indication that the most consistently successful process would be Automated Encapsulation System.

A volts-per-mil value was calculated for each of the four processes by taking the voltage breakdown value and dividing it by the insulation thickness. A histogram was made to obtain an X-bar and three sigma values for each process (Appendix B).

To provide a possible criteria for choosing insulation thickness, the following evaluations were made.

The Vacuum Pour Process had one test result below 57.87 MV/mm (1470 V/mil), the AES had four test results below 55.11 MV/mm (1400 V/mil), and the Vacuum-Pour-Pressure-Cure Process had three test results below 55.11 MV/mm--resulting in an overall total of

11 UNITS IMPREGNATED (TIME IS IN MINUTES)

0 _____
1 MIXING
2 _____
3 EVACUATE TO 400 Pa (3 mm Hg)
4 _____
5 HOLD VACUUM TO
6 <400 Pa
7 _____
8 _____
9 _____
10 POUR UNITS
11 _____
12 _____
13 _____
14 _____
15 _____
16 CONTINUED
17 VACUUM FOR
18 10 MINUTES
19 _____
20 _____
21 _____
22 _____
23 PRESSURIZE HULL CHAMBER
24 _____
25 POSITIVE PRESSURE CURE FOR
2 HOURS AT A MAXIMUM OBTAINABLE
HULL CHAMBER PRESSURE OF 290 kPa (42 PSI)

Figure 5. Vacuum-Pour-With-Positive-Pressure-Cure Mixture Process

8 test values out of 173 (4.6 percent) being below 55.11 MV/mm. This could set a rough criteria of around 39.32 MV/mm (1000 V/mil) when using the AES or the Vacuum Pour Process since there are only three test results below this value, representing a 1.7 percent failure rate.

The Bench Pour Process has a very high sigma value, resulting in a very wide base for the normal distribution curve. The AES and the Vacuum-Pour-Pressure-Cure Process had the lowest sigma values, indicating more consistent results. The volts per mil $\bar{X}$ values for a Vacuum Pour, AES, and Vacuum-Pour-Pressure-Cure are all approximately 78.7 MV/mm (2000 V/mil).

Table 2. Insulation Breakdown Voltages of Kraft Paper

Insulation Thickness	$\bar{X}$ Value in Volts			
	Bench Pour	Vacuum Pour	Vacuum Pour Pressure Cure	AES
0.0254 mm (1 mil)	730.8	2070.8	2233.3	1844.4
0.0508 mm (2 mil)	536.6	3983.3	3083.3	4800
0.0762 mm (3 mil)	1663.0	5792.8	6200	6185.7
0.127 mm (5 mil)	1543	9675	8950	9511

The tables in Appendix A were assembled from data gathered during voltage breakdown and corona starting voltage tests. An $\bar{X}$ value was obtained for each group within each process and then an overall $\bar{X}$ value for the process was calculated. Sigma and 3-sigma values for each process were also calculated. The tables contain the high, low, and range of data for each group within a process as well as for the overall process. These tables represent the total amount of data obtained during this project.

Table 3 contains a rough grading of each process. A process was given a 1 for each table in which it had the highest breakdown voltage; a 2 was given for the second best process, and so on until all processes were rated. The process with the lowest overall total is the process with the highest rating.

Encapsulation Versus Insulation Type

A comparison of Kraft paper insulation with Mylar insulation and half-wrapped fiberglass tape is shown in Tables 4 and 5. Voltage breakdown values of Mylar, according to specifications (MIL-I-631D, Military Specification, Insulation, Electrical, Synthetic-Resin Composition, Nonrigid) is between 3000 and 3500 volts. This information was confirmed by Table 4. For the highest voltage breakdown values, Mylar is a better insulator than Kraft paper of comparable thickness.

Figure 6. Voltage Breakdown Versus Thickness of Each Process

Table 3. Rating of Each Process Based on Data in Appendix A

Insulation	Bench Pour	Vacuum Pour	AES	Vacuum Pour Positive Pressure
0.0254 mm (1 mil) Kraft	4	2	3	1
0.0508 mm (2 mil) Kraft	4	2	1	3
0.0762 mm (3 mil) Kraft	4	3	2	1
0.127 mm (5 mil) Kraft	4	1	1	2
0.0254 (1 mil) Mylar	2	4	1	3
0.0762 mm (3 mil) Fiberglass	4	1	2	3
0.0508 mm (2 mil) Mylar	4	2	1	3
Totals	26	15	11	16

The difference between Kraft paper and fiberglass tape, which was half-wrapped, is significant (Table 5). The thickness of fiberglass tape is double that of Kraft paper for almost the same voltage breakdown values.

ACCOMPLISHMENTS

The results of the evaluation of the four encapsulation processes show that an AES system is the most reliable, accurate, and consistent of the four. It produced the highest volts per millimeter (V/mil) for the greatest number of thicknesses of insulation.

Table 4. Comparison of Kraft Paper Insulation to Mylar Insulation

Insulation Thickness	$\bar{X}$ Value in Volts			
	Bench Pour	Vacuum Pour	Vacuum Pour Pressure Cure	AES
0.0254 mm (1 mil) Kraft Paper	730.83	2070.8	2233.3	1844.4
0.0508 mm (2 mil) Kraft Paper	536.6	3983.3	1933	4800
0.0254 mm (1 mil) Mylar	2700	2182	2600	3056
0.0508 mm (2 mil) Mylar	5783.3	6700	6233	6878

Table 5. Comparison of Kraft Paper Insulation to Fiberglass Tape Half Wrapped

Insulation Thickness	$\bar{X}$ Value in Volts			
	Bench Pour	Vacuum Pour	Vacuum Pour Pressure Cure	AES
0.762 mm (3 mil) Kraft Paper	1663	5792.8	6200	6185.7
0.152 mm (6 mil) Fiberglass	2458	8267	5800	6189

The results also provide information on voltage breakdown values that can be used when assembling or designing high voltage transformers.

Information gained on the effectiveness of each process makes it possible to choose the process that fits individual needs and capabilities.

FUTURE WORK

No future work is planned on this project at this time.

Appendix A
TABULAR DATA

Table A-1. Breakdown Voltage for 0.0254 mm (1 mil) Kraft Paper

Process	$\bar{X}$	Σ	$3-\Sigma$	High	Low	Range
Bench Pour						
Group 1	730.83	531.75	1595.24	1800	200	1600
Group 2	--	--	--	--	--	--
Overall	730.83	531.75	1595.24	1800	200	1600
Vacuum Pour Overall	2070.83	160.20	480.59	2300	1800	500
AES						
Groups 1, 2, 3	1383.33	530.72	1592.17	2000	800	1200
Group 4	1844.4	218.58	655.74	2100	1500	600
Overall	1660	427.28	1281.85	2100	800	1300
Vacuum Pour Pressure Cure Overall*	2233.33	251.66	755	2500	2000	500
*Only three pieces of data						

Table A-2. Breakdown Voltage for 0.0508 mm (2 mil) Kraft Paper

Process	$\bar{X}$	Σ	3- Σ	High	Low	Range
Bench Pour						
Group 1*	466.6	41.63	124.9	500	420	80
Group 2*	536.6	102.2	306.4	610	420	190
Overall	501.7	79.60	238.8	610	420	190
Vacuum Pour Overall	3983.3	306.05	918.2	4600	3800	800
AES						
Groups 1, 2, 3	4766.7	301.1	903.3	5000	4300	700
Group 4*	4800	264.58	793.7	5000	4500	500
Overall	4777.8	272.85	818.5	5000	4300	700
Vacuum Pour Pressure Cure Overall	3083.3	1330	4080	5000	1600	3400

*Only three pieces of data .

Table A-3. Breakdown Voltage for 0.0762 mm (3 mil) Kraft Paper

Process	$\bar{X}$	Σ	$3-\Sigma$	High	Low	Range
Bench Pour						
Group 1	924.44	636.2	1908.7	2600	550	2050
Group 2	1663.0	849.6	2548.9	3300	840	2460
Overall	1313.2	827.3	2481.8	3300	550	2750
Vacuum Pour Overall	5792.86	1254.8	3764.4	8400	4200	4200
AES						
Groups 1, 2, 3	5791.7	1076.58	3229.7	8100	5000	3100
Group 4	6185.7	865.45	2596.4	7800	4500	3300
Overall	6003.9	969.3	2907.9	8100	4500	3600
Vacuum Pour Pressure Cure Overall	6200	1018.6	3055.7	8400	5000	3400

Table A-4. Breakdown Voltage for 0.127 mm (5 mil) Kraft Paper

Process	$\bar{X}$	Σ	$3-\Sigma$	High	Low	Range
Bench Pour						
Group 1	2266.7	1125.46	3376.4	4300	1300	3000
Group 2	1543.3	1010.24	3030.7	3600	1020	2580
Overall	1905	1087.4	3262.08	4300	1020	3280
Vacuum Pour Overall	9675.00	2186.37	6559.12	15,000	7500	7500
AES						
Groups 1, 2, 3	9800	1430.9	4292.7	11,700	7500	4200
Group 4	9222.2	637.9	1913.7	9900	8100	1800
Overall	9511.1	1115.1	3345.2	11,700	7500	4200
Vacuum Pour Pressure Cure Overall	8950	1320.23	3960.68	10,800	7500	3300

Table A-5. Breakdown Voltage for 0.0508 mm (2 mil) Polyethylene Terephthalate

Process	$\bar{X}$	Σ	$3-\Sigma$	High	Low	Range
Bench Pour						
Group 1	2833.3	125.83	377.49	2950	2700	250
Group 2	2700	264.6	793.7	2900	2400	500
Overall	2766.7	199.16	597.5	2950	2400	550
Vacuum Pour Overall	2181.67	619.37	1858.10	2500	940	1560
AES						
Groups 1, 2, 3	3100	275.68	827.04	3600	2800	800
Group 4*	2966.7	152.75	458.26	3100	2800	300
Overall	3055.6	240.37	721.11	3600	2800	800
Vacuum Pour Pressure Cure Overall*	2600	132.29	396.86	2700	2450	250

*Only three pieces of data

Table A-6. Breakdown Voltage for 0.0762 mm (3 mil) Fiberglass Tape

Process	$\bar{X}$	Σ	$3-\Sigma$	High	Low	Range
Bench Pour						
Group 1	2458.3	1868.4	5605.2	5000	710	4290
Group 2	--	--	--	--	--	--
Overall	2458.3	1868.4	5605.2	5000	710	4290
Vacuum Pour Overall	8266.67	1026.97	3080.9	9600	6900	2700
AES						
Groups 1, 2, 3	6188.89	1826.5	5479.5	9900	4200	5700
Group 4	--	--	--	--	--	--
Overall	6188.89	1826.5	5479.5	9900	4200	5700
Vacuum Pour Pressure Cure Overall*	5800	3019.93	9059.8	9000	3000	6000

*Only three pieces of data

Table A-7. Breakdown Voltage for 0.0508 mm (2 mil) Mylar

Process	$\bar{X}$	Σ	$3-\Sigma$	High	Low	Range
Bench Pour						
Group 1	--	--	--	--	--	--
Group 2	5783.3	793.54	2395.6	6600	4300	2300
Overall	5783.3	793.54	2395.6	6600	4300	2300
Vacuum Pour Overall	6700	589.9	1769.8	7200	6000	1200
AES						
Groups 1, 2, 3	6916.67	630.6	1891.8	7500	6000	1500
Group 4*	6800	346.4	1039.2	7200	6600	600
Overall	6877.8	530.98	1592.95	7500	6000	1500
Vacuum Pour Pressure Cure Overall*	6233.3	802.08	2406.24	7000	5400	1600

*Only three pieces of data

Table A-8. Corona Starting Voltage for 0.0254 mm (1 mil) Kraft Paper

Process	$\bar{X}$	Σ	$3-\Sigma$	High	Low	Range
Bench Pour						
Group 1*	592.5	326.3	978.9	900	220	680
Group 2**	290	62.45	187.35	360	240	120
Overall***	462.8	284.06	852.18	900	220	680
Vacuum Pour Overall†	1300	141.42	424.26	1400	1200	200
AES††						
Groups 1, 2, 3	--	--	--	--	--	--
Group 4	--	--	--	--	--	--
Overall	--	--	--	--	--	--
Vacuum Pour Pressure Cure Overall††	--	--	--	--	--	--
*4 of 9 had corona **3 of 3 had corona ***7 of 12 had corona †2 of 9 had corona ††No corona before breakdown						

Table A-9. Corona Starting Voltage for 0.0508 mm (2 mil) Kraft Paper

Process	$\bar{X}$	Σ	$3-\Sigma$	High	Low	Range
Bench Pour						
Group 1*	430	34.64	103.9	450	390	60
Group 2*	320	34.64	103.9	360	300	60
Overall**	375	67.75	203.25	450	300	150
Vacuum Pour Overall***	480	--	--	480	480	0
AES						
Groups 1, 2, 3†	2200	692.8	2078.5	3000	1800	1200
Group 4††	--	--	--	--	--	--
Overall†††	2200	692.8	2078.5	3000	1800	1200
Vacuum Pour						
Pressure Cure Overall††	--	--	--	--	--	--

*3 of 3 had corona
 **6 of 6 had corona
 ***1 of 9 had corona
 †3 of 6 had corona
 ††No corona before breakdown
 †††3 of 9 had corona

Table A-10. Corona Starting Voltage for 0.0762 mm (3 mil) Kraft Paper

Process	$\bar{X}$	Σ	$3-\Sigma$	High	Low	Range
Bench Pour						
Group 1	487.22	109.7	329.07	680	280	400
Group 2	496.67	139.9	419.73	840	340	500
Overall	491.94	122.06	366.17	840	280	560
Vacuum Pour Overall*	1954	1727.6	5182.78	4600	420	4180
AES						
Groups 1, 2, 3**	4580	1277.5	3832.5	6000	3000	3000
Group 4***	5275	1354.9	4064.8	6600	3500	3100
Overall†	4888.9	1280.1	3840.25	6600	3000	3600
Vacuum Pour Pressure Cure Overall††	5600	916.52	2749.55	6600	4800	1800
*5 of 18 had corona **5 of 12 had corona ***4 of 15 had corona †9 of 27 had corona ††3 of 9 had corona (only three pieces of data)						

Table A-11. Corona Starting Voltage for 0.127 mm (5 mil) Kraft Paper

Process	$\bar{X}$	Σ	3- Σ	High	Low	Range
Bench Pour						
Group 1	1128.3	369.5	1108.5	1750	790	960
Group 2	598.3	100.88	302.64	750	480	270
Overall	863.3	378.5	1135.6	1750	480	1270
Vacuum Pour Overall*	7037.5	1721.24	5163.7	8400	3900	4500
AES						
Groups 1, 2, 3**	6387.5	1386.09	4158.27	8200	4500	3700
Group 4***	6714.3	1496.03	4488.08	8500	4500	4000
Overall†	6540	1395.8	4187.4	8500	4500	4000
Vacuum Pour Pressure Cure Overall	6083.3	1963.1	5889.23	9900	4500	5400
*8 of 12 had corona **8 of 9 had corona ***7 of 9 had corona †15 of 18 had corona						

Table A-12. Corona Starting Voltage for Polyethylene Terephthalate

Process	$\bar{X}$	Σ	$3-\Sigma$	High	Low	Range
Bench Pour						
Group 1*	255.0	18.03	54.08	275	240	35
Group 2*	320.0	34.64	103.9	360	300	60
Overall	287.5	43.33	129.99	360	240	120
Vacuum Pour Overall**	620.0	224.3	672.83	990	390	600
AES						
Groups 1, 2, 3***	--	--	--	--	--	--
Group 4†	2000	--	--	2000	2000	0
Overall††	--	--	--	2000	2000	0
Vacuum Pour						
Pressure Cure Overall***	--	--	--	--	--	--
*Only three pieces of data **5 of 6 had corona ***No corona †1 of 3 had corona ††1 of 9 had corona						

Table A-13. Corona Starting Voltage for 0.0762 mm (3 mil) Fiberglass Tape

Process	$\bar{X}$	Σ	$3-\Sigma$	High	Low	Range
Bench Pour						
Group 1*	750	0	0	750	750	0
Group 2**	--	--	--	--	--	--
Overall*	750	0	0	750	750	0
Vacuum Pour Overall***	6800	1414.2	4242.64	7800	5800	2000
AES						
Groups 1, 2, 3†	4250.0	1060.7	3181.98	5000	3500	1500
Group 4**	--	--	--	--	--	--
Overall†	4250.0	1060.7	3181.98	5000	3500	1500
Vacuum Pour						
Pressure Cure Overall††	--	--	--	6000	6000	0
*3 of 6 had corona **No corona; no units ***2 of 6 had corona †2 of 9 had corona ††1 of 3 had corona						

Table A-14. Corona Starting Voltage for 0.0508 mm (2 mil) Mylar

Process	$\bar{X}$	Σ	$3-\Sigma$	High	Low	Range
Bench Pour						
Group 1*	--	--	--	--	--	--
Group 2	1245.0	1104.4	3313.2	3200	340	2860
Overall	1245.0	1104.4	3313.2	3200	340	2860
Vacuum Pour Overall**	--	--	--	--	--	--
AES						
Groups 1, 2, 3***	--	--	--	6000	6000	0
Group 4†	6900	1555.6	4666.9	8000	5800	2200
Overall††	6600	1216.6	3649.7	8000	5800	2200
Vacuum Pour						
Pressure Cure Overall†	5000	1414.21	4242.64	6000	4000	2000
*No corona; no units **No corona found in 6 tests ***1 of 6 had corona †2 of 3 had corona ††3 of 9 had corona						

Appendix B
HISTOGRAMS

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