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By

Lee Miller

Donald J. Doan

Earl S. Carr

EAGLE-PICHER INDUSTRIES, INC.
ELECTRONICS DIVISION
COUPLES DEPARTMENT
JOPLIN, MISSOURI
64801

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FOURTH QUARTERLY REPORT

FOR

STUDY OF PROCESS VARIABLES ASSOCIATED WITH MANUFACTURING HERMETICALLY-SEALED NICKEL-CADMIUM CELLS

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LEE MILLER
DONALD J. DOAN
EARL S. CARR

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GODDARD SPACE FLIGHT CENTER

CONTRACTING OFFICER
J. A. MALONEY

TECHNICAL MONITOR
FLOYD E. FORD

PREPARED BY

EAGLE-PICHER INDUSTRIES, INC.
ELECTRONICS DIVISION
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ABSTRACT

This report describes the fourth quarter of a program to determine and study the critical process variables associated with the manufacture of aerospace, hermetically-sealed, nickel-cadmium cells. The work consummated in the fourth phase was primarily concerned with the determination and study of the process variables associated with the positive and negative plaque impregnation/polarization process. The experimental data resulting from the implementation of fractional factorial design experiments are analyzed by means of a linear multiple regression analysis technique. This analysis permitted the selection of preferred levels for certain process variables to achieve desirable impregnated plaque characteristics. Assuming the maximization of plaque pick-up weight in conjunction with good electrical capacity and physical characteristics is desired, the following are some of the major conclusions drawn from the results of this effort:

POSITIVE PROCESS VARIABLES

A high nickel nitrate solution specific gravity is preferred in the positive plaque impregnation/polarization process.

A high nickel nitrate solution temperature is preferred.

A long impregnation time is preferred.

A short polarization time is preferred.

NEGATIVE PROCESS VARIABLES

A low cadmium nitrate solution specific gravity is preferred in the negative plaque impregnation/polarization process.

A long impregnation time is preferred.

A long polarization time is preferred.

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I. INTRODUCTION

The objective of this program is to develop a process procedure and control for manufacturing nickel-cadmium aerospace cells with reliable five (5) year life capability. In order to achieve these objectives, each component part will be investigated separately and collectively to determine the critical variables and related interactions.

The total program consists of four (4) distinct, yet interrelated phases. The first phase consisted of a detailed analysis of our procedures in conjunction with a review of pertinent literature of nickel-cadmium batteries to assess critical variables of the various processes that affect cell performance. The second phase will involve the evaluation and testing (verification) of the variables and their interrelation as determined in Phase 1. This will include a design of experiments to experimentally identify critical variables and to establish tolerances required for uniform performance. Phase 3 includes the detailed preparation of a Quality and Reliability Assurance Program, Acceptance and Manufacturing Flow Sheets and a complete hardware specification that can be practically implemented in a cost effective manner. This specification will be patterned after "S-716-P-23, Interim Model Specification for High Reliability Nickel-Cadmium Spacecraft Cells." The Fourth Phase of the program will be to implement the results of Phases 1 through 3 on a production basis. This effort will "prove out" the conclusions and will establish both validity of concept and applicability to production equipment and overall operational capability. During this phase, the deliverable items of separation, positive and negative plates will be prepared. Also, 20 nickel-cadmium cells of 20 ampere-hour size will be manufactured to the developed procedure. Inspection levels will be 100% minimum and complete traceability maintained.

The first quarter of this program was devoted to investigating the dry-sintering process used in manufacturing porous nickel plaque. A factorial experiment was designed to examine the sintered plaque characteristics as a function of the process variables. The data gathered from this experiment were analyzed using a step-wise multiple regression technique designed for use with the IBM 1130 computer. At the completion of analysis, plaques with different characteristics were selected for use in the impregnation factorial experiment.

The second quarter's work encompassed additional variability analyses of the data from the unimpregnated plaque experiments. This effort included the prediction of the variability of the plaque manufacturing process within the normal tolerance range of the equipment and was instrumental in determining the critical variables and their effects upon the process for the purpose of instituting new control limits. This was followed by a short production run of three (3) different types of plaques (high strength-low porosity, average strength-average porosity and low strength-high porosity). These plaques are being used for the impregnation studies of the experimental program. Also during the second quarter, major effort was directed toward the setting up of a separate facility for the impregnation, polarization, formation, washing and other items related to the cell assembly for the contract. An experimental program was designed to study impregnation, polarization, formation and washing.

During the second reporting period, work began on the preparation of specifications for separator, ceramic-to-metal seal cover assembly and unimpregnated plaque manufacturing control.

The third quarterly period included an investigation (strength tests and scanning electron micrographic analysis) of the properties of the three groups of sintered plaques produced for use during the impregnation/polarization study. This effort revealed an anomalous group of low strength which was attributed to a high sintering temperature in conjunction with a strong sintering furnace reducing atmosphere. This investigation also revealed a plaque group exhibiting characteristic highly desirable in a nickel-cadmium cell plaque; this included high strength and a very uniform distribution of the porous void.

The experimental data resulting from previously performed impregnation/polarization design experiments was analyzed to determine the effects of certain process variables which were selected for investigation in the present process study. This information was used during the following period to reduce the number of process variables considered for study in the new impregnation/polarization design experiments.

Preliminary drafts of Quality Assurance Specifications for sintered nickel plaques, separator materials, and ceramic-to-metal seals were also completed during this period.

This fourth quarter period of the program was devoted to the implementation and evaluation of the impregnation/polarization factorial design experiments formulated for the study of the associated process variables. The first section of this report presents the experimental data and discusses problems encountered which required the reformulation of design experiments. The second section presents the results of a linear multiple regression analysis of the experimental data, and discusses the interpretation of these results. The last section presents the conclusions and recommendations which resulted from the total effort performed during the subject period.

II. IMPREGNATION/POLARIZATION EXPERIMENTAL WORK

A. Impregnation/Polarization Process

An impregnation/polarization process is the means by which the active material of the nickel-cadmium couple is impregnated in the porous sintered nickel plaque. In the Eagle-Picher process, impregnation is accomplished by immersion of the unimpregnated plaques in a hot, slightly acidic solution of either nickel or cadmium nitrate. This operation may be performed under a vacuum. Polarization or the conversion of the electrically inactive nitrate form of nickel or cadmium to the electrically active hydroxide form is accomplished by immersion of the impregnated plaques in a strong caustic solution (may be either sodium hydroxide or potassium hydroxide) accompanied by the passage of a polarizing cathodic current. The plaques are then washed in deionized water to remove the caustic solution.

The above operation is repeated until a predetermined amount of active material impregnation is achieved. The impregnated plaques are then subjected to an electrochemical cleaning or formation operation in preparation to their fabrication into cells.

B. Impregnation/Polarization Study

To study the effects of the numerous process variables associated with the impregnation/polarization process, a statistical, partially replicated, fractional factorial design experiment was formulated to measure impregnated plaque characteristics as a function of the process variables. This technique permits the evaluation of a large number of variables with a limited amount of experimental work.

The design experiments for the positive plaque impregnation/polarization study and the negative plaque impregnation/polarization study were presented in Section III.B of the Second Quarterly Report.[1] For continuity, they will be presented at the beginning of the experimental data sections of this report.

A multiple regression program design for use with the IBM Model 1130 digital computer will be used for data processing during this work. The program evaluates the data resulting from the design experiments by weighing each variable with respect to its effect upon a particular impregnated plaque characteristic i.e., pickup weight; and then calculates a numerical value for its significance to the overall process. More detail will be given concerning the multiple regression analysis technique in the data analysis section of this report.

Pertinent information is contained in both the Second and Third Quarterly Reports[2] concerning the impregnation/polarization study. The following sections should be reviewed for a more thorough understanding of the present work.

Section III.C of the Second Quarterly Report contains a discussion and photographs of the scaled down production equipment used during the experimental phase of the present effort. A brief description of the impregnation/polarization tank, formation tank, nitrate/caustic storage tanks, and the deionized water and power supply systems may be found therein.

Section III.D of the Second Quarterly Report and Section III.B of the Third Quarterly Report describes the physical and chemical test procedures used during the program to gain information about the process and outlines a general implementation procedure to fulfill the intent of the subject study.

Section IV of the Third Quarterly Report contains a discussion of a standardized formation or electrochemical cleaning process which all of the impregnated plaques resulting from the impregnation/polarization study were subjected to.

One of the responses measured by the design experiment is termed plate capacity. Section V of the above Quarterly Report presents a description, by means of a discussion and a photograph, of the equipment and procedures utilized to measure the electrical capacity of a single positive or negative plate. All plate capacities listed in this report have been determined by the indicated standardized procedure.

A portion of the information contained in the above referenced sections is restated here for continuity in this report.

Three groups of unimpregnated plaques were produced for use during the impregnation/polarization study to assess the effects of raw plaque variation upon impregnated plaque characteristics. Lot 151 consists of plaques of high strength and low porosity, Lot 153 consists of plaques of medium strength and medium porosity, and Lot 152 consists of plaques of low strength and high porosity. Specific information concerning these three groups of plaques is contained in section II of the Third Quarterly Report.

As the impregnation/polarization tank is large enough to accommodate only ten plaques, a sample size had to be selected accordingly. Three plaques were selected from each of the three plaque lots described above; these nine plaques then constituted the sample for an experiment. This procedure offers several advantages; time was saved by the evaluation of three variables (three different types of plaques) with a single experiment and the three types of plaques are assured of exposure to identical experimental conditions. The formation tank is larger than the impregnation/polarization tank and can accommodate 20 plaques. For maximum utilization, the procedure followed during this study was to complete two impregnation/polarization experiments and then subject the resulting 18 plaques to the formation operation.

C. Positive Impregnation/Polarization Experiments

TABLE I

POSITIVE IMPREGNATION STUDY

Variables	Designation	Levels
1	Specific Gravity of Nickel Nitrates	1.700 - 1.800
2	Free Acid	1 - 4 gm liter
3	Temperature of Nitrate	140°F - 200°F
4	Time of Impregnation	15 Minutes - 1 Hour
5	Vacuum	0 - 15 Inches
6	Wash Time	10 - 30 Minutes
7	Wash (Number of Cycles)	1 - 3
8	Wash Water Temperature	R.T. - 150°F
9	pH of Wash Water	Measured
10	Type of Caustic	KOH - NaOH
11	Specific Gravity of Caustic	1.200 - 1.300
12	Temperature of Caustic	80°F - 150°F
13	Amount of NH_3 in Caustic	Measured
14	Amount of CO_2 in Caustic	Measured
15	Amount of OH in Caustic	Measured
16	Polarization Current	.1-.4 amps/sq.in.
17	Polarization Time	15 minutes - 1 hour
18	Voltage of Plaque of Ref. Electrode	Measured
19	Amount of Cycles with Same Caustic	1 - 5
20	Number of Total Cycles	Measured
21	Type of Plaque	3 Types

RESPONSES

1	Pick-up Weight
2	Capacity
3	Plaque (Characterization)

The following interpretation may be applied to the three responses for both the positive and negative impregnation/polarization design experiments:

1. Pickup Weight - This is simply the amount of active material impregnation determined by subtracting the starting weight of the unimpregnated plaque from the weight of impregnated plaque after completion of the formation process.
2. Capacity - This is the electrical capacity of a single plate expressed in ampere-hours and determined by a procedure previously described (see Section V of the Third Quarterly Report).

   The capacity test procedure used in this program involved the selection of three plates from each group of three plaques, one plate from each plaque. A plaque contains five plates, a top row of three and a lower row of two (see Figure 1). For identification, the plates are assumed to be numbered as if reading a page in a book. The top three plates are numbered from left to right 1, 2, and 3; and the lower plates are 4 and 5.

   Normally, the middle plate in the top row (Plate Number 2) is selected from the first plaque. From the second plaque, the second plate in the lower row (Plate Number 5) is usually chosen. Then, for the third plaque, Plate Number 2 is selected again. This procedure allows the evaluation of the difference in plate capacity from plaque to plaque within a group of assumed identical plaques and evaluation of the capacity difference associated with different areas

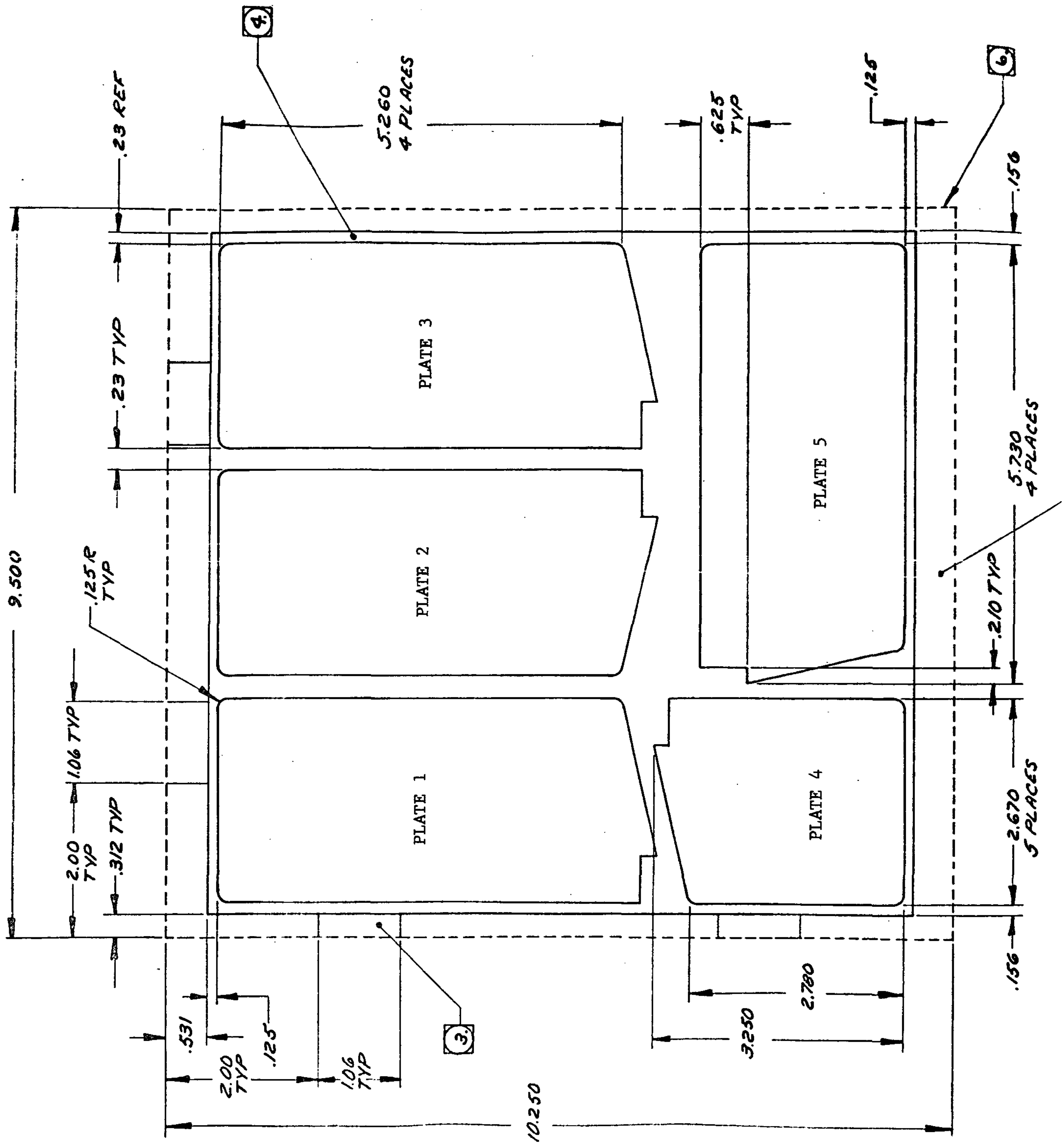
PLATE 1
PLATE 2
PLATE 3
PLATE 4
PLATE 5
4.
3.
6.
.23 REF
5.260
4 PLACES
.625
TYP
.125
.156
.23 TYP
9.500
.125 R
TYP
1.06 TYP
2.00
TYP
.312 TYP
5.730
4 PLACES
.210 TYP
2.670
5 PLACES
.156
.531
.125
2.00
TYP
1.06
TYP
2.780
3.250
10.250

FIGURE NO. 1

of a plaque.

Two terms are used to express electrical capacity: The first term is ampere-hours/plate which is the capacity of a single standard (approximately 15 in^2) plate used throughout this work. The second term is ampere-hours/gram which may be considered an efficiency factor. The actual grams of active material impregnated in a test plate is determined and the ampere-hours capacity is expressed in terms of this quantity.

In addition to the three responses listed above, selected positive and negative plaques were subjected to an individual plate dimensional analysis before and after the impregnation/polarization process. The purpose of this analysis was to determine if there was any growth in plates associated with the operation. The dimensional data for the selected plaques may be found in Appendix B of this report.

3. Plaque Characterization

This is a subjective assessment of a plaque or group of plaques relative physical appearance or degree of cleanliness. For the purpose of entering data in the regression program, a particular plaque appearance is assigned a numerical value which rates it with respect to other plaque appearances.

PLAQUE CHARACTERIZATION RATING SYSTEM

5.0 - Best impregnated plaques produced, smooth clean surfaces, no cracks.
4.0 - Good plaques, smooth clean surfaces, minor cracks.
3.0 - Fair plaques, rough surfaces, moderate cracking.
2.0 - Marginal plaques, very rough surfaces, severe cracking, mostly unsatisfactory for use.
1.0 - Very poor plaques, blistered surfaces, material flaking off, completely unsatisfactory for use.

The following photographs (See Figures 2 and 3) demonstrate the physical appearance of two plaques which received a 1.0 rating. The first photograph is of Plaque No. 2, Lot 152, Experiment No. 9B after completion of the impregnation/polarization process. The second photograph is of plaque No. 2, Lot 152, Experiment No. 10B after completion of the formation process. In addition, a photograph (see Figure 4) included in the discussion section of this report demonstrates the physical appearance of two plates receiving 5.0 and 3.0 ratings.

In the descriptions of variable levels for a particular experiment, the actual measured values, where applicable, were reported. Normally, an impregnation/polarization experiment involves three to four cycles; in the case where a variable's value changes between cycles, the maximum and minimum values are recorded.

Space did not permit the inclusion of all plaque to reference voltage measurements (variable Number 18) recorded during the process in the data section. This data may be found in the Appendix A of this report. Considerable difference will be observed in the voltage between similar experiments as the result of experimentation with different reference electrodes. The reference electrode used for some experiments was a standard nickel-cadmium negative plate, in others a positive plate was used, and in still others, the side of the impregnation/polarization tank was used as a reference electrode. In an interpretation of the plaque to reference voltages, these differences will have to be taken into consideration.

POSITIVE IMPREGNATED PLAQUE
AFTER COMPLETION OF THE
IMPREGNATION/POLARIZATION PROCESS

FIGURE 2

POSITIVE IMPREGNATED PLAQUE
AFTER COMPLETION OF THE
FORMATION PROCESS

FIGURE 3

D. Reassessment of Positive Experimental Work

During the initial implementation of the positive design experiments, two problems arose. The first problem was associated with the physical integrity of the impregnated plaques. A number of the plaques exhibited a "blistering" phenomenon which resulted in the loss of the nickel matrix and the impregnated active material. It appeared the degree of latitude available in the selection of process variable levels was considerably more limited than originally assumed. The second problem involved the time element allocated to this phase of the study. A re-examination of the study time factor in light of the experience gained from the first four experiments indicated this phase of the overall program would consume considerably more time than allotted in the planned scope of work.

As a solution to the first problem, the data resulting from the first four experiments was reviewed in an attempt to determine which variable and its level or variables and their levels were most influential in affecting the poor results. It became obvious that Experiment Number Two produced somewhat better appearing plaques than the other experiments and that it differed in being impregnated under 0 inches of vacuum. It was decided to set this variable (Number 5) constant at its lower level (0 inches of vacuum) and continue the experiment.

As a solution to the second problem, it was necessary to reduce the original list of process variables (21) considered for investigation. The regression program requires that at least one more experiment be performed than the number of variables to be evaluated. So by reducing the number of variables, the number of experiments required to be performed for evaluation is reduced.

In this program, a variable is eliminated by making it a constant value in the experiments. To this end, a reduction in the number of variables was effected by the utilization of the applicable variable level preference data described in Section III.A of the Third Quarterly Report, and through a process of engineering judgment to determine which of the remaining variables is important enough to remain a variable and which should be relegated to constants.

A variable is set constant at one of the levels defined in the original design experiment. This action will permit the use of the data generated by the experiments performed during this work at some further date if it is decided to continue the study of process variables with the original design experiments. The following summarizes the results of this variable reduction effort:

VARIABLES

1 Specific Gravity of Nickel Nitrates - Selected to remain a variable.

2 Free Acid - Selected to remain a variable.

3 Temperature of Nitrate - The effect of this variable on the subject responses was determined by previous design experiments referenced above. Throughout this work, the desired impregnated plaque parameters were high pick-up weight, good electrical capacity and a smooth, clean appearance. The above design experiments demonstrated a preference for a high nitrate solution temperature to achieve these results. This variable was set constant at its higher level of 200°F.

4 Time of Impregnation - Selected to remain a variable.

5 Vacuum - Set constant at its lower level of 0 inches for reasons previously stated.

6 Wash Time - This variable and the next two concerned with plaque washing were set constant at levels convenient to the performance of the experiments, but which would still result in an adequate degree of washing as judged by the present production procedures. This first variable was set constant at its lower level of 10 minutes.

7 Wash (Number of Cycles) - Set constant at higher level of 3 cycles, see Variable Number 6.

8 Wash Water Temperature - Set constant at lower level of room temperature, see Variable Number 6.

9 pH of Wash Water - Experience with the first experiments indicated the value of this variable changed very little and did not appear to be very important to the process. This measurement is to be continued, but the variable will not be considered for entry in the regression program.

10 Type of Caustic - selected to remain a variable.

11 Specific Gravity of Caustic - Set constant at higher level of 1.30 for reasons stated in Variable Number 3.

12 Temperature of Caustic - Set constant at higher level of 150°F for reasons stated in Variable Number 3.

13 Amount of NH_3 in Caustic - Same as Variable Number 9.

14 Amount of CO_3 in Caustic - Same as Variable Number 9.

15 Amount of OH in Caustic - Same as Variable Number 9.

16 Polarization Current - Set constant at higher level of 0.4 amps/in^2 for reasons stated in Variable Number 3.

17 Polarization Time - Select to remain a variable.

18 Voltage of Plaque to Reference Electrode - Same as Variable Number 9.

19 Amount of Cycles With Same Caustic - The first experiment performed utilized fresh caustic for each cycle and there was no discernable difference in the measured responses for this experiment with respect to the experiments which were cycled in the same caustic. Based on this and the need for expediency, this variable was set constant at the higher level of 5 cycles.

20 Number of Total Cycles - This measured variable was set constant at 4 cycles, it was felt this number of cycles would result in approximately the same amount of active material pick-up as experienced in the present production operation; and would render the results of this experiment work more comparable to the present "state-of-the-art".

21 Type of Plaque - Selected to remain a variable.

The culmination of the above total effort is the following abbreviated list of process variables now subject of an investigation by the multiple regression analysis technique:

	VARIABLES	LEVELS
1	Specific Gravity of Nitrate	1.70 - 1.80
2	Free Acid	1.0 - 4.0 gms/liter
4	Time of Impregnation	15 Minutes - 60 Minutes
10	Type of Caustic	KOH - NaOH
17	Polarization Time	15 Minutes - 60 Minutes
21	Type of Plaque	3 Types

For identification purposes, the experiment numbers used to identify experiments performed under the provisions of this new abbreviated design experiment will be designated with the letter "A".

After the completion of three (3) more experiments under the provisions of the new shorter design experiment, it became apparent the old problem of impregnated plaque blistering with the associated flaking of active material was not yet resolved. The second attempt to solve this problem took the same approach as described before. The data resulting from the now seven performed experiments was reviewed to determine if a certain variable level or variables might be associated with the experiments exhibiting the most destructive effect upon the plaques. This approach revealed that polarization in a caustic solution KOH was a much more destructive environment than polarization in a caustic solution of NaOH under similar process conditions. The use of a high free acid nitrate solution content also appeared to afford a much more destructive environment than the use of low free acid levels. The combination of the above two variable levels in one experiment resulted in the complete destruction of all impregnated plaques associated with the experiment.

It was elected to relegate these two variables (Numbers 2 and 10) to constants at their levels more compatible to the impregnation/polarization process (1.0 gm/liter and NaOH) and to continue the study with the investigation of the remaining variables.

Positive experiments performed from this point are additionally designated with the letter "B".

E. Negative Impregnation/Polarization Experiments

TABLE II

NEGATIVE IMPREGNATION STUDY

Variables	Designation	Levels
1	Specific Gravity of Cadmium Nitrate	1.800 - 1.900
2	Free Acid	.2 - .5 gm/liter
3	Temperature of Nitrate	110°F - 140°F
4	Time of Impregnation	15 Minutes - 1 Hour
5	Vacuum	0 - 15 Inches
6	Wash Time	10 Minutes - 30 Minutes
7	Wash (Number of Cycles)	1 - 3
8	Wash Water Temperature	R.T. - 150°F
9	pH of Wash Water	Measured
10	Type of Caustic	KOH - NaOH
11	Specific Gravity of Caustic	1.200 - 1.300
12	Temperature of Caustic	80°F - 150°F
13	Amount of NH_3 in Caustic	Measured
14	Amount of CO_2 in Caustic	Measured
15	Amount of OH in Caustic	Measured
16	Polarization Current	.1 - .4 Amps/sq.in.
17	Polarization Time	15 Minutes - 1 Hour
18	Voltage of Plaque to Ref. Electrode	Measured
19	Amount of Cycles with Same Caustic	1 - 5
20	Number of Total Cycles	Measured
21	Type of Plaque	3 Types

Responses

1	Pick-up Weight
2	Capacity
3	Plaque (Characterization)

As in the case of the positive design experiment, the original negative design experiment was subjected to a variable reduction effort to derive a more feasible experimental program. The same variables finally selected for investigation during the positive impregnation/polarization study were also chosen for the negative study.

Again, utilizing the impregnation/polarization multiple regression data presented in Section III.A of the Third Quarterly Report, the applicable variables of the negative design experiments were set constant at the indicated preferred levels. The following summarizes the subject variables and the preferred levels:

VARIABLES

3 Temperature of Nitrate - High nitrate temperature was preferred in the previous design experiments. This variable was set constant at the higher level of 140°F.

11 Specific Gravity of Caustic - High level preferred, set constant at higher level of 1.30.

12 Temperature of Caustic - Low level preferred, set constant at lower level of 80°F.

16 Polarization Current - High level preferred, set constant at a higher level of 0.4 $Amps/in^2$.

The remaining variables relegated to the status of constants, and the measured variables are treated in a fashion identical to the positive experimental work. The higher free acid level of variable Number 2 was chosen because this is very close to the level presently used in the production operation (0.4 grams/liter free acid).

The following summarizes the negative impregnation/polarization process variables selected for study in the revised negative design experiment:

	VARIABLES	LEVELS
1	Specific Gravity of Nitrate	1.80 - 1.90
4	Time of Impregnation	15 Minutes - 60 Minutes
17	Polarization Time	15 Minutes - 60 Minutes
21	Type of Plaque	3 Types

F. Positive and Negative Impregnation/Polarization Experimental Data

Table Number III is a composite of the process variable values recorded throughout the impregnation/polarization process study.

Table Number IV is a composite of the response values recorded throughout the process study. Except for the plaque characterization rating (which is the same for all three plaques which make-up a single experiment), the individual response values are an average of three measurements for each response.

Individual measurements for each response and specific comments concerning the plaque characterization response may be found in Appendix C of this report.

TABLE NUMBER III

POSITIVE IMPREGNATION/POLARIZATION EXPERIMENT VARIABLE LEVELS

VARIABLES	EXPERIMENTS 1	2	3	4	5A	6A	7A	8B	9A	10B
1. Sp.Gr. of Nitrate	1.70	1.70	1.70	1.70	1.70	1.80	1.80	1.80	1.80	1.70
2. Free Acid (Controlled By Addition of HNO_3)	gms/liter 1.0	1.2-1.4	1.0	1.0	0.8-1.0	3.8	3.4-4.4	0.8-1.0	1.0-1.2	1.0-1.8
3. Temp. of Nitrate (In I/P Tank) °F	132-137	136-145	175-189	180-188	178-186	182-190	188-194	188-196	186-190	182-195
4. Time of Impregnation	1 Hr.	15 Min.	15 Min.	1 Hr.	1 Hr.	1 Hr.	15 Min.	15 Min.	1 Hr.	15 Min.
5. Vacuum (Inches)	15	0	15	15	0	0	0	0	0	0
6. Wash Time (Minutes)	30	10	10	10	10	10	10	10	10	10
7. Wash (No. of Cycles)	1	1	3	3	3	3	3	3	3	3
8. Wash Water Temp. (°F)	59	64-70	52-54	50-56	50-52	48-50	46-48	48-49	49	48
9. pH of Wash Water (Measured pH Paper)	4.5-5.3	4.5-5.0	4.5-5.3	4.5	4.5	4.5	4.5	4.5	4.5	4.0
10. Type of Caustic	NaOH	KOH	KOH	KOH	NaOH	NaOH	KOH	NaOH	NaOH	NaOH
11. Sp.Gr. of Caustic	1.30	1.20	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30
12. Temp. of Caustic (I/P Tank)	64-74	140-151	150-158	150-156	150-160	150-160	150-160	150-170	138-156	135-148
13. Amt. of NH_3 in Caustic (N)	0.021-0.037	0.008-0.013	0.010-0.015	0.010-0.016	0.007-0.018	0.009-0.024	0.006	0.014-0.026	0.012-0.014	0.009-0.010
14. Amt. of CO_3 in Caustic (N)	0.2	0.24-0.44	0.84-* 1.40	0.44-0.60	0.28-0.44	0.16-0.24	0.12	0.20-0.44	0.32-0.36	0.32
15. Amt. of OH in Caustic (N)	9.2	0.50-0.55	7.1-7.4	7.0-7.4	9.4-9.8	9.6-9.9	7.6	9.2-9.7	9.2-9.5	8.9
16. Polarization Current	0.4 amps/in^2	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
17. Polarization Time	1 Hr.	1 Hr.	15 Min.	1 Hr.	1 Hr.	1 Hr.	15 Min.	1 Hr.	15 Min.	15 Min.
18. Voltage of Plaque to Ref.	See Appendix		--	--	--	--	--	--	--	--
19. Amt. of Cycles W/Same Caustic	1	4	4	4	4	4	4	4	4	4
20. No. of Total Cycles	4	4	4	4	4	4	4	4	4	4
21. Type of Plaque (Type)	3	3	3	3	3	3	3	3	3	3

*The high carbonate contamination indicated here is suspected to be the result of use of carbonate contaminated deionized water.

TABLE NUMBER IIIA

NEGATIVE IMPREGNATION/POLARIZATION EXPERIMENT VARIABLE LEVELS

VARIABLES	EXPERIMENTS 1	2	3	4
1. Sp. Gr. of Nitrate	1.90	1.90	1.80	1.80
2. Free Acid (Controlled By Addition of NHO3	gms/liter 0.4-0.5	0.5-0.6	0.4-0.6	0.5
3. Temp. of Nitrate (In I/P Tank) °F	130-138	132-140	130-138	128-135
4. Time of Impregnation	15 Minutes	1 Hour	1 Hour	15 Minutes
5. Vacuum (Inches)	0 Inches	0 Inches	0 Inches	0 Inches
6. Wash Time (Minutes)	10 Minutes	10 Minutes	10 Minutes	10 Minutes
7. Wash (No. of Cycles)	3 Cycles	3 Cycles	3 Cycles	3 Cycles
8. Wash Water Temp. (°F)	48 to 52	50	48	52 to 54
9. pH of Wash Water (Measured pH Paper)	4.5	4.5	4.5	4.5
10. Type of Caustic	NaOH	NaOH	NaOH	NaOH
11. Sp. Gr. of Caustic	1.30	1.30	1.30	1.30
12. Temp. of Caustic (I/P Tank)	78-88	78-94	92-103	92-110
13. Amt. of NH_3 in Caustic (N)	0.012-0.017	0.007	0.009	0.009
14. Amt. of CO_3 in Caustic (N)	0.20-0.28	0.16	0.20-0.92*	0.16-0.20
15. Amt. of OH in Caustic (N)	8.6 to 9.1	8.3	9.0 to 9.3	7.8 to 8.7
16. Polarization Current	0.4 amps/in^2	0.4	0.4	0.4
17. Polarization Time	1 Hour	15 Minutes	1 Hour	15 Minutes
18. Voltage of Plaque to Ref.	See Appendix			
19. Amt. of Cycles W/Same Caustic	3	3	3	3
20. No. of Total Cycles	3	3	3	3
21. Type of Plaque (Type)	3	3	3	3

*Suspect high carbonate indication is the result of the use of carbonate contaminated deionized water.

TABLE NUMBER IV

POSITIVE IMPREGNATION/POLARIZATION RESPONSE DATA (AVERAGED)

RESPONSES	EXPERIMENTS	1			2			3			4		
	PLAQUE LOTS	151	152	153	151	152	153	151	152	153	151	152	153
Pick-up Wt. (After Formation, Grams)		57.7	42.8	51.7	41.0	43.3	41.7	46.0	*	*	*	*	*
Ampere-Hours/Plate		2.41	1.91	2.05	1.41	*	1.38	1.78	*	*	*	*	*
Ampere-Hours/Gram		0.227	0.220	0.288	0.217	*	0.222	0.234	*	*	*	*	*
Characterization Rating		3.0	2.0	2.0	3.0	1.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0

5A			6A			7A			8B			9B			10B		
151	152	153	151	152	153	151	152	153	151	152	153	151	152	153	151	152	153
55.8	62.8	57.5	60.2	*	61.7	*	*	*	56.5	51.7	56.3	66.5	*	67.8	46.8	*	45.0
2.44	3.05	2.41	3.08	*	3.01	*	*	*	2.41	2.25	2.20	2.91	*	*	1.93	*	1.63
0.265	0.257	0.242	0.294	*	0.282	*	*	*	0.261	0.247	0.243	*	*	0.249	*	*	0.231
5.0	1.0	5.0	5.0	1.0	4.0	1.0	1.0	1.0	5.0	1.0	4.0	4.0	1.0	1.0	5.0	1.0	3.0

*The poor physical condition of the impregnated plaques prevented the determination of a response value.

NEGATIVE IMPREGNATION/POLARIZATION RESPONSE DATA (AVERAGED)

RESPONSES	EXPERIMENTS	1			2			3			4		
	PLAQUE LOTS	151	152	153	151	152	153	151	152	153	151	152	153
Pick-up Weight (After Form., Gms)		46.3	53.9	47.9	63.1	73.9	63.2	66.2	69.8	54.7	47.2	60.5	43.0
Ampere-Hours/Plate		1.97	2.33	2.05	2.63	3.10	2.80	3.04	3.29	2.31	2.30	2.82	2.00
Ampere-Hours/Gram		0.270	0.253	0.265	0.247	0.233	0.257	0.258	0.272	0.270	0.275	0.278	0.293
Characterization Rating		4.0	3.0	4.0	5.0	4.0	5.0	4.0	1.0	5.0	5.0	4.0	4.0

III. DATA ANALYSIS

The analysis of the results from the impregnation/polarization design experiments described in the previous section was performed by means of a coded, stepwise linear multiple regression and correlation program designed for use with the IBM Model 1130 digital computer.[3]

A linear regression program assumes that each dependent variable (response) is a linear function of each of the independent variables. Through a multiple correlation coefficient technique, the program combines the effects of all the relationships among the dependent and independent variables and yields a single numerical measure of the overall relationship in the form of a regression equation.

$$Y = C + B_1 X_1 + B_2 X_2 + \ldots + Bn\, Xn$$

In the above example, the Y terms represents a dependent variable (response); the X_1, X_2, . . ., Xn terms represent independent variables (values of the process variables); C is a constant term; and the B_1, B_2, . . ., Bn terms are the respective equation coefficients. Through the interpretation of these coefficients, the effect of each independent variable upon a particular dependent variable may be determined.

The raw data consisting of values of independent variables is coded by the regression program prior to its compilation in the regression matrix for further processing. This operation standardizes the numerical values of each independent variable which are usually of different magnitudes. The maximum value of each independent variable is set equal to +1 and the minimum value is set equal to -1. All intermediate values are prorated between these two values. The use of coded raw data permits the direct comparison of the coefficients within a regression. The independent variable associated with the largest coefficient exerts the greatest effect upon the subject response.

The following computer print-outs summarizes the regression analyses performed on the impregnation/polarization design experiment data. There are four major regressions (Tables I, II, III and IV); each subdivided into separate regression for each response (Tables Ia, Ib, etc.).

POSITIVE DESIGN EXPERIMENT, REGRESSION I

RAW DATA LISTING, LOT 151

	VARIABLES (X)			RESPONSES (Y)				
	1 SPECIFIC GRAVITY OF NITRATE	2 IMPREGNATION TIME - (MINUTES)	3 POLARIZATION TIME - (MINUTES)	4 PICKUP WEIGHT - (GRAMS)	5 PLATE CAPACITY - (AMP-HRS)	6 GRAM CAPACITY - (AMP-HRS)	7 PLAQUE CHARACTERI-ZATION LOT 151	8 PLAQUE CHARACTERI-ZATION ALL LOTS AVERAGED
NO. 1	1.70	60.00	60.00	54.00	2.37	0.26	5.00	3.70
NO. 2	1.70	60.00	60.00	57.50	2.59	0.25	5.00	3.70
NO. 3	1.70	60.00	60.00	56.00	2.37	0.27	5.00	3.70
NO. 4	1.80	15.00	60.00	56.00	2.41	0.25	4.00	3.00
NO. 5	1.80	15.00	60.00	57.00	2.47	0.25	4.00	3.00
NO. 6	1.80	15.00	60.00	56.50	2.36	0.26	4.00	3.00
NO. 7	1.80	60.00	15.00	67.00	2.82	0.27	5.00	2.30
NO. 8	1.80	60.00	15.00	65.50	2.97	0.27	5.00	2.30
NO. 9	1.80	60.00	15.00	67.00	2.94	0.27	5.00	2.30
NO. 10	1.70	15.00	15.00	46.50	1.93	0.25	3.00	2.00
NO. 11	1.70	15.00	15.00	46.50	2.02	0.25	3.00	2.00
NO. 12	1.70	15.00	15.00	47.50	1.85	0.24	3.00	2.00

TOT NO. OBS= 12

REGRESSION I

CORRELATION MATRIX

	1	2	3	4	5	6	7	8
1	1.000	0.000	0.000	0.724	0.669	0.459	0.301	-0.152
2	0.000	1.000	0.000	0.677	0.712	0.673	0.904	0.380
3	0.000	0.000	1.000	-0.035	0.009	0.076	0.301	0.912
4	0.724	0.677	-0.035	1.000	0.975	0.764	0.820	0.114
5	0.669	0.712	0.009	0.975	1.000	0.734	0.849	0.177
6	0.459	0.673	0.076	0.764	0.734	1.000	0.771	0.256
7	0.301	0.904	0.301	0.820	0.849	0.771	1.000	0.573
8	-0.152	0.380	0.912	0.114	0.177	0.256	0.573	1.000

REGRESSION Ia

RESPONSE (Y), PICKUP WEIGHT

ANALYSIS OF Y 1

X	RSQR X	B COEF	SE(B)	T
1	0.0000	5.0830	0.3033	16.75
2	0.0000	4.7497	0.3033	15.65
3	-0.0000	-0.2499	0.3033	-0.82

CONSTANT	MULT F	DF1	DF2	RSQR	RESIDUAL
56.41666	175.57	3	8	0.985	1.10417

VARIABLES IN MODEL - Y 1

X	B COEF
1	5.0830
2	4.7497
3	-0.2499

CONSTANT= 56.41666

RESIDUALS AND PREDICTIONS

OBS	Y(OBS)	Y(PRED)	RESIDUAL	S.E.(Y)	NORM DEV	RESIDUALS SSQS
1	54.0000	55.8333	-1.8333	0.6066	-1.744	3.3610925
2	57.5000	55.8333	1.6666	0.6066	1.586	6.1388874
3	56.0000	55.8333	0.1666	0.6066	0.158	6.1666660
4	56.0000	56.5000	-0.4999	0.6066	-0.475	6.4166584
5	57.0000	56.5000	0.5000	0.6066	0.475	6.6666660
6	56.5000	56.5000	0.0000	0.6066	0.000	6.6666660
7	67.0000	66.5000	0.5000	0.6066	0.475	6.9166813
8	65.5000	66.5000	-0.9999	0.6066	-0.951	7.9166507
9	67.0000	66.5000	0.5000	0.6066	0.475	8.1666660
10	46.5000	46.8333	-0.3333	0.6066	-0.317	8.2777729
11	46.5000	46.8333	-0.3333	0.6066	-0.317	8.3888798
12	47.5000	46.8333	0.6666	0.6066	0.634	8.8333301

REGRESSION Ib

RESPONSE (Y), PLATE CAPACITY

X	RSQR X	B COEF	SE(B)	T	ANALYSIS OF Y 2
1	0.0000	0.2366	0.0260	9.06	
2	0.0000	0.2516	0.0260	9.64	
3	-0.0000	0.0033	0.0260	0.12	0.333317E-02

CONSTANT	MULT F	DF1	DF2	RSQR	RESIDUAL
2.42499	58.40	3	8	0.956	0.8175017E-02

VARIABLES IN MODEL - Y 2

X	B COEF
1	0.2366
2	0.2516
3	0.0033

CONSTANT= 2.42499

RESIDUALS AND PREDICTIONS

OBS	Y(OBS)	Y(PRED)	RESIDUAL	S.E.(Y)	NORM DEV	RESIDUALS SSQS
1	2.3700	2.4433	-0.0733	0.0522	-0.811	0.0053774
2	2.5900	2.4433	0.1466	0.0522	1.622	0.0268891
3	2.3700	2.4433	-0.0733	0.0522	-0.811	0.0322666
4	2.4100	2.4133	-0.0033	0.0522	-0.036	0.0322777
5	2.4700	2.4133	0.0566	0.0522	0.626	0.0354890
6	2.3600	2.4133	-0.0533	0.0522	-0.589	0.0383332
7	2.8200	2.9099	-0.0899	0.0522	-0.995	0.0464329
8	2.9700	2.9099	0.0600	0.0522	0.663	0.0500331
9	2.9400	2.9099	0.0300	0.0522	0.331	0.0509332
10	1.9300	1.9333	-0.0033	0.0522	-0.036	0.0509443
11	2.0200	1.9333	0.0866	0.0522	0.958	0.0584557
12	1.8500	1.9333	-0.0833	0.0522	-0.921	0.0653999

REGRESSION Ic

RESPONSE (Y), GRAM CAPACITY

X	RSQR X	B COEF	SE(B)	T	ANALYSIS OF Y 3
1	0.0000	0.0049	0.0022	2.26	0.499975E-02
2	0.0000	0.0073	0.0022	3.32	0.733296E-02
3	-0.0000	0.0008	0.0022	0.37	0.833287E-03

CONSTANT	MULT F	DF1	DF2	RSQR	RESIDUAL
0.26216	5.43	3	8	0.670	0.5850007E-04

VARIABLES IN MODEL - Y 3

X	B COEF
1	0.0049
2	0.0073
3	0.0009

CONSTANT= 0.26216

RESIDUALS AND PREDICTIONS

OBS	Y(OBS)	Y(PRED)	RESIDUAL	S.E.(Y)	NORM DEV	RESIDUALS SSQS
1	0.2630	0.2653	-0.0023	0.0044	-0.305	0.0000054
2	0.2540	0.2653	-0.0113	0.0044	-1.481	0.0001338
3	0.2790	0.2653	0.0136	0.0044	1.786	0.0003206
4	0.2570	0.2606	-0.0036	0.0044	-0.479	0.0003341
5	0.2570	0.2606	-0.0036	0.0044	-0.479	0.0003475
6	0.2680	0.2606	0.0073	0.0044	0.958	0.0004013
7	0.2740	0.2736	0.0003	0.0044	0.043	0.0004014
8	0.2750	0.2736	0.0013	0.0044	0.174	0.0004032
9	0.2720	0.2736	-0.0016	0.0044	-0.217	0.0004060
10	0.2540	0.2489	0.0050	0.0044	0.653	0.0004310
11	0.2500	0.2489	0.0010	0.0044	0.130	0.0004320
12	0.2430	0.2489	-0.0059	0.0044	-0.784	0.0004680

REGRESSION Id

RESPONSE (Y), PLAQUE CHARACTERIZATION
LOT 151

ANALYSIS OF Y 4

X	RSQR X	B COEF	SE(B)	T
1	0.0000	0.2499	0.0002	1023.99
2	0.0000	0.7499	0.0002	3072.00
3	-0.0000	0.2499	0.0002	1023.99

CONSTANT	MULT F	DF1	DF2	RSQR	RESIDUAL
4.25000	3844776.50	3	8	0.999	0.7152558E-06

VARIABLES IN MODEL - Y 4

X	B COEF
1	0.2499
2	0.7499
3	0.2499

CONSTANT= 4.25000

RESIDUALS AND PREDICTIONS

OBS	Y(OBS)	Y(PRED)	RESIDUAL	S.E.(Y)	NORM DEV	RESIDUALS SSQS
1	5.0000	5.0000	0.0000	0.0004	0.001	0.0000000
2	5.0000	5.0000	0.0000	0.0004	0.001	0.0000000
3	5.0000	5.0000	0.0000	0.0004	0.001	0.0000000
4	4.0000	3.9999	0.0000	0.0004	0.001	0.0000000
5	4.0000	3.9999	0.0000	0.0004	0.001	0.0000000
6	4.0000	3.9999	0.0000	0.0004	0.001	0.0000000
7	5.0000	5.0000	0.0000	0.0004	0.001	0.0000000
8	5.0000	5.0000	0.0000	0.0004	0.001	0.0000000
9	5.0000	5.0000	0.0000	0.0004	0.001	0.0000000
10	3.0000	2.9999	0.0000	0.0004	0.001	0.0000000
11	3.0000	2.9999	0.0000	0.0004	0.001	0.0000000
12	3.0000	2.9999	0.0000	0.0004	0.001	0.0000000

REGRESSION Ie

RESPONSE (Y), PLAQUE CHARACTERIZATION
ALL LOTS AVERAGED

X	RSQR X	B COEF	SE(B)	T
1	0.0000	-0.0999	0.0000	-1003.30
2	0.0000	0.2499	0.0000	2508.27
3	-0.0000	0.5999	0.0000	6019.86

ANALYSIS OF Y 5
-0.999949E-01

CONSTANT	MULT F	DF1	DF2	RSQR	RESIDUAL
2.74999	**********	3	8	1.000	-0.1192093E-06

VARIABLES IN MODEL - Y 5

X	B COEF
1	-0.0999
2	0.2499
3	0.5999

CONSTANT= 2.74999

RESIDUALS AND PREDICTIONS

OBS	Y(OBS)	Y(PRED)	RESIDUAL	S.E.(Y)	NORM DEV	RESIDUALS SSQS
1	3.7000	3.6999	0.0000	0.0001	0.004	0.0000000
2	3.7000	3.6999	0.0000	0.0001	0.004	0.0000000
3	3.7000	3.6999	0.0000	0.0001	0.004	0.0000000
4	3.0000	2.9999	0.0000	0.0001	0.004	0.0000000
5	3.0000	2.9999	0.0000	0.0001	0.004	0.0000000
6	3.0000	2.9999	0.0000	0.0001	0.004	0.0000000
7	2.3000	2.2999	0.0000	0.0001	0.002	0.0000000
8	2.3000	2.2999	0.0000	0.0001	0.002	0.0000000
9	2.3000	2.2999	0.0000	0.0001	0.002	0.0000000
10	2.0000	1.9999	0.0000	0.0001	0.002	0.0000000
11	2.0000	1.9999	0.0000	0.0001	0.002	0.0000000
12	2.0000	1.9999	0.0000	0.0001	0.002	0.0000000

POSITIVE DESIGN EXPERIMENT, REGRESSION II

RAW DATA LISTING, LOTS 151, 152 AND 153

	VARIABLES (X)				RESPONSES (Y)			
	1 SP.GR. OF NITRATE	2 IMPREGNATION TIME (MINUTES)	3 POLARIZATION TIME (MINUTES)	4 POROSITY (% VOID PLAQUE)	5 PICKUP WEIGHT (GRAMS)	6 PLATE CAPACITY (AMP-HRS)	7 GRAM CAPACITY (AMP-HRS)	8 PLAQUE CHARACTERIZATION INDEX
NO. 1	1.70	60.00	60.00	83.30	54.00	2.37	0.27	5.00
NO. 2	1.70	60.00	60.00	83.30	57.50	2.59	0.25	5.00
NO. 3	1.70	60.00	60.00	83.30	56.00	2.37	0.27	5.00
NO. 4	1.70	60.00	60.00	86.00	66.50	3.23	0.24	1.00
NO. 5	1.70	60.00	60.00	86.00	65.50	2.95	0.26	1.00
NO. 6	1.70	60.00	60.00	86.00	56.50	2.97	0.26	1.00
NO. 7	1.70	60.00	60.00	85.70	54.00	2.16	0.25	5.00
NO. 8	1.70	60.00	60.00	85.70	59.50	2.54	0.22	5.00
NO. 9	1.70	60.00	60.00	85.70	59.00	2.54	0.24	5.00
NO. 10	1.80	15.00	60.00	83.30	56.00	2.41	0.25	4.00
NO. 11	1.80	15.00	60.00	83.30	57.00	2.47	0.25	4.00
NO. 12	1.80	15.00	60.00	83.30	56.50	2.36	0.26	4.00
NO. 13	1.80	15.00	60.00	86.00	48.50	2.05	0.25	1.00
NO. 14	1.80	15.00	60.00	86.00	52.00	2.28	0.23	1.00
NO. 15	1.80	15.00	60.00	86.00	54.50	2.43	0.25	1.00
NO. 16	1.80	15.00	60.00	85.70	56.50	2.17	0.23	4.00
NO. 17	1.80	15.00	60.00	85.70	57.00	2.32	0.24	4.00
NO. 18	1.80	15.00	60.00	85.70	55.50	2.12	0.25	4.00
NO. 19	1.80	60.00	15.00	83.30	67.00	2.82	0.27	5.00
NO. 20	1.80	60.00	15.00	83.30	65.50	2.97	0.27	5.00
NO. 21	1.80	60.00	15.00	83.30	67.00	2.94	0.27	5.00
NO. 22	1.70	15.00	15.00	83.30	46.50	1.93	0.25	3.00
NO. 23	1.70	15.00	15.00	83.30	46.50	2.02	0.25	3.00
NO. 24	1.70	15.00	15.00	83.30	47.50	1.85	0.24	3.00
NO. 25	1.70	15.00	15.00	85.70	45.50	1.70	0.23	2.00
NO. 26	1.70	15.00	15.00	85.70	46.00	1.65	0.22	2.00
NO. 27	1.70	15.00	15.00	85.70	43.50	1.53	0.23	2.00

TOT NO. OBS= 27

REGRESSION II

CORRELATION MATRIX

	1	2	3	4	5	6	7	8
1	1.000	-0.350	0.158	-0.088	0.302	0.175	0.246	0.095
2	-0.350	1.000	0.158	-0.088	0.685	0.716	0.451	0.381
3	0.158	0.158	1.000	0.337	0.276	0.336	0.039	0.000
4	-0.088	-0.088	0.337	1.000	-0.107	-0.091	-0.583	-0.576
5	0.302	0.685	0.276	-0.107	1.000	0.924	0.526	0.335
6	0.175	0.716	0.336	-0.091	0.924	1.000	0.543	0.138
7	0.246	0.451	0.039	-0.583	0.526	0.543	1.000	0.342
8	0.095	0.381	0.000	-0.576	0.335	0.138	0.342	1.000

REGRESSION IIa

RESPONSE (Y), PICKUP WEIGHT

ANALYSIS OF Y 1

X	RSQR X	B COEF	SE(B)	T
1	0.2141	4.1996	0.7229	5.80
2	0.2141	6.1439	0.7229	8.49
3	0.2255	0.2366	0.7676	0.30
4	0.1814	0.1179	0.7560	0.15

CONSTANT	MULT F	DF1	DF2	RSQR	RESIDUAL
56.51052	23.08	4	22	0.807	10.95439

VARIABLES IN MODEL - Y 1

X	B COEF
1	4.1996
2	6.1439
3	0.2366
4	0.1179

CONSTANT= 56.51052

RESIDUALS AND PREDICTIONS

OBS	Y(OBS)	Y(PRED)	RESIDUAL	S.E.(Y)	NORM DEV	RESIDUALS SSQS
1	54.0000	58.5737	-4.5737	1.4573	-1.381	20.9190826
2	57.5000	58.5737	-1.0737	1.4573	-0.324	22.0719948
3	56.0000	58.5737	-2.5737	1.4573	-0.777	28.6961212
4	66.5000	58.8095	7.6904	1.2372	2.323	87.8390657
5	65.5000	58.8095	6.6904	1.2372	2.021	132.6011051
6	56.5000	58.8095	-2.3095	1.2372	-0.697	137.9351199
7	54.0000	58.7833	-4.7833	1.1708	-1.445	160.8155216
8	59.5000	58.7833	0.7166	1.1708	0.216	161.3291019
9	59.0000	58.7833	0.2166	1.1708	0.065	161.3760379
10	56.0000	54.6848	1.3151	1.4573	0.397	163.1056216
11	57.0000	54.6848	2.3151	1.4573	0.699	168.4655154
12	56.5000	54.6848	1.8151	1.4573	0.548	171.7602543
13	49.5000	54.9206	-6.4206	1.2372	-1.939	212.9852298
14	52.0000	54.9206	-2.9206	1.2372	-0.882	221.5155338
15	54.5000	54.9206	-0.4206	1.2372	-0.127	221.6924747
16	56.5000	54.8944	1.6055	1.1708	0.485	224.2702029
17	57.0000	54.8944	2.1055	1.1708	0.636	228.7034610
18	55.5000	54.8944	0.6055	1.1708	0.182	229.0701298
19	67.0000	66.5000	0.5000	1.9108	0.151	229.3201298
20	65.5000	66.5000	-0.9999	1.9108	-0.302	230.3200992
21	67.0000	66.5000	0.5000	1.9108	0.151	230.5700992
22	46.5000	45.8118	0.6881	1.5091	0.207	231.0436404
23	46.5000	45.8118	0.6881	1.5091	0.207	231.5171817
24	47.5000	45.8118	1.6881	1.5091	0.510	234.3670048
25	45.5000	46.0214	-0.5214	1.5091	-0.157	234.6389164
26	46.0000	46.0214	-0.0214	1.5091	-0.006	234.6393741
27	43.5000	46.0214	-2.5214	1.5091	-0.761	240.9971622

REGRESSION IIb

RESPONSE (Y), PLATE CAPACITY

X	RSQR X	B COEF	SE(B)	T	ANALYSIS OF Y 2
1	0.2141	0.1937	0.0532	3.64	
2	0.2141	0.3665	0.0532	6.88	
3	0.2255	0.0631	0.0565	1.11	0.631072E-01
4	0.1814	-0.0103	0.0556	-0.18	-0.103608E-01

CONSTANT	MULT F	DF1	DF2	RSQR	RESIDUAL
2.40235	15.39	4	22	0.736	0.593711OE-01

VARIABLES IN MODEL - Y 2

X	B COEF
1	0.1937
2	0.3665
3	0.0631
4	-0.0103

CONSTANT= 2.40235

RESIDUALS AND PREDICTIONS

OBS	Y(OBS)	Y(PRED)	RESIDUAL	S.E.(Y)	NORM DEV	RESIDUALS SSQS
1	2.3700	2.6486	-0.2785	0.1072	-1.143	0.0776178
2	2.5900	2.6486	-0.0585	0.1072	-0.240	0.0810517
3	2.3700	2.6486	-0.2785	0.1072	-1.143	0.1586695
4	3.2300	2.6278	0.6021	0.0910	2.471	0.5212209
5	2.9500	2.6278	0.3221	0.0910	1.322	0.6249837
6	2.9700	2.6278	0.3421	0.0910	1.404	0.7420315
7	2.1600	2.6301	-0.4701	0.0861	-1.929	0.9631003
8	2.5400	2.6301	-0.0901	0.0861	-0.370	0.9712325
9	2.5400	2.6301	-0.0901	0.0861	-0.370	0.9793647
10	2.4100	2.3030	0.1069	0.1072	0.438	0.9908041
11	2.4700	2.3030	0.1669	0.1072	0.685	1.0186784
12	2.3600	2.3030	0.0569	0.1072	0.233	1.0219221
13	2.0500	2.2823	-0.2323	0.0910	-0.953	1.0758955
14	2.2800	2.2823	-0.0023	0.0910	-0.009	1.0759007
15	2.4300	2.2823	0.1476	0.0910	0.606	1.0977094
16	2.1700	2.2846	-0.1146	0.0861	-0.470	1.1108481
17	2.3200	2.2846	0.0353	0.0861	0.145	1.1120994
18	2.1200	2.2846	-0.1646	0.0861	-0.675	1.1392004
19	2.8200	2.9099	-0.0899	0.1406	-0.369	1.1472995
20	2.9700	2.9099	0.0600	0.1406	0.246	1.1508998
21	2.9400	2.9099	0.0300	0.1406	0.123	1.1517999
22	1.9300	1.7892	0.1407	0.1111	0.577	1.1716222
23	2.0200	1.7892	0.2307	0.1111	0.947	1.2248873
24	1.8500	1.7892	0.0607	0.1111	0.249	1.2285831
25	1.7000	1.7707	-0.0707	0.1111	-0.290	1.2335937
26	1.6500	1.7707	-0.1207	0.1111	-0.495	1.2481830
27	1.5300	1.7707	-0.2407	0.1111	-0.988	1.3061614

REGRESSION IIc

RESPONSE (Y), GRAM CAPACITY

X	RSQR X	B COEF	SE(B)	T	ANALYSIS OF Y 3
1	0.2141	0.0054	0.0021	2.55	0.541653E-02
2	0.2141	0.0076	0.0021	3.60	0.763864E-02
3	0.2255	0.0012	0.0022	0.53	0.120569E-02
4	0.1814	-0.0083	0.0022	-3.74	-0.831143E-02

CONSTANT	MULT F	DF1	DF2	RSQR	RESIDUAL
0.25350	9.72	4	22	0.638	0.9424144E-04

VARIABLES IN MODEL - Y 3

X	B COEF
1	0.0054
2	0.0076
3	0.0012
4	-0.0083

CONSTANT= 0.25350

RESIDUALS AND PREDICTIONS

OBS	Y(OBS)	Y(PRED)	RESIDUAL	S.E.(Y)	NORM DEV	RESIDUALS SSQS
1	0.2630	0.2652	-0.0022	0.0042	-0.231	0.0000050
2	0.2540	0.2652	-0.0112	0.0042	-1.158	0.0001314
3	0.2790	0.2652	0.0137	0.0042	1.416	0.0003206
4	0.2430	0.2486	-0.0056	0.0036	-0.578	0.0003522
5	0.2680	0.2486	0.0193	0.0036	1.996	0.0007278
6	0.2600	0.2486	0.0113	0.0036	1.172	0.0008573
7	0.2510	0.2504	0.0005	0.0034	0.054	0.0008576
8	0.2260	0.2504	-0.0244	0.0034	-2.520	0.0014562
9	0.2490	0.2504	-0.0014	0.0034	-0.151	0.0014584
10	0.2570	0.2607	-0.0037	0.0042	-0.391	0.0014728
11	0.2570	0.2607	-0.0037	0.0042	-0.391	0.0014873
12	0.2680	0.2607	0.0072	0.0042	0.741	0.0015391
13	0.2560	0.2441	0.0118	0.0036	1.217	0.0016789
14	0.2350	0.2441	-0.0091	0.0036	-0.945	0.0017631
15	0.2500	0.2441	0.0058	0.0036	0.599	0.0017970
16	0.2360	0.2460	-0.0100	0.0034	-1.032	0.0018975
17	0.2420	0.2460	-0.0040	0.0034	-0.414	0.0019137
18	0.2520	0.2460	0.0059	0.0034	0.615	0.0019494
19	0.2740	0.2736	0.0003	0.0056	0.034	0.0019495
20	0.2750	0.2736	0.0013	0.0056	0.137	0.0019513
21	0.2720	0.2736	-0.0016	0.0056	-0.171	0.0019541
22	0.2540	0.2475	0.0064	0.0044	0.663	0.0019956
23	0.2500	0.2475	0.0024	0.0044	0.251	0.0020016
24	0.2430	0.2475	-0.0045	0.0044	-0.469	0.0020223
25	0.2330	0.2327	0.0002	0.0044	0.022	0.0020224
26	0.2260	0.2327	-0.0067	0.0044	-0.698	0.0020683
27	0.2350	0.2327	0.0022	0.0044	0.228	0.0020733

REGRESSION IId

RESPONSE (Y), PLAQUE CHARACTERIZATION

ANALYSIS OF Y 4

X	RSQR X	B COEF	SE(B)	T
1	0.2141	0.2469	0.2722	0.90
2	0.2141	0.5802	0.2722	2.13
3	0.2255	0.1791	0.2890	0.61
4	0.1814	-0.9509	0.2846	-3.34

CONSTANT	MULT F	DF1	DF2	RSQR	RESIDUAL
3.40077	5.12	4	22	0.482	1.55318

VARIABLES IN MODEL - Y 4

X	B COEF
1	0.2469
2	0.5802
3	0.1791
4	-0.9509

CONSTANT= 3.40077

RESIDUALS AND PREDICTIONS

OBS	Y(OBS)	Y(PRED)	RESIDUAL	S.E.(Y)	NORM DEV	RESIDUALS SSQS
1	5.0000	4.8642	0.1357	0.5487	0.108	0.0184264
2	5.0000	4.8642	0.1357	0.5487	0.108	0.0368529
3	5.0000	4.8642	0.1357	0.5487	0.108	0.0552793
4	1.0000	2.9622	-1.9622	0.4658	-1.574	3.9055185
5	1.0000	2.9622	-1.9622	0.4658	-1.574	7.7557573
6	1.0000	2.9622	-1.9622	0.4658	-1.574	11.6059971
7	5.0000	3.1735	1.8264	0.4408	1.465	14.9419613
8	5.0000	3.1735	1.8264	0.4408	1.465	18.2779274
9	5.0000	3.1735	1.8264	0.4408	1.465	21.6138916
10	4.0000	4.1975	-0.1975	0.5487	-0.158	21.6529312
11	4.0000	4.1975	-0.1975	0.5487	-0.158	21.6919708
12	4.0000	4.1975	-0.1975	0.5487	-0.158	21.7310104
13	1.0000	2.2955	-1.2955	0.4658	-1.039	23.4094238
14	1.0000	2.2955	-1.2955	0.4658	-1.039	25.0878372
15	1.0000	2.2955	-1.2955	0.4658	-1.039	26.7662506
16	4.0000	2.5068	1.4931	0.4408	1.198	28.9956818
17	4.0000	2.5068	1.4931	0.4408	1.198	31.2251129
18	4.0000	2.5068	1.4931	0.4408	1.198	33.4545441
19	5.0000	4.9999	0.0000	0.7195	0.000	33.4545441
20	5.0000	4.9999	0.0000	0.7195	0.000	33.4545441
21	5.0000	4.9999	0.0000	0.7195	0.000	33.4545441
22	3.0000	3.3453	-0.3453	0.5682	-0.277	33.5738144
23	3.0000	3.3453	-0.3453	0.5682	-0.277	33.6930848
24	3.0000	3.3453	-0.3453	0.5682	-0.277	33.8123551
25	2.0000	1.6546	0.3453	0.5682	0.277	33.9316254
26	2.0000	1.6546	0.3453	0.5682	0.277	34.0508957
27	2.0000	1.6546	0.3453	0.5682	0.277	34.1701661

NEGATIVE DESIGN EXPERIMENT, REGRESSION III

RAW DATA LISTING, LOT 151

	VARIABLES (X)			RESPONSES (Y)				
	1 SPECIFIC GRAVITY OF NITRATE	2 IMPREGNATION TIME - (MINUTES)	3 POLARIZATION TIME - (MINUTES)	4 PICKUP WEIGHT - (GRAMS)	5 PLATE CAPACITY - (AMP-HRS)	6 GRAM CAPACITY - (AMP-HRS)	7 PLAQUE CHARACTERI-ZATION LOT 151	PLAQUE CHARACTERIZATION ALL LOTS AVERAGED
*FILES(4,FFFF2)								
NO. 1	1.90	15.00	60.00	47.20	1.98	0.26	4.00	3.70
NO. 2	1.90	15.00	60.00	47.80	2.08	0.27	4.00	3.70
NO. 3	1.90	15.00	60.00	43.90	1.84	0.26	4.00	3.70
NO. 4	1.90	60.00	15.00	64.10	2.71	0.24	5.00	4.70
NO. 5	1.90	60.00	15.00	63.00	2.63	0.24	5.00	4.70
NO. 6	1.90	60.00	15.00	62.20	2.56	0.24	5.00	4.70
NO. 7	1.80	60.00	60.00	65.00	3.07	0.25	4.00	3.30
NO. 8	1.80	60.00	60.00	66.50	3.04	0.26	4.00	3.30
NO. 9	1.80	60.00	60.00	67.00	3.01	0.25	4.00	3.30
NO. 10	1.80	15.00	15.00	38.00	1.61	0.25	5.00	4.30
NO. 11	1.80	15.00	15.00	52.00	2.65	0.27	5.00	4.30
NO. 12	1.80	15.00	15.00	51.50	2.63	0.28	5.00	4.30

TOT NO. OBS= 12

REGRESSION III

CORRELATION MATRIX

	1	2	3	4	5	6	7	8
1	1.000	0.000	0.000	-0.101	-0.391	-0.329	-0.000	0.371
2	0.000	1.000	0.000	0.928	0.749	-0.777	-0.000	0.000
3	0.000	0.000	1.000	0.057	0.040	0.131	-1.000	-0.928
4	-0.101	0.928	0.057	1.000	0.922	-0.531	-0.057	-0.090
5	-0.391	0.749	0.040	0.922	1.000	-0.215	-0.040	-0.183
6	-0.329	-0.777	0.131	-0.531	-0.215	1.000	-0.131	-0.244
7	-0.000	-0.000	-1.000	-0.057	-0.040	-0.131	1.000	0.928
8	0.371	0.000	-0.928	-0.090	-0.183	-0.244	0.928	1.000

REGRESSION IIIa

RESPONSE (Y), PICKUP WEIGHT

ANALYSIS OF Y 1

X	RSQR X	B COEF	SE(B)	T
1	-0.0000	-0.9832	1.2031	-0.81
2	0.0000	8.9495	1.2031	7.43
3	0.0000	0.5499	1.2031	0.45

CONSTANT	MULT F	DF1	DF2	RSQR	RESIDUAL
55.68331	18.73	3	8	0.875	17.37169

VARIABLES IN MODEL - Y 1

X	B COEF
1	-0.9832
2	8.9495
3	0.5499

CONSTANT= 55.68331

RESIDUALS AND PREDICTIONS

OBS	Y(OBS)	Y(PRED)	RESIDUAL	S.E.(Y)	NORM DEV	RESIDUALS SSQS
1	47.2000	46.2999	0.9000	2.4063	0.215	0.8100302
2	47.8000	46.2999	1.5000	2.4063	0.359	3.0600762
3	43.9000	46.2999	-2.3999	2.4063	-0.575	8.8200111
4	64.1000	63.0999	1.0000	2.4063	0.239	9.8200416
5	63.0000	63.0999	-0.0999	2.4063	-0.023	9.8300361
6	62.2000	63.0999	-0.8999	2.4063	-0.215	10.6399975
7	65.0000	66.1666	-1.1666	2.4063	-0.279	12.0010490
8	66.5000	66.1666	0.3333	2.4063	0.079	12.1121769
9	67.0000	66.1666	0.8333	2.4063	0.199	12.8066635
10	38.0000	47.1666	-9.1666	2.4063	-2.199	96.8341218
11	52.0000	47.1666	4.8333	2.4063	1.159	120.1954042
12	51.5000	47.1666	4.3333	2.4063	1.039	138.9733279

REGRESSION IIIb

RESPONSE (Y), PLATE CAPACITY

X	RSQR X	B COEF	SE(B)	T	ANALYSIS OF Y 2
1	-0.0000	-0.1841	0.0883	-2.08	
2	0.0000	0.3524	0.0883	3.99	
3	0.0000	0.0191	0.0883	0.21	0.191657E-01

CONSTANT	MULT F	DF1	DF2	RSQR	RESIDUAL
2.48416	6.76	3	8	0.717	0.9359997E-01

VARIABLES IN MODEL - Y 2

X	B COEF
1	-0.1841
2	0.3524
3	0.0191

CONSTANT= 2.48416

RESIDUALS AND PREDICTIONS

OBS	Y(OBS)	Y(PRED)	RESIDUAL	S.E.(Y)	NORM DEV	RESIDUALS SSQS
1	1.9800	1.9666	0.0133	0.1767	0.043	0.0001778
2	2.0800	1.9666	0.1133	0.1767	0.370	0.0130226
3	1.8400	1.9666	-0.1266	0.1767	-0.413	0.0290666
4	2.7100	2.6333	0.0766	0.1767	0.250	0.0349446
5	2.6300	2.6333	-0.0033	0.1767	-0.010	0.0349557
6	2.5600	2.6333	-0.0733	0.1767	-0.239	0.0403332
7	3.0700	3.0399	0.0300	0.1767	0.098	0.0412333
8	3.0400	3.0399	0.0000	0.1767	0.000	0.0412333
9	3.0100	3.0399	-0.0299	0.1767	-0.097	0.0421332
10	1.6100	2.2966	-0.6866	0.1767	-2.243	0.5136412
11	2.6500	2.2966	0.3533	0.1767	1.154	0.6384871
12	2.6300	2.2966	0.3333	0.1767	1.088	0.7495995

REGRESSION IIIc

RESPONSE (Y), GRAM CAPACITY

X	RSQR X	B COEF	SE(B)	T	ANALYSIS OF Y 3
1	-0.0000	-0.0041	0.0023	-1.79	-0.416645E-02
2	0.0000	-0.0098	0.0023	-4.23	-0.983283E-02
3	0.0000	0.0016	0.0023	0.71	0.166657E-02

CONSTANT	MULT F	DF1	DF2	RSQR	RESIDUAL
0.26233	7.23	3	8	0.730	0.6458350E-04

VARIABLES IN MODEL - Y 3

X	B COEF
1	-0.0041
2	-0.0099
3	0.0016

CONSTANT= 0.26233

RESIDUALS AND PREDICTIONS

OBS	Y(OBS)	Y(PRED)	RESIDUAL	S.E.(Y)	NORM DEV	RESIDUALS SSQS
1	0.2680	0.2696	-0.0016	0.0046	-0.207	0.0000027
2	0.2740	0.2696	0.0043	0.0046	0.539	0.0000215
3	0.2670	0.2696	-0.0026	0.0046	-0.331	0.0000286
4	0.2440	0.2466	-0.0026	0.0046	-0.331	0.0000357
5	0.2480	0.2466	0.0013	0.0046	0.165	0.0000375
6	0.2480	0.2466	0.0013	0.0046	0.165	0.0000393
7	0.2580	0.2583	-0.0003	0.0046	-0.041	0.0000394
8	0.2620	0.2583	0.0036	0.0046	0.456	0.0000528
9	0.2550	0.2583	-0.0033	0.0046	-0.414	0.0000640
10	0.2590	0.2746	-0.0156	0.0046	-1.949	0.0003094
11	0.2760	0.2746	0.0013	0.0046	0.165	0.0003112
12	0.2890	0.2746	0.0143	0.0046	1.783	0.0005166

REGRESSION IIId

RESPONSE (Y), PLAQUE CHARACTERIZATION
LOT 151

X	RSQR X	B COEF	SE(B)	T	ANALYSIS OF Y 4
1	-0.0000	-0.0000	0.0000	-0.00	-0.933174E-08
2	0.0000	0.0000	0.0000	0.00	0.353216E-07
3	0.0000	-0.4999	0.0000	-0.49	

CONSTANT	MULT F	DF1	DF2	RSQR	RESIDUAL
4.50000	0.99	3	8	1.000	0.0000000E 00

VARIABLES IN MODEL - Y 4

X	B COEF
1	-0.0000
2	0.0000
3	-0.4999

CONSTANT= 4.50000

RESIDUALS AND PREDICTIONS

OBS	Y(OBS)	Y(PRED)	RESIDUAL	S.E.(Y)	NORM DEV	RESIDUALS SSQS
1	4.0000	3.9999	0.0000	0.0000	0.000	0.0000000
2	4.0000	3.9999	0.0000	0.0000	0.000	0.0000000
3	4.0000	3.9999	0.0000	0.0000	0.000	0.0000000
4	5.0000	5.0000	0.0000	0.0000	0.000	0.0000000
5	5.0000	5.0000	0.0000	0.0000	0.000	0.0000000
6	5.0000	5.0000	0.0000	0.0000	0.000	0.0000000
7	4.0000	3.9999	0.0000	0.0000	0.000	0.0000000
8	4.0000	3.9999	0.0000	0.0000	0.000	0.0000000
9	4.0000	3.9999	0.0000	0.0000	0.000	0.0000000
10	5.0000	5.0000	0.0000	0.0000	0.000	0.0000000
11	5.0000	5.0000	0.0000	0.0000	0.000	0.0000000
12	5.0000	5.0000	0.0000	0.0000	0.000	0.0000000

REGRESSION IIIe

RESPONSE (Y), PLAQUE CHARACTERIZATION
ALL LOTS AVERAGED

X	RSQR X	B COEF	SE(B)	T
1	-0.0000	0.1999	0.0001	1638.40
2	0.0000	0.0000	0.0001	0.00
3	0.0000	-0.4999	0.0001	-4095.99

ANALYSIS OF Y 5

0.125912E-06

CONSTANT	MULT F	DF1	DF2	RSQR	RESIDUAL
3.99999	**********	3	8	1.000	-0.1788139E-06

VARIABLES IN MODEL - Y 5

X	B COEF
1	0.1999
2	0.0000
3	-0.4999

CONSTANT= 3.99999

RESIDUALS AND PREDICTIONS

OBS	Y(OBS)	Y(PRED)	RESIDUAL	S.E.(Y)	NORM DEV	RESIDUALS SSQS
1	3.7000	3.6999	0.0000	0.0002	0.004	0.0000000
2	3.7000	3.6999	0.0000	0.0002	0.004	0.0000000
3	3.7000	3.6999	0.0000	0.0002	0.004	0.0000000
4	4.7000	4.6999	0.0000	0.0002	0.004	0.0000000
5	4.7000	4.6999	0.0000	0.0002	0.004	0.0000000
6	4.7000	4.6999	0.0000	0.0002	0.004	0.0000000
7	3.3000	3.2999	0.0000	0.0002	0.004	0.0000000
8	3.3000	3.2999	0.0000	0.0002	0.004	0.0000000
9	3.3000	3.2999	0.0000	0.0002	0.004	0.0000000
10	4.3000	4.2999	0.0000	0.0002	0.004	0.0000000
11	4.3000	4.2999	0.0000	0.0002	0.004	0.0000000
12	4.3000	4.2999	0.0000	0.0002	0.004	0.0000000

NEGATIVE DESIGN EXPERIMENT, REGRESSION IV

RAW DATA LISTING, LOTS 151, 152 AND 153

	VARIABLES (X)				RESPONSES (Y)			
	1 SPECIFIC GRAVITY OF NITRATE	2 IMPREGNATION TIME - (MINUTES)	3 POLARIZATION TIME - (MINUTES)	4 POROSITY (PERCENT VOID/ PLAQUE)	5 PICKUP WEIGHT - (GRAMS)	6 PLATE CAPACITY - (AMP-HRS)	7 GRAM CAPACITY - (AMP-HRS)	8 PLAQUE CHARACTERI-ZATION
NO. 1	1.90	15.00	60.00	83.30	47.20	1.98	0.26	4.00
NO. 2	1.90	15.00	60.00	83.30	47.80	2.08	0.27	4.00
NO. 3	1.90	15.00	60.00	83.30	43.90	1.84	0.26	4.00
NO. 4	1.90	15.00	60.00	86.00	54.90	2.42	0.26	3.00
NO. 5	1.90	15.00	60.00	86.00	55.30	2.39	0.25	3.00
NO. 6	1.90	15.00	60.00	86.00	51.40	2.17	0.24	3.00
NO. 7	1.90	15.00	60.00	85.70	48.00	2.12	0.27	4.00
NO. 8	1.90	15.00	60.00	85.70	49.10	2.15	0.26	4.00
NO. 9	1.90	15.00	60.00	85.70	46.60	1.89	0.25	4.00
NO. 10	1.90	60.00	15.00	83.30	64.10	2.71	0.24	5.00
NO. 11	1.90	60.00	15.00	83.30	63.00	2.63	0.24	5.00
NO. 12	1.90	60.00	15.00	83.30	62.20	2.56	0.24	5.00
NO. 13	1.90	60.00	15.00	86.00	73.00	3.00	0.24	4.00
NO. 14	1.90	60.00	15.00	86.00	75.10	3.12	0.23	4.00
NO. 15	1.90	60.00	15.00	86.00	73.20	3.18	0.22	4.00
NO. 16	1.90	60.00	15.00	85.70	62.00	2.64	0.26	5.00
NO. 17	1.90	60.00	15.00	85.70	63.00	2.90	0.24	5.00
NO. 18	1.90	60.00	15.00	85.70	63.90	2.85	0.26	5.00
NO. 19	1.80	60.00	60.00	83.[illegible]	65.00	3.07	0.25	4.00

NEGATIVE DESIGN EXPERIMENT, REGRESSION IV
(CONTINUED)

RAW DATA LISTING, LOTS 151, 152 AND 153

NO. 21	1.80	60.00	60.00	83.30	66.50	3.04	0.26	4.00
NO. 22	1.80	60.00	60.00	83.30	67.00	3.01	0.25	4.00
NO. 23	1.80	60.00	60.00	86.00	70.50	3.48	0.26	1.00
NO. 24	1.80	60.00	60.00	86.00	70.00	3.09	0.25	1.00
NO. 25	1.80	60.00	60.00	86.00	69.00	3.29	0.25	1.00
NO. 26	1.80	60.00	60.00	85.70	49.00	1.98	0.25	5.00
NO. 27	1.80	60.00	60.00	85.70	53.50	2.37	0.28	5.00
NO. 28	1.80	60.00	60.00	85.70	61.50	2.57	0.27	5.00
NO. 29	1.80	15.00	15.00	83.30	38.00	1.61	0.25	5.00
NO. 30	1.80	15.00	15.00	83.30	52.00	2.65	0.27	5.00
NO. 31	1.80	15.00	15.00	83.30	51.50	2.63	0.28	5.00
NO. 32	1.80	15.00	15.00	86.00	63.00	2.93	0.27	4.00
NO. 33	1.80	15.00	15.00	86.00	62.00	2.92	0.27	4.00
NO. 34	1.80	15.00	15.00	86.00	56.50	2.62	0.27	4.00
NO. 35	1.80	15.00	15.00	85.70	50.00	2.30	0.29	4.00
NO. 36	1.80	15.00	15.00	85.70	39.00	1.84	0.27	4.00
	1.80	15.00	15.00	85.70	39.50	1.85	0.30	4.00

TOT NO. OBS= 36

REGRESSION IV

CORRELATION MATRIX

	1	2	3	4	5	6	7	8
1	1.000	0.000	0.000	-0.000	0.055	-0.152	-0.545	0.154
2	0.000	1.000	0.000	0.000	0.754	0.645	-0.526	-0.000
3	0.000	0.000	1.000	-0.000	-0.095	-0.116	-0.021	-0.462
4	-0.000	0.000	-0.000	1.000	0.171	0.151	0.001	-0.383
5	0.055	0.754	-0.095	0.171	1.000	0.943	-0.560	-0.269
6	-0.152	0.645	-0.116	0.151	0.943	1.000	-0.356	-0.347
7	-0.545	-0.526	-0.021	0.001	-0.560	-0.356	1.000	0.047
8	0.154	-0.000	-0.462	-0.383	-0.269	-0.347	0.047	1.000

REGRESSION IVa

RESPONSE (Y), PICKUP WEIGHT

ANALYSIS OF Y 1

X	RSQR X	B COEF	SE(B)	T
1	-0.0000	0.5610	1.1360	0.49
2	0.0000	7.6607	1.1360	6.74
3	0.0000	-0.9666	1.1360	-0.85
4	-0.0000	1.9398	1.2692	1.52

CONSTANT	MULT F	DF1	DF2	RSQR	RESIDUAL
56.91925	12.19	4	31	0.611	46.46823

REGRESSION IVa

(CONTINUED)

VARIABLES IN MODEL - Y 1

X	B COEF
1	0.5610
2	7.6607
3	-0.9666
4	1.9398

CONSTANT= 56.91925

RESIDUALS AND PREDICTIONS

OBS	Y(OBS)	Y(PRED)	RESIDUAL	S.E.(Y)	NORM DEV	RESIDUALS SSQS
1	47.2000	46.9126	0.2873	2.7781	0.042	0.0825852
2	47.8000	46.9126	0.8873	2.7781	0.130	0.8700194
3	43.9000	46.9126	-3.0126	2.7781	-0.441	9.9459400
4	54.9000	50.7925	4.1074	2.4591	0.602	26.8169784
5	55.3000	50.7925	4.5074	2.4591	0.661	47.1339798
6	51.4000	50.7925	0.6074	2.4591	0.089	47.5029526
7	48.0000	50.3614	-2.3614	2.3656	-0.346	53.0794678
8	49.1000	50.3614	-1.2614	2.3656	-0.185	54.6707612
9	46.6000	50.3614	-3.7614	2.3656	-0.551	68.8193971
10	64.1000	64.1681	-0.0681	2.7781	-0.009	68.8240358
11	63.0000	64.1681	-1.1681	2.7781	-0.171	70.1885683
12	62.2000	64.1681	-1.9681	2.7781	-0.288	74.0621339
13	73.0000	68.0480	4.9519	2.4591	0.726	98.5836336
14	75.1000	68.0480	7.0519	2.4591	1.034	148.3130801
15	73.2000	68.0480	5.1519	2.4591	0.755	174.8553165
16	62.0000	67.6169	-5.6169	2.3656	-0.823	206.4057011
17	63.0000	67.6169	-4.6169	2.3656	-0.677	227.7221378
18	63.9000	67.6169	-3.7169	2.3656	-0.545	241.5380558
19	65.0000	61.1125	3.8874	2.7781	0.570	256.6500251
20	66.5000	61.1125	5.3874	2.7781	0.790	285.6741950
21	67.0000	61.1125	5.8874	2.7781	0.863	320.3358162
22	70.5000	64.9925	5.5074	2.4591	0.807	350.6680916
23	70.0000	64.9925	5.0074	2.4591	0.734	375.7428596
24	69.0000	64.9925	4.0074	2.4591	0.587	391.8026741
25	49.0000	64.5614	-15.5614	2.3656	-2.282	633.9608168
26	53.5000	64.5614	-11.0614	2.3656	-1.622	756.3160414
27	61.5000	64.5614	-3.0614	2.3656	-0.449	765.6883559
28	38.0000	47.7237	-9.7237	2.7781	-1.426	860.2390151
29	52.0000	47.7237	4.2762	2.7781	0.627	878.5255143
30	51.5000	47.7237	3.7762	2.7781	0.553	892.7857680
31	63.0000	51.6036	11.3963	2.4591	1.671	1022.6624770
32	62.0000	51.6036	10.3963	2.4591	1.525	1130.7465853
33	56.5000	51.6036	4.8963	2.4591	0.718	1154.7207059
34	50.0000	51.1725	-1.1725	2.3656	-0.172	1156.0954618
35	39.0000	51.1725	-12.1725	2.3656	-1.785	1304.2666049
36	39.5000	51.1725	-11.6725	2.3656	-1.712	1440.5151395

REGRESSION IVb

RESPONSE (Y), PLATE CAPACITY

X	RSQR X	B COEF	SE(B)	T	ANALYSIS OF Y 2
1	-0.0000	-0.0727	0.0621	-1.17	-0.727744E-01
2	0.0000	0.3083	0.0621	4.96	
3	0.0000	-0.0555	0.0621	-0.89	-0.555529E-01
4	-0.0000	0.0810	0.0694	1.16	0.810312E-01

CONSTANT	MULT F	DF1	DF2	RSQR	RESIDUAL
2.53120	7.04	4	31	0.476	0.13894

REGRESSION IVb

VARIABLES IN MODEL - Y 2

X	B COEF
1	-0.0727
2	0.3083
3	-0.0555
4	0.0810

CONSTANT= 2.53120

RESIDUALS AND PREDICTIONS

OBS	Y(OBS)	Y(PRED)	RESIDUAL	S.E.(Y)	NORM DEV	RESIDUALS SSQS
1	1.9800	2.0135	-0.0335	0.1519	-0.089	0.0011226
2	2.0800	2.0135	0.0664	0.1519	0.178	0.0055440
3	1.8400	2.0135	-0.1735	0.1519	-0.465	0.0356485
4	2.4200	2.1755	0.2444	0.1344	0.655	0.0953911
5	2.3900	2.1755	0.2144	0.1344	0.575	0.1413684
6	2.1700	2.1755	-0.0055	0.1344	-0.014	0.1413995
7	2.1200	2.1575	-0.0375	0.1293	-0.100	0.1428109
8	2.1500	2.1575	-0.0075	0.1293	-0.020	0.1428682
9	1.8900	2.1575	-0.2675	0.1293	-0.717	0.2144614
10	2.7100	2.7412	-0.0312	0.1519	-0.083	0.2154401
11	2.6300	2.7412	-0.1112	0.1519	-0.298	0.2278243
12	2.5600	2.7412	-0.1812	0.1519	-0.486	0.2606881
13	3.0000	2.9033	0.0966	0.1344	0.259	0.2700284
14	3.1200	2.9033	0.2166	0.1344	0.581	0.3169636
15	3.1800	2.9033	0.2766	0.1344	0.742	0.3934961
16	2.6400	2.8853	-0.2453	0.1293	-0.658	0.4536913
17	2.9000	2.8853	0.0146	0.1293	0.039	0.4539060
18	2.8500	2.8853	-0.0353	0.1293	-0.094	0.4551553
19	3.0700	2.7757	0.2942	0.1519	0.789	0.5417507
20	3.0400	2.7757	0.2642	0.1519	0.708	0.6115900
21	3.0100	2.7757	0.2342	0.1519	0.628	0.6664729
22	3.4800	2.9377	0.5422	0.1344	1.454	0.9604537
23	3.0900	2.9377	0.1522	0.1344	0.408	0.9836186
24	3.2900	2.9377	0.3522	0.1344	0.944	1.1076638
25	1.9800	2.9197	-0.9397	0.1293	-2.521	1.9908726
26	2.3700	2.9197	-0.5497	0.1293	-1.474	2.2931437
27	2.5700	2.9197	-0.3497	0.1293	-0.938	2.4154977
28	1.6100	2.2701	-0.6601	0.1519	-1.771	2.8513274
29	2.6500	2.2701	0.3798	0.1519	1.018	2.9955945
30	2.6300	2.2701	0.3598	0.1519	0.965	3.1250686
31	2.9300	2.4322	0.4977	0.1344	1.335	3.3728289
32	2.9200	2.4322	0.4877	0.1344	1.308	3.6107339
33	2.6200	2.4322	0.1877	0.1344	0.503	3.6459880
34	2.3000	2.4142	-0.1142	0.1293	-0.306	3.6590356
35	1.8400	2.4142	-0.5742	0.1293	-1.540	3.9887833
36	1.8500	2.4142	-0.5642	0.1293	-1.513	4.3071460

REGRESSION IVc

RESPONSE (Y), GRAM CAPACITY

X	RSQR X	B COEF	SE(B)	T	ANALYSIS OF Y 3
1	-0.0000	-0.0091	0.0019	-4.66	-0.919399E-02
2	0.0000	-0.0088	0.0019	-4.49	-0.886065E-02
3	0.0000	-0.0003	0.0019	-0.18	-0.361103E-03
4	-0.0000	0.0000	0.0022	0.01	0.308393E-04

CONSTANT	MULT F	DF1	DF2	RSQR	RESIDUAL
0.26324	10.49	4	31	0.575	0.1399343E-03

VARIABLES IN MODEL - Y 3

X	B COEF
1	-0.0091
2	-0.0088
3	-0.0003
4	0.0000

CONSTANT= 0.26324

RESIDUALS AND PREDICTIONS

OBS	Y(OBS)	Y(PRED)	RESIDUAL	S.E.(Y)	NORM DEV	RESIDUALS SSQS
1	0.2680	0.2625	0.0054	0.0048	0.463	0.0000300
2	0.2740	0.2625	0.0114	0.0048	0.970	0.0001619
3	0.2670	0.2625	0.0044	0.0048	0.379	0.0001820
4	0.2600	0.2625	-0.0025	0.0042	-0.217	0.0001887
5	0.2540	0.2625	-0.0085	0.0042	-0.725	0.0002622
6	0.2440	0.2625	-0.0185	0.0042	-1.570	0.0006074
7	0.2790	0.2625	0.0164	0.0041	1.388	0.0008773
8	0.2620	0.2625	-0.0005	0.0041	-0.048	0.0008776
9	0.2550	0.2625	-0.0075	0.0041	-0.640	0.0009349
10	0.2440	0.2455	-0.0015	0.0048	-0.128	0.0009372
11	0.2480	0.2455	0.0024	0.0048	0.209	0.0009434
12	0.2480	0.2455	0.0024	0.0048	0.209	0.0009496
13	0.2400	0.2455	-0.0055	0.0042	-0.471	0.0009807
14	0.2380	0.2455	-0.0075	0.0042	-0.640	0.0010381
15	0.2210	0.2455	-0.0245	0.0042	-2.077	0.0016422
16	0.2660	0.2455	0.0204	0.0041	1.726	0.0020595
17	0.2440	0.2455	-0.0015	0.0041	-0.132	0.0020620
18	0.2610	0.2455	0.0154	0.0041	1.304	0.0023000
19	0.2580	0.2631	-0.0051	0.0048	-0.438	0.0023269
20	0.2620	0.2631	-0.0011	0.0048	-0.099	0.0023283
21	0.2550	0.2631	-0.0081	0.0048	-0.691	0.0023953
22	0.2680	0.2632	0.0047	0.0042	0.401	0.0024179
23	0.2580	0.2632	-0.0052	0.0042	-0.443	0.0024454
24	0.2590	0.2632	-0.0042	0.0042	-0.358	0.0024634
25	0.2570	0.2632	-0.0062	0.0041	-0.527	0.0025023
26	0.2820	0.2632	0.0187	0.0041	1.586	0.0028543
27	0.2700	0.2632	0.0067	0.0041	0.571	0.0029000
28	0.2590	0.2816	-0.0226	0.0048	-1.912	0.0034120
29	0.2760	0.2816	-0.0056	0.0048	-0.475	0.0034437
30	0.2890	0.2816	0.0073	0.0048	0.623	0.0034981
31	0.2790	0.2816	-0.0026	0.0042	-0.227	0.0035053
32	0.2780	0.2816	-0.0036	0.0042	-0.311	0.0035189
33	0.2760	0.2816	-0.0056	0.0042	-0.480	0.0035513
34	0.2910	0.2816	0.0093	0.0041	0.787	0.0036381
35	0.2790	0.2816	-0.0026	0.0041	-0.226	0.0036453
36	0.3080	0.2816	0.0263	0.0041	2.224	0.0043379

REGRESSION IVd

RESPONSE (Y), PLAQUE CHARACTERIZATION

X	RSQR X	B COEF	SE(B)	T
1	-0.0000	0.1666	0.1521	1.09
2	0.0000	0.0000	0.1521	0.00
3	0.0000	-0.4999	0.1521	-3.28
4	-0.0000	-0.4623	0.1699	-2.71

ANALYSIS OF Y 4

0.452518E-07

CONSTANT	MULT F	DF1	DF2	RSQR	RESIDUAL
4.11986	4.84	4	31	0.384	0.83340

VARIABLES IN MODEL - Y 4

X	B COEF
1	0.1666
2	0.0000
3	-0.4999
4	-0.4623

CONSTANT= 4.11986

RESIDUALS AND PREDICTIONS

OBS	Y(OBS)	Y(PRED)	RESIDUAL	S.E.(Y)	NORM DEV	RESIDUALS SSQS
1	4.0000	4.2488	-0.2488	0.3720	-0.272	0.0619291
2	4.0000	4.2488	-0.2488	0.3720	-0.272	0.1238582
3	4.0000	4.2488	-0.2488	0.3720	-0.272	0.1857873
4	3.0000	3.3242	-0.3242	0.3293	-0.355	0.2908942
5	3.0000	3.3242	-0.3242	0.3293	-0.355	0.3960012
6	3.0000	3.3242	-0.3242	0.3293	-0.355	0.5011081
7	4.0000	3.4269	0.5730	0.3168	0.627	0.8295065
8	4.0000	3.4269	0.5730	0.3168	0.627	1.1579048
9	4.0000	3.4269	0.5730	0.3168	0.627	1.4863030
10	5.0000	5.2488	-0.2488	0.3720	-0.272	1.5482320
11	5.0000	5.2488	-0.2488	0.3720	-0.272	1.6101610
12	5.0000	5.2488	-0.2488	0.3720	-0.272	1.6720900
13	4.0000	4.3242	-0.3242	0.3293	-0.355	1.7771966
14	4.0000	4.3242	-0.3242	0.3293	-0.355	1.8823032
15	4.0000	4.3242	-0.3242	0.3293	-0.355	1.9874098
16	5.0000	4.4269	0.5730	0.3168	0.627	2.3158087
17	5.0000	4.4269	0.5730	0.3168	0.627	2.6442074
18	5.0000	4.4269	0.5730	0.3168	0.627	2.9726061
19	4.0000	3.9155	0.0844	0.3720	0.092	2.9797425
20	4.0000	3.9155	0.0844	0.3720	0.092	2.9868788
21	4.0000	3.9155	0.0844	0.3720	0.092	2.9940152
22	1.0000	2.9908	-1.9908	0.3293	-2.180	6.9575748
23	1.0000	2.9908	-1.9908	0.3293	-2.180	10.9211349
24	1.0000	2.9908	-1.9908	0.3293	-2.180	14.8846931
25	5.0000	3.0936	1.9063	0.3168	2.088	18.5190315
26	5.0000	3.0936	1.9063	0.3168	2.088	22.1533661
27	5.0000	3.0936	1.9063	0.3168	2.088	25.7877006
28	5.0000	4.9155	0.0844	0.3720	0.092	25.7948341
29	5.0000	4.9155	0.0844	0.3720	0.092	25.8019676
30	5.0000	4.9155	0.0844	0.3720	0.092	25.8091011
31	4.0000	3.9908	0.0091	0.3293	0.010	25.8091812
32	4.0000	3.9908	0.0091	0.3293	0.010	25.8092613
33	4.0000	3.9908	0.0091	0.3293	0.010	25.8093414
34	4.0000	4.0936	-0.0936	0.3168	-0.102	25.8181000
35	4.0000	4.0936	-0.0936	0.3168	-0.102	25.8268585
36	4.0000	4.0936	-0.0936	0.3168	-0.102	25.8356171

The regressions contained in Tables I and III analyses data associated with the positive and negative design experiments utilizing responses which characterizes only Lot 151 plaques. Lot 151 plaques were elevated to this somewhat privileged position because they withstood the rigors of the experimental process better than the other two lots, and a greater degree of confidence is attached to the experimental results associated with them. The remaining regression, Tables II and IV, analyses the total data associated with the positive and negative design experiments respectively. The responses of all three lots of plaques are introduced into the regression picture by the incorporation of the plaque lot discriminating independent variables of plaque porosity.

A second plaque characterization response is associated with the regressions I and III. In this response, the numerical rating value is an average of the rating values for each lot of plaques in the experiment. The purpose of this additional response is to gain some insight into the harshness of the experimental conditions. For example, in a particular experiment, the stronger plaques of Lot 151 might exhibit a good physical appearance and be rated 5.0 while the remaining weaker two lots are very poor and receive ratings of 2.0 or 1.0. In a second experiment, Lot 151 plaques may again be very good and receive a rating of 5.0, but in this case, the two weaker lots are also good and receive ratings of 5.0 or 4.0. The average rating value for the second experiment would be considerably higher than for the first and permit the regression program to distinguish between the two experiments in reference to the harshness of the experimental conditions.

Referring back to the example regression equation and to regression Number Ia (Positive Design Experiment, Lot 151; Response, Pickup Weight) the ensuing discussion describes the procedure used in the interpretation of the regression results. The independent variable (X) coefficients are found under the "B Coef" column in the same order as listed in the raw data.

1	5.0830	(Specific Gravity)
2	4.7497	(Impregnation Time)
3	-0.2499	(Polarization Time)

To maximize plaque pickup weight during the impregnation/polarization process, the coefficients dictate a preference for the higher values of independent variables 1 and 2 (specific gravity 1.80, impregnation time 1 hour), and the lower value for independent variable Number 3 (polarization time 15 minutes). This procedure, of course, just involves mathematically maximizing the response or the Y term of the regression equation. It should also be noted the first two variables exhibits a much greater effect upon the response of pickup weight than the third variable (polarization time).

A problem which frequently arises in an attempt to optimize the process variable levels in a study such as this is the variable levels dictated by one regression for a particular desired response may not be the same variable levels dictated by a second regression for an equally desired response. For example, the third independent variable in regression Number Ib (response, plate capacity) dictates a preference for the higher level of polarization time in contrast to the lower level preferred for pickup weight (Regression Number Ia). In this situation, engineering judgment must be applied to determine the process variable levels which will optimize the process.

To facilitate the interpretation of the various subregression of a major regression, tables were compiled summarizing the independent variable coefficients. Table Number V summarizes the coefficient of regression Number I and Table Number VI summarizes the coefficients of regression Number III. It should be remembered in the interpretation, a positive coefficient value requires an increasing independent variable value to increase the response value and a negative coefficient value requires a decreasing independent variable value to increase the response value.

TABLE V

POSITIVE STUDY COEFFICIENT SUMMATION
REGRESSION I

RESPONSES	1 PICKUP WEIGHT	2 PLATE CAPACITY	3 GRAM CAPACITY	4 PLAQUE CHARACTER. LOT 151	5 PLAQUE CHARACTER. AVERAGED
VARIABLES					
1. Specific Gravity of Nitrate	5.0830	0.2366	0.0049	0.2499	-0.0999
2. Impregnation Time	4.7497	0.2516	0.0073	0.7499	0.2499
3. Polarization Time	-0.2499	0.0033	0.0008	0.2499	0.5999

VARIABLE NUMBER 1

Response Number 1 - Strong effect upon pickup weight, high nickel nitrate specific gravity preferred.

Response Number 2 - Strong effect upon plate capacity, high specific gravity preferred. As expected, these two responses are highly correlated. Observing the correlation matrix for regression Number I, a correlation factor of 0.975 is listed (intersection of Row 4 and Column 5.)

Response Number 3 - Positive value, high specific gravity preferred.

Response Number 4 - Positive value, high specific gravity preferred.

Response Number 5 - Negative value indicating high specific gravity is a more harsh process condition, but is the smallest coefficient in the regression indicating the variable effect is not very important in relation to the other variables.

VARIABLE NUMBER 2

All the coefficients are positive values dictating a preference for high impregnation times.

VARIABLE NUMBER 3

Response Number 1 - Negative value indicating a preference for low polarization times, but exhibits the smallest effect in the pick-up weight regression.

The remaining coefficients are positive values lending support for a preference of high polarization times; but in general, the polarization time variable exhibits the least effect upon the responses considered for investigation. From a production stand point, it would appear little is to be gained from the time and expense of long polarization times.

Summarizing the preceding interpretation, the following process conditions are preferred in the positive impregnation/polarization process assuming high plaque pick-up weight in conjunction with good electrical capacity and physical appearance are the desired impregnated plaque characteristics:

(1) High nickel nitrate specific gravity (upper experimental limit, 1.80).

(2) High impregnation time (upper experimental limit, one hour).

(3) Low polarization time (lower experimental limit, 15 minutes).

TABLE VI

NEGATIVE STUDY COEFFICIENT SUMMATION
REGRESSION III

RESPONSES	1 PICKUP WEIGHT	2 PLATE CAPACITY	3 GRAM CAPACITY	4 PLAQUE CHARACTER. LOT 151	5 PLAQUE CHARACTER. AVERAGED
VARIABLES					
1. Specific Gravity of Nitrate	-0.9832	-0.1841	-0.0041	-0.0000	0.1999
2. Impregnation Time	8.9495	0.3524	-0.0098	0.0000	0.0000
3. Polarization Time	0.5499	0.0191	0.0016	-0.4999	0.4999

VARIABLE NUMBER 1

The first four negative coefficient values dictates a preference for a low cadmium nitrate solution specific gravity. The fifth coefficient which represents all three lots of plaques is a positive value indicating that a low specific gravity is a more harsh process condition, but the plaque characterization responses do not have the same significance in the negative study as they did in the positive study. For the most part, satisfactory impregnated plaques were obtained even with the weakest plaque lot.

VARIABLE NUMBER 2

The very strong effects on pickup weight and plate capacity dictates a preference for long impregnation times. But, there would be some sacrifice in the electrical efficiency of the plaque as indicated by the negative coefficient of response Number 3 (gram capacity).

VARIABLE NUMBER 3

Not considering the negative coefficient values for the plaque characterization responses (4 and 5) for the reason stated before, the first three positive coefficient values dictate a preference for the high polarization time.

Summarizing the preceding negative study interpretation, the following process conditions are preferred in the negative impregnation/polarization process assuming high plaque pick-up weight inconjunction with good electrical capacity and physical appearance are the desired impregnated plaque characteristics:

(1) Low cadmium nitrate specific gravity (lower experimental limit, 1.80).

(2) High impregnation time (upper experimental limit, one hour).

(3) High polarization time (upper experimental limit, one hour).

To evaluate the effects of the different type plaques upon the responses, the coefficient summation procedure was applied to the results of regressions Number II and IV.

TABLE VII

POSITIVE STUDY COEFFICIENT SUMMATION
REGRESSION II

RESPONSES	1 PICKUP WEIGHT	2 PLATE CAPACITY	3 GRAM CAPACITY	4 PLAQUE CHARACT.
VARIABLES				
1. Specific Gravity of Nitrate	4.1996	0.1937	0.0054	0.2469
2. Impregnation Time	6.1439	0.0631	0.0076	0.5802
3. Polarization Time	0.2266	0.0631	0.0012	0.1791
4. Porosity	0.1179	-0.0103	-0.0083	-0.9509

Variable Number 4 defines the different type plaques; high porosity would be a characteristic of Lot 152 (low strength, high porosity), medium porosity would be a characteristic of Lot 153 (medium strength, medium porosity), and low porosity would be a characteristic of Lot 151 (high strength, low porosity). The entire summation is presented in order that the magnitude of the effect of the fourth variable may be compared to the other variables in the regressions.

VARIABLE NUMBER 4

Response 1 - Positive value indicating high porosity desired for increased pick-up weight, but variable least important in pick-up weight regression.

Response 2 - Negative value indicating low porosity desired for increased plate capacity, again least important variable in the regression.

Response 3 - Negative value indicating low porosity (greater strength) desired for increased plate electrical efficiencies; most important variable in regression.

Response 4 - Negative value indicating low porosity desired for enhanced plaque physical characteristics (appearance) most important variable in the regression.

Summarizing, high strength, low porosity plaques (Lot 151) are to be preferred in the positive impregnation/polarization process. Some reduction in pickup capacity would have to be tolerated, but this does not appear to be significant.

TABLE VIII

NEGATIVE STUDY COEFFICIENT SUMMATION
REGRESSION IV

RESPONSES	1 PICKUP WEIGHT	2 PLATE CAPACITY	3 GRAM CAPACITY	4 PLAQUE CHARACT.
VARIABLES				
1. Specific Gravity of Nitrate	0.5610	-0.0727	-0.0091	0.1666
2. Impregnation Time	7.6607	0.3083	-0.0088	0.0000
3. Polarization Time	-0.9666	-0.0555	-0.0003	-0.4999
4. Porosity	1.9398	0.0810	0.0000	-0.4623

VARIABLE NUMBER 4

Response Number 1 - Positive value indicating high porosity desired for increased pickup weight, second most important variable in the regression.

Response Number 2 - Positive value indicating high porosity desired for increased plate capacity, second most important variable in the regression.

Response Number 3 - The value here indicates porosity does not exhibit a significant effect upon the electrical efficiency or gram capacity of a plaque.

Response Number 4 - Negative value indicating low porosity desired for enhanced plaque physical characteristics (appearance), second most important variable in the regression.

Summarizing, low strength, high porosity plaques (Lot 152) are to be preferred in the negative impregnation/polarization process. There will be some sacrifice in the physical appearance of the plaques; but as stated before, in the case of the negative plaques, there was very little difference in the physical appearances throughout the experiments.

IV. DISCUSSION

1. As evidenced by the difficulty encountered during the experimental phase of the positive plaque impregnation/polarization study (poor physical integrity of impregnated plaques, flaking material, etc.), the range of the process variable levels selected for the fractional factorial design experiments did not exhibit the expected latitude. The combination of certain levels of variables such as impregnation under vacuum, high free acid content of the nitrate solution, and polarization in a caustic solution of potassium hydroxide (KOH) resulted in the destruction of the impregnated plaques.

It is suggested that in any future approach to this type of investigation, the finalization of the variable levels in the factorial design experiments be preceded by pilot experimental runs to test the more questionable levels and combinations.

2. The design experiments which were formulated and completed investigating process variables associated with the plaque impregnation/polarization process demonstrated the following process conditions are to be preferred in the optimization of the process based upon a linear multiple regression analysis of the experimental data. An assumption is made here that high pick-up weight, good electrical capacity and a smooth clean physical appearance are the desired impregnated plaque parameters.

Preferred process conditions for the positive plaque impregnation/polarization process:

(1) High nickel nitrate specific gravity (upper experimental limit, 1.80).

(2) High impregnation time (upper experimental limit, one hour).

(3) Low polarization time (lower experimental limit, 15 minutes).

Preferred process conditions for the negative plaque impregnation/polarization process:

(1) Low cadmium nitrate specific gravity (lower experimental limit, 1.80).

(2) High impregnation time (upper experimental limit, one hour).

(3) High polarization time (upper experimental limit, one hour).

3. Three types of raw plaques which varied in strength and porosity were selected for use during the experimental work in order to evaluate their effect upon the impregnation/polarization process. Additional multiple regression analysis, incorporating this fourth variable, indicated a preference for a particular type plaque to be used in a process, assuming the same desired plaque parameters as described above.

Positive Impregnation/Polarization Process

A high strength, low porosity (experimental limits strength 525 lbs/in^3 - porosity 83.3% void) plaque is preferred.

Negative Impregnation/Polarization Process

A low strength, high porosity (experimental limits, strength 250 lbs/in^3 - porosity 86.0% void) plaque is preferred.

4. Significant improvement in the physical appearance and electrical efficiency (grams capacity) of positive plaques was obtained by impregnation with a high temperature (200°F) nickel nitrate solution and without vacuum. The enclosed photograph (see Figure 4) presents two plates from the same raw plaque lot (Lot 151) impregnated under similar conditions with the exception of nitrate temperature and vacuum. Plate Number One is from Experiment 5A (nitrate temperature 200°F, vacuum 0 inches). Plate No. 2 is from Experiment 1

POSITIVE IMPREGNATED PLATES
EXPERIMENT 5A (FIRST)
EXPERIMENT 1 (SECOND)

PLATE #1

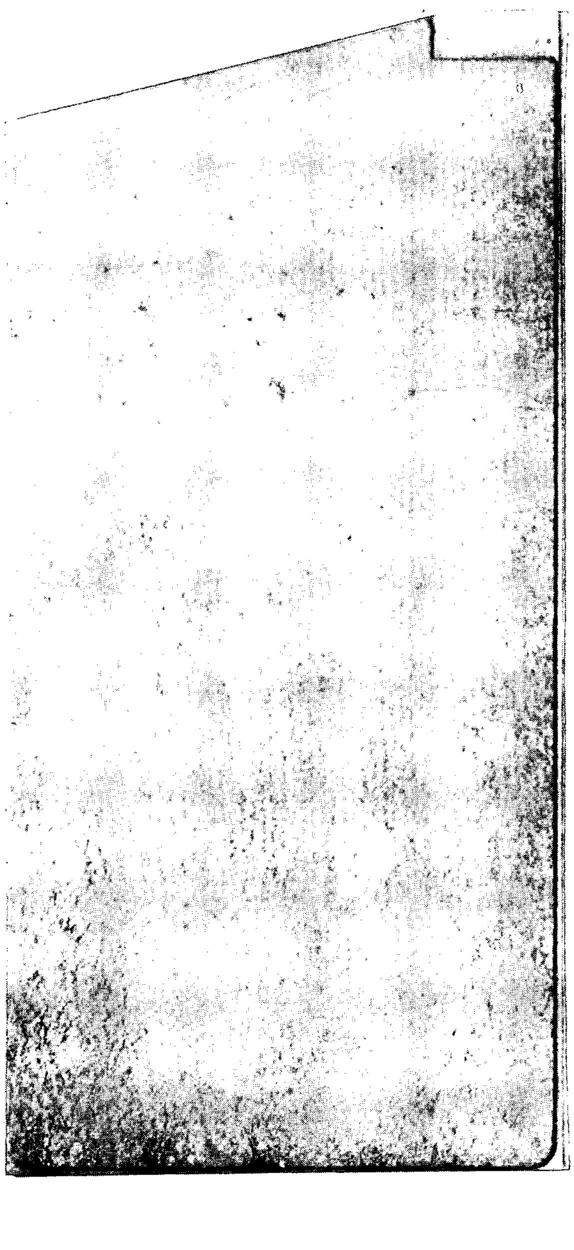

PLATE #2

FIGURE 4

(nitrate temperature 140°F, vacuum 15 inches). Plate Number Two is observed to exhibit a very rough surface with the active material apparently caked on the outside of the plate. The suspicion that this active material would not be utilized electrically is supported by the gram capacity (active material utilization) results for the plaques in these two experiments.

PLAQUE LOT 151 GRAM CAPACITIES

(AMPERE-HOURS/GRAMS)

	EXPERIMENT 5A	EXPERIMENT 1
Plaque (1)	0.263	0.228
(2)	0.254	0.226
(3)	0.279	0.228

5. An interesting occurrence with respect to plaque pickup weight was observed between the two above mentioned experiments. No explanation can be given but the data will be presented for information. It would be expected that the plaque lot exhibiting the highest porosity (Lot 152; low strength, high porosity) would exhibit the greatest pickup weight of the three lots within an experiment. Generally this was true throughout this work with the exception of Experiment Number 1. In this case, the lowest porosity plaque Lot (151, high strength, low porosity) exhibited the greatest pickup weight, the medium porosity plaque lot (Lot 153; medium strength, medium porosity) exhibited the next highest pickup weight and the high porosity plaque lot (Lot 152) exhibited the least pickup weight.

The following is a comparison of the pickup weights (after formation) of Experiment Number 1 with Experiment Number 5A which exemplifies a more typical ratio of pickup weights.

	EXPERIMENT 1	EXPERIMENT 5A
LOT 151 PLAQUE		
(1)	59.9 grams	54.0
(2)	58.1	57.5
(3)	55.1	56.0
LOT 152		
(1)	43.4	66.5
(2)	43.3	65.5
(3)	41.6	56.5*
LOT 153		
(1)	50.5	54.0
(2)	51.0	59.5
(3)	53.5	59.0

*Low value as the result of loss of material during scrubbing operation following formation process.

6. The active material utilization factor for positive plaques was increased by impregnation with a high level free acid nickel nitrate solution. Experiment 6A utilized a high free acid level nitrate solution (4 grams/liter); this may be compared with Experiment 5A which was processed under the same experimental conditions with the exception of the free acid level (1 gram/liter).

PLAQUE LOT 151 GRAM CAPACITIES

(AMPERE-HOURS/GRAMS)

	EXPERIMENT 5A	EXPERIMENT 6A
Plaque (1)	0.263	0.289
(2)	0.254	0.297
(3)	0.279	0.296

A question arises in connection with this practice in that the increase in utilization may be the result of the higher free acid's attack on the sintered nickel mesh (conversion to nickel nitrate) resulting in a damaged (weaker) plaque.

It is suggested that the effect of impregnation with a high free acid level nickel nitrate solution be investigated with respect to the strength of the impregnated plaques.

7. Polarization in a caustic solution of potassium hydroxide (KOH) of a specific normality and with the passage of a specific current is a much more destructive environment with respect to its effect upon impregnated plaques than polarization in a caustic solution of sodium hydroxide (NaOH) with the same normality and current. No explanation can be given for this occurrence at this time, but it will be the subject of further study.

8. In general, it can be stated under the process variable levels selected for this study, the positive plaque impregnation/polarization process is a far more critical operation than the negative plaque impregnation/polarization process in respect to its effect upon the physical integrity of the impregnated plaques. In reference to the weaker plaque lot (Lot 152, low strength, high porosity), few positive experiments produced impregnated plaques suitable for the measurements of the various responses and none would have been suitable for use in cells. On the other hand, all the negative experiments except one produced satisfactory impregnated plaques from the weaker raw plaque lot.

9. The width and thickness dimensions of plate Number One were recorded for selected positive and negative plaques before and after the impregnation/polarization and formation process. As mentioned earlier, this effort was instituted to determine if there was any significant growth in the plates as a result of the process.

No discernable growth was noted with the exception of a small increase in thickness as the result of impregnation with active material. The actual measured dimensions may be found in Appendix B of this report.

10. A straightforward review of the data did not reveal any significant trends in pick-up weight, electrical capacity, or physical appearance in respect to a plate's position on a plaque or a plaque's position in the process tank.

V. CONCLUSIONS AND RECOMMENDATIONS

1. Because of the difficulty encountered during the experimental phase of the positive plaque impregnation/polarization process study, it is recommended that in any future approach to this type of investigation, the finalization of the variable levels in the factorial design experiment be preceded by pilot experimental runs to test the more questionable levels and combinations.

2. As a result of the process variable investigation, the following variable levels were determined to be preferred in achieving high plaque pick-up weight inconjunction with good electrical capacity and a smooth clean physical appearance:

Positive Impregnation/Polarization Process

(1) High nickel nitrate specific gravity preferred (upper experimental limit, 1.80).

(2) High impregnation time preferred (upper experimental limit, one hour).

(3) Low polarization time preferred (lower experimental limit, 15 minutes).

Negative Impregnation/Polarization Process

(1) Low cadmium nitrate specific gravity preferred (lower experimental limit, 1.80).

(2) High impregnation time preferred (upper experimental limit, one hour).

(3) High polarization time preferred (upper experimental limit, one hour).

3. The following raw plaques characteristics (parameters, strength and porosity) were determined to be preferred in the two processes assuming the same impregnated plaque qualities described above:

Positive Impregnation/Polarization Process

High strength, low porosity plaques preferred (experimental limits, strength 525 lbs/in^3 - porosity 83.3% void).

Negative Impregnation/Polarization Process

Low strength, high porosity plaques preferred (experimental limits, strength 250 lbs/in^3 - porosity 86.0% void).

4. A significant improvement in the physical appearance and electrical efficiency (gram capacity) of positive plaques were obtained by impregnation with a high temperature (200°F) nickel nitrate solution without the use of vacuum.

5. The active material utilization factor or efficiency (gram capacity) of the positive impregnated plaques was increased by impregnation with a high level free acid nickel nitrate solution (4 grams/liter).

It is recommended that this phenomenon be further investigated by determining the degree of attack on the nickel nitrate by the higher free acid levels through strength measurements of impregnated plaques.

6. The performance of the polarization operation in a caustic solution of NaOH results in superior impregnated positive plaques (stronger, smooth and clean physical appearance) in comparison to polarization in a caustic of KOH (polarization rate 0.4 $amps/in^2$).

It is recommended this area of the program receive additional effort to determine why KOH caustic solutions exhibit a more destructive effect upon the impregnated plaques.

7. In general, the positive impregnation/polarization process is a far more critical operation than the negative in respect to the range of the process variable levels which may be used.

8. No significant dimensional growth in the individual plates or on impregnated plaques could be discerned as a result of the impregnation/polarization process.

9. No discernable trends in pick-up weight, electrical capacity, or physical appearance with respect to a plate's position on a plaque or a plaque's position in the process tank were evident.

VI. PROGRAM PLAN

1. Additional information will be gained concerning the impregnation/polarization process during the next period by subjecting the resulting impregnated plaques to a scanning electro micrographic analysis. Through the examination of the resulting photomicrographs, it is hoped to determine the distribution of the active materials within the plaque pores and to gain a comparative knowledge of the porosity of the various impregnated plaques.

2. An experiment will be formulated and completed during the next period to determine why the polarization in a caustic solution of potassium hydroxide (KOH) presents a much more destructive environment to the impregnated plaque than polarization in a caustic solution of sodium hydroxide (NaOH). The areas of interest will be the viscosity of the two solutions and their gassing characteristics.

3. Work will also begin during the next period in the characterization of nickel-cadmium cell separator materials. The first step will be to investigate the organic impurity levels associated with the various materials; this will be followed by an investigation of the inorganic impurity levels. In addition to these first two steps, the materials will be subjected to the scanning electron micrographic analysis mentioned before to determine what this technique may reveal.

4. The following reporting period will also include work in the characterization of the nickel-cadmium cell auxiliary or "signal" electrode. It is planned to begin the investigation with the fabrication of standard signal electrodes incorporating cells modified to accept an external source of oxygen. The signal emanating from the electrode as a function of a controlled oxygen pressure will then be measured.

5. The implementation of the fraction factorial design experiment (defined in the previous Quarterly Report) formulated for the purpose of investigating the process variables associated with the electrochemical cleaning or formation process will begin in the following period. The work will begin with the processing of impregnated test plaques using impregnation/polarization processes incorporating the knowledge gained from the studies described in this report and the Third Quarterly Report.

REFERENCES

(1) Second Quarterly Report, Study of Process Variables Associated With Manufacturing Hermetically-Sealed Nickel-Cadmium Cells, Eagle-Picher Industries, Inc., Joplin, Missouri, December, 1970; prepared for NASA/GSFC, Contract Number NAS5-21159.

(2) Third Quarterly Report, Study of Process Variables Associated With Manufacturing Hermetically-Sealed Nickel-Cadmium Cells, Eagle-Picher Industries, Inc., Joplin, Missouri, June , 1971; prepared for NASA/GSFC, Contract Number NAS5-21159.

(3) Gardner, Donald S., Multiple Regression Program/1130, IBM 1130-13.6 .003.

APPENDIX A

INDIVIDUAL PLAQUE POLARIZATION VOLTAGES

The plaque polarization voltage with respect to a reference electrode was recorded for each cycle of each experiment at the beginning and end of a polarization period. In all cases, the plaque voltage with respect to the reference electrode was a negative value and the negative sign "-" will be dropped in the presentation of the data. The three plaque lots were introduced into the impregnation/polarization tank in a standard order and the following index identifies the location of each lot:

	LOT 151	LOT 152	LOT 153
PLAQUE	1	4	7
	2	5	8
	3	6	9

In addition, the voltage of one plaque was continuously monitored on a recorder during the polarization cycles of positive impregnation (polarization Experiment Number 4) (see Figure 5). This information was obtained to evaluate the voltage fluctuations during the polarization period. The actual recorder tracing may be found with positive Experiment Number 4 data in this Appendix.

EXPERIMENT NUMBER 1

REFERENCE ELECTRODE - NEGATIVE PLATE

CYCLE 1

BEGIN

1.	0.543	4.	0.579	7.	0.555
2.	0.576	5.	0.585	8.	0.579
3.	0.580	6.	0.544	9.	0.570

END

1.	0.654	4.	0.687	7.	0.625
2.	0.677	5.	0.692	8.	0.680
3.	0.686	6.	0.665	9.	0.670

CYCLE 2

BEGIN

1.	0.725	4.	0.760	7.	0.722
2.	0.770	5.	0.765	8.	0.740
3.	0.770	6.	0.715	9.	0.727

END

1.	0.570	4.	0.629	7.	0.530
2.	0.625	5.	0.639	8.	0.635
3.	0.630	6.	0.590	9.	0.620

CYCLE 3

BEGIN

1.	0.650	4.	0.680	7.	0.660
2.	0.690	5.	0.680	8.	0.686
3.	0.689	6.	0.630	9.	0.670

END

1.	0.629	4.	0.675	7.	0.590
2.	0.670	5.	0.683	8.	0.678
3.	0.674	6.	0.639	9.	0.665

CYCLE 4

BEGIN

1.	0.638	4.	0.690	7.	0.688
2.	0.687	5.	0.699	8.	0.715
3.	0.690	6.	0.650	9.	0.706

END

1.	0.718	4.	0.773	7.	0.690
2.	0.760	5.	0.778	8.	0.760
3.	0.770	6.	0.736	9.	0.746

EXPERIMENT NUMBER 2

REFERENCE ELECTRODE - NEGATIVE PLATE (CYCLE 1)
REFERENCE ELECTRODE - POSITIVE PLATE (CYCLES 2, 3 & 4)

CYCLE 1

BEGIN

1.	0.393	4.	0.445	7.	0.360
2.	0.439	5.	0.449	8.	0.434
3.	0.450	6.	0.404	9.	0.429

END

1.	0.494	4.	0.540	7.	0.470
2.	0.529	5.	0.538	8.	0.522
3.	0.536	6.	0.506	9.	0.516

CYCLE 2

BEGIN

1.	1.495	4.	1.576	7.	1.535
2.	1.570	5.	1.597	8.	1.596
3.	1.586	6.	1.546	9.	1.587

END

1.	1.648	4.	1.695	7.	1.625
2.	1.690	5.	1.707	8.	1.680
3.	1.695	6.	1.659	9.	1.670

CYCLE 3

BEGIN

1.	1.387	4.	1.440	7.	1.390
2.	1.420	5.	1.440	8.	1.420
3.	1.430	6.	1.400	9.	1.417

END

1.	1.650	4.	1.704	7.	1.629
2.	1.687	5.	1.700	8.	1.687
3.	1.696	6.	1.660	9.	1.675

CYCLE 4

BEGIN

1.	1.390	4.	1.448	7.	1.379
2.	1.428	5.	1.453	8.	1.437
3.	1.440	6.	1.409	9.	1.435

END

1.	1.658	4.	1.707	7.	1.636
2.	1.689	5.	1.710	8.	1.690
3.	1.700	6.	1.667	9.	1.680

EXPERIMENT NUMBER 3

REFERENCE ELECTRODE - POSITIVE PLATE

CYCLE 1

BEGIN

1.	1.630	4.	1.600	7.	1.630
2.	1.640	5.	1.610	8.	1.630
3.	1.640	6.	1.620	9.	1.630

END

1.	1.670	4.	1.660	7.	1.690
2.	1.680	5.	1.660	8.	1.690
3.	1.680	6.	1.670	9.	1.690

CYCLE 2

BEGIN

1.	1.480	4.	1.480	7.	1.470
2.	1.480	5.	1.470	8.	1.470
3.	1.480	6.	1.470	9.	1.470

END

1.	1.630	4.	1.620	7.	1.630
2.	1.630	5.	1.600	8.	1.630
3.	1.630	6.	1.620	9.	1.630

CYCLE 3

BEGIN

1.	1.470	4.	1.520	7.	1.540
2.	1.470	5.	1.530	8.	1.550
3.	1.490	6.	1.530	9.	1.550

END

1.	1.620	4.	1.590	7.	1.630
2.	1.620	5.	1.570	8.	1.620
3.	1.630	6.	1.570	9.	1.630

CYCLE 4

BEGIN

1.	1.466	4.	1.457	7.	1.476
2.	1.459	5.	1.450	8.	1.490
3.	1.470	6.	1.450	9.	1.477

END

1.	1.625	4.	1.620	7.	1.590
2.	1.629	5.	1.627	8.	1.590
3.	1.630	6.	1.608	9.	1.630

EXPERIMENT NUMBER 4

REFERENCE ELECTRODE - POSITIVE PLATE

CYCLE 1

BEGIN

1.	1.371	4.	1.380	7.	1.400
2.	1.380	5.	1.380	8.	1.410
3.	1.380	6.	1.370	9.	1.400

END

1.	1.710	4.	1.710	7.	1.710
2.	1.716	5.	1.717	8.	1.710
3.	1.710	6.	1.700	9.	1.710

CYCLE 2

BEGIN

1.	1.377	4.	1.387	7.	1.370
2.	1.385	5.	1.380	8.	1.370
3.	1.378	6.	1.378	9.	1.370

END

1.	1.616	4.	1.610	7.	1.610
2.	1.620	5.	1.619	8.	1.615
3.	1.615	6.	1.608	9.	1.613

CYCLE 3

BEGIN

1.	1.430	4.	1.437	7.	1.426
2.	1.420	5.	1.447	8.	1.419
3.	1.410	6.	1.430	9.	1.426

END

1.	1.617	4.	1.627	7.	1.619
2.	1.625	5.	1.640	8.	1.625
3.	1.619	6.	1.617	9.	1.625

CYCLE 4

BEGIN

1.	1.474	4.	1.438	7.	1.436
2.	1.480	5.	1.489	8.	1.450
3.	1.480	6.	1.425	9.	1.445

END

1.	1.590	4.	1.614	7.	1.595
2.	1.597	5.	1.650	8.	1.598
3.	1.590	6.	1.605	9.	1.600

POLARIZATION VOLTAGE (PLAQUE TO SIDE OF TANK) TRACE
FOR POSITIVE EXPERIMENT NUMBER 4

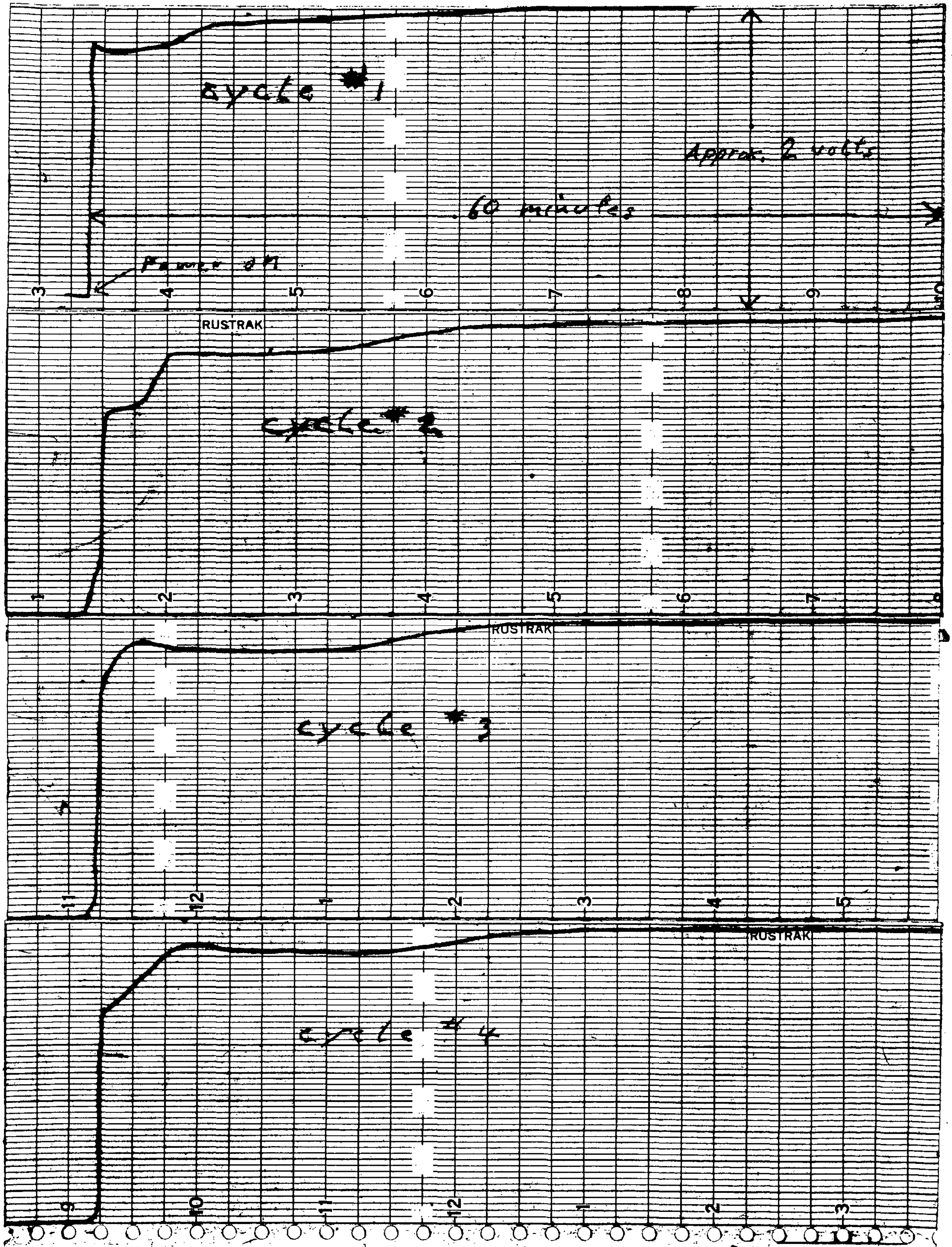

FIGURE 5

EXPERIMENT NUMBER 5A

REFERENCE ELECTRODE - POSITIVE PLATE

CYCLE 1

BEGIN

1. 1.356	4. 1.360	7. 1.380
2. 1.360	5. 1.360	8. 1.369
3. 1.360	6. 1.370	9. 1.380

END

1. 1.747	4. 1.749	7. 1.740
2. 1.750	5. 1.755	8. 1.753
3. 1.745	6. 1.758	9. 1.760

CYCLE 2

BEGIN

1. 1.440	4. 1.455	7. 1.437
2. 1.440	5. 1.450	8. 1.450
3. 1.446	6. 1.459	9. 1.460

END

1. 1.690	4. 1.690	7. 1.684
2. 1.698	5. 1.696	8. 1.697
3. 1.699	6. 1.704	9. 1.708

CYCLE 3

BEGIN

1. 1.405	4. 1.419	7. 1.400
2. 1.420	5. 1.470	8. 1.410
3. 1.420	6. 1.420	9. 1.420

END

1. 1.674	4. 1.689	7. 1.669
2. 1.680	5. 1.680	8. 1.680
3. 1.680	6. 1.687	9. 1.687

CYCLE 4

BEGIN

1. 1.420	4. 1.427	7. 1.419
2. 1.428	5. 1.420	8. 1.420
3. 1.430	6. 1.428	9. 1.440

END

1. 1.669	4. 1.679	7. 1.660
2. 1.676	5. 1.670	8. 1.670
3. 1.670	6. 1.679	9. 1.680

EXPERIMENT NUMBER 6A

REFERENCE ELECTRODE - POSITIVE PLATE

CYCLE 1

BEGIN

1.	1.357	4.	1.356	7.	1.357
2.	1.356	5.	1.344	8.	1.358
3.	1.350	6.	1.366	9.	1.360

END

1.	1.647	4.	1.644	7.	1.647
2.	1.650	5.	1.644	8.	1.647
3.	1.657	6.	1.657	9.	1.646

CYCLE 2

BEGIN

1.	1.395	4.	1.370	7.	1.398
2.	1.386	5.	1.340	8.	1.400
3.	1.325	6.	1.385	9.	1.400

END

1.	1.586	4.	1.600	7.	1.609
2.	1.616	5.	1.560	8.	1.617
3.	1.603	6.	1.606	9.	1.620

CYCLE 3

BEGIN

1.	1.298	4.	1.320	7.	1.319
2.	1.325	5.	1.250	8.	1.324
3.	1.317	6.	1.327	9.	1.322

END

1.	1.599	4.	1.614	7.	1.607
2.	1.624	5.	1.540	8.	1.617
3.	1.617	6.	1.615	9.	1.616

CYCLE 4

BEGIN

1.	1.394	4.	1.420	7.	1.428
2.	1.423	5.	1.350	8.	1.436
3.	1.413	6.	1.426	9.	1.433

END

1.	1.596	4.	1.620	7.	1.613
2.	1.620	5.	1.549	8.	1.620
3.	1.618	6.	1.620	9.	1.620

EXPERIMENT NUMBER 7A

REFERENCE ELECTRODE - POSITIVE PLATE

CYCLE 1

BEGIN

1.	1.255	4.	1.267	7.	1.260
2.	1.265	5.	1.260	8.	1.278
3.	1.270	6.	1.276	9.	1.270

END

1.	1.410	4.	1.418	7.	1.410
2.	1.420	5.	1.410	8.	1.419
3.	1.426	6.	1.416	9.	1.419

CYCLE 2

BEGIN

1.	1.320	4.	1.310	7.	1.309
2.	1.320	5.	1.292	8.	1.310
3.	1.320	6.	1.310	9.	1.310

END

1.	1.400	4.	1.385	7.	1.417
2.	1.415	5.	1.350	8.	1.420
3.	1.420	6.	1.400	9.	1.420

CYCLE 3

BEGIN

1.	1.306	4.	1.290	7.	1.286
2.	1.310	5.	1.266	8.	1.296
3.	1.316	6.	1.295	9.	1.297

END

1.	1.404	4.	1.360	7.	1.386
2.	1.417	5.	1.315	8.	1.387
3.	1.418	6.	1.364	9.	1.378

EXPERIMENT NUMBER 8B

REFERENCE ELECTRODE - POSITIVE PLATE

CYCLE 1

BEGIN

1. 1.330	4. 1.370	7. 1.380
2. 1.350	5. 1.370	8. 1.370
3. 1.370	6. 1.380	9. 1.380

END

1. 1.570	4. 1.570	7. 1.570
2. 1.570	5. 1.570	8. 1.570
3. 1.570	6. 1.570	9. 1.570

CYCLE 2

BEGIN

1. 1.300	4. 1.310	7. 1.300
2. 1.300	5. 1.300	8. 1.300
3. 1.300	6. 1.310	9. 1.300

END

1. 1.580	4. 1.590	7. 1.580
2. 1.590	5. 1.590	8. 1.580
3. 1.580	6. 1.590	9. 1.590

CYCLE 3

BEGIN

1. 1.330	4. 11.340	7. 1.340
2. 1.340	5. 1.340	8. 1.340
3. 1.340	6. 1.350	9. 1.340

END

1. 1.600	4. 1.600	7. 1.610
2. 1.610	5. 1.610	8. 1.600
3. 1.610	6. 1.610	9. 1.610

CYCLE 4

BEGIN

1. 1.300	4. 1.310	7. 1.320
2. 1.310	5. 1.310	8. 1.320
3. 1.310	6. 1.320	9. 1.320

END

1. 1.540	4. 1.550	7. 1.550
2. 1.550	5. 1.550	8. 1.550
3. 1.550	6. 1.550	9. 1.550

EXPERIMENT NUMBER 9B

REFERENCE ELECTRODE - POSITIVE PLATE

CYCLE 1

BEGIN

1.	1.300	4.	1.310	7.	1.300
2.	1.300	5.	1.300	8.	1.300
3.	1.300	6.	1.300	9.	1.300

END

1.	1.440	4.	1.440	7.	1.440
2.	1.450	5.	1.440	8.	1.440
3.	1.450	6.	1.440	9.	1.440

CYCLE 2

BEGIN

1.	1.250	4.	1.270	7.	1.260
2.	1.300	5.	1.270	8.	1.260
3.	1.270	6.	1.270	9.	1.260

END

1.	1.340	4.	1.350	7.	1.350
2.	1.370	5.	1.350	8.	1.350
3.	1.350	6.	1.350	9.	1.350

CYCLE 3

BEGIN

1.	1.300	4.	1.300	7.	1.320
2.	1.300	5.	1.300	8.	1.320
3.	1.300	6.	1.300	9.	1.320

END

1.	1.370	4.	1.380	7.	1.380
2.	1.400	5.	1.380	8.	1.380
3.	1.380	6.	1.380	9.	1.380

CYCLE 4

BEGIN

1.	1.270	4.	1.270	7.	1.310
2.	1.300	5.	1.260	8.	1.310
3.	1.300	6.	1.280	9.	1.320

END

1.	1.400	4.	1.400	7.	1.400
2.	1.420	5.	1.390	8.	1.400
3.	1.420	6.	1.400	9.	1.400

EXPERIMENT NUMBER 10B

REFERENCE ELECTRODE - POSITIVE PLATE

CYCLE 1

BEGIN

1.	1.290	4.	1.290	7.	1.310
2.	1.290	5.	1.290	8.	1.300
3.	1.290	6.	1.300	9.	1.300

END

1.	1.640	4.	1.640	7.	1.640
2.	1.650	5.	1.640	8.	1.650
3.	1.640	6.	1.640	9.	1.650

CYCLE 2

BEGIN

1.	1.300	4.	1.300	7.	1.310
2.	1.300	5.	1.300	8.	1.310
3.	1.310	6.	1.310	9.	1.310

END

1.	1.540	4.	1.540	7.	1.570
2.	1.550	5.	1.540	8.	1.560
3.	1.550	6.	1.550	9.	1.570

CYCLE 3

BEGIN

1.	1.300	4.	1.320	7.	1.340
2.	1.310	5.	1.320	8.	1.340
3.	1.310	6.	1.320	9.	1.350

END

1.	1.520	4.	1.520	7.	1.540
2.	1.520	5.	1.520	8.	1.540
3.	1.530	6.	1.530	9.	1.540

CYCLE 4

BEGIN

1.	1.420	4.	1.430	7.	1.440
2.	1.430	5.	1.430	8.	1.450
3.	1.430	6.	1.440	9.	1.460

END

1.	1.550	4.	1.560	7.	1.570
2.	1.560	5.	1.550	8.	1.570
3.	1.560	6.	1.560	9.	1.570

NEGATIVE EXPERIMENT NUMBER 1

REFERENCE ELECTRODE - POSITIVE PLATE

CYCLE 1

BEGIN

1.	1.370	4.	1.370	7.	1.380
2.	1.380	5.	1.370	8.	1.390
3.	1.380	6.	1.370	9.	1.390

END

1.	1.570	4.	1.570	7.	1.560
2.	1.580	5.	1.570	8.	1.570
3.	1.580	6.	1.570	9.	1.570

CYCLE 2

BEGIN

1.	1.370	4.	1.400	7.	1.430
2.	1.390	5.	1.410	8.	1.440
3.	1.400	6.	1.420	9.	1.440

END

1.	1.570	4.	1.570	7.	1.570
2.	1.580	5.	1.580	8.	1.580
3.	1.570	6.	1.580	9.	1.580

CYCLE 3

BEGIN

1.	1.370	4.	1.380	7.	1.370
2.	1.380	5.	1.380	8.	1.370
3.	1.370	6.	1.380	9.	1.380

END

1.	1.580	4.	1.580	7.	1.580
2.	1.590	5.	1.590	8.	1.590
3.	1.580	6.	1.590	9.	1.590

NEGATIVE EXPERIMENT NUMBER 2

REFERENCE ELECTRODE - POSITIVE PLATE

CYCLE 1

BEGIN

1.	1.350	4.	1.350	7.	1.360
2.	1.360	5.	1.360	8.	1.360
3.	1.350	6.	1.360	9.	1.370

END

1.	1.380	4.	1.390	7.	1.380
2.	1.380	5.	1.400	8.	1.390
3.	1.390	6.	1.400	9.	1.400

CYCLE 2

BEGIN

1.	1.350	4.	1.360	7.	1.370
2.	1.360	5.	1.360	8.	1.370
3.	1.360	6.	1.370	9.	1.370

END

1.	1.390	4.	1.400	7.	1.390
2.	1.400	5.	1.410	8.	1.400
3.	1.400	6.	1.410	9.	1.400

CYCLE 3

BEGIN

1.	1.350	4.	1.400	7.	1.400
2.	1.390	5.	1.410	8.	1.410
3.	1.400	6.	1.420	9.	1.420

END

1.	1.470	4.	1.470	7.	1.460
2.	1.470	5.	1.480	8.	1.470
3.	1.470	6.	1.480	9.	1.480

NEGATIVE EXPERIMENT NUMBER 3

REFERENCE ELECTRODE - POSITIVE PLATE

CYCLE 1

BEGIN

1.	1.320	4.	1.320	7.	1.330
2.	1.320	5.	1.330	8.	1.330
3.	1.320	6.	1.330	9.	1.330

END

1.	1.500	4.	1.490	7.	1.490
2.	1.500	5.	1.490	8.	1.490
3.	1.500	6.	1.500	9.	1.500

CYCLE 2

BEGIN

1.	1.300	4.	1.320	7.	1.340
2.	1.300	5.	1.330	8.	1.340
3.	1.310	6.	1.330	9.	1.330

END

1.	1.510	4.	1.490	7.	1.510
2.	1.520	5.	1.500	8.	1.500
3.	1.520	6.	1.500	9.	1.500

CYCLE 3

BEGIN

1.	1.390	4.	1.400	7.	1.400
2.	1.400	5.	1.410	8.	1.400
3.	1.400	6.	1.420	9.	1.400

END

1.	1.570	4.	1.550	7.	1.560
2.	1.580	5.	1.550	8.	1.550
3.	1.580	6.	1.550	9.	1.570

NEGATIVE EXPERIMENT NUMBER 4

REFERENCE ELECTRODE - POSITIVE PLATE

CYCLE 2

BEGIN

1.	1.320	4.	1.316	7.	1.326
2.	1.300	5.	1.320	8.	1.346
3.	1.317	6.	1.330	9.	1.339

END

1.	1.380	4.	1.386	7.	1.376
2.	1.335	5.	1.390	8.	1.380
3.	1.385	6.	1.390	9.	1.384

CYCLE 3

BEGIN

1.	1.344	4.	1.360	7.	1.360
2.	1.332	5.	1.369	8.	1.370
3.	1.367	6.	1.370	9.	1.369

END

1.	1.399	4.	1.407	7.	1.397
2.	1.402	5.	1.410	8.	1.400
3.	1.406	6.	1.410	9.	1.405

APPENDIX B

PLAQUE DIMENSIONAL MEASUREMENTS

The following dimensions were taken from plate Number One (See Figure 1) of a plaque in all cases. The recorded values are the results of a single measurement in the mid portion of the subject plate.

POSITIVE EXPERIMENT 1

		WIDTH	THICKNESS
LOT 151			
(Start)	1	2.678"	0.030"
	2	2.679"	0.030"
	3	2.672"	0.030"
(After Polarization)	1	2.683"	0.035"
	2	2.683"	0.035"
	3	2.677"	0.034"
(After Formation)	1	2.675"	0.032"
	2	2.679"	0.031"
	3	2.675"	0.031"
LOT 152			
(Start)	1	2.675"	0.033"
	2	2.673"	0.029"
	3	2.671"	0.030"
(After Polarization)	1	2.694"	0.034"
	2	2.685"	0.031"
	3	2.686"	0.030"
(After Formation)	1	2.669"	0.032"
	2	2.678"	0.028"
	3	2.675"	0.028"
LOT 153			
(Start)	1	2.677"	0.031"
	2	2.670"	0.027"
	3	2.672"	0.030"
(After Polarization)	1	2.688"	0.035"
	2	2.683"	0.035"
	3	2.679"	0.035"
(After Formation)	1	2.675"	0.033"
	2	2.670"	0.030"
	3	2.675"	0.030"

POSITIVE EXPERIMENT 2

		WIDTH	THICKNESS
LOT 151			
(Start)	1	2.675"	0.030"
	2	2.670"	0.030"
	3	2.671"	0.030"
(After Polarization)	1	2.675"	0.031"
	2	2.680"	0.031"
	3	2.680"	0.031"
(After Formation)	1	2.671"	0.030"
	2	2.675"	0.030"
	3	2.675"	0.030"
LOT 152			
(Start)	1	2.675"	0.030"
	2	2.671"	0.030"
	3	2.669"	0.030"
(After Polarization)	1	2.687"	0.032"
	2	2.690"	0.032"
	3	2.681"	0.031"
(After Formation)	1	2.676"	0.031"
	2	2.676"	0.030"
	3	2.673"	0.030"
LOT 153			
(Start)	1	2.680"	0.030"
	2	2.670"	0.030"
	3	2.675"	0.031"
(After Polarization)	1	2.686"	0.031"
	2	2.685"	0.031"
	3	2.680"	0.031"
(After Formation)	1	2.677"	0.030"
	2	2.675"	0.030"
	3	2.680"	0.030"

POSITIVE EXPERIMENT 3

		WIDTH	THICKNESS
LOT 151			
(Start)	1	2.680"	0.030"
	2	2.675"	0.030"
	3	2.675"	0.029"
(After Polarization)	1	2.675"	0.035"
	2	2.677"	0.033"
	3	2.683"	0.032"
(After Formation)	1	2.675"	0.032"
	2	2.677"	0.032"
	3	2.679"	0.032"
LOT 152			
(Start)	1	2.670"	0.030"
	2	2.675"	0.030"
	3	2.675"	0.030"
(After Polarization)	1	2.679"	0.025"*
	2	2.675"	0.025"
	3	2.675"	0.025"
(After Formation)	1	*	*
	2		
	3		
LOT 153			
(Start)	1	2.675"	0.030"
	2	2.675"	0.030"
	3	2.675"	0.030"
(After Polarization)	1	2.675"	0.035"
	2	2.675"	0.035"
	3	2.675"	0.032"
(After Formation)	1	*	*
	2		
	3		

*The flaking and subsequent loss of the nickel matrix and active material resulted in the thickness reduction of Lot 152 and prevented the measurement of dimensions after formation for Lots 152 and 153.

NEGATIVE EXPERIMENT 1

		LENGTH	THICKNESS
LOT 151			
(Start)	1	5.515"	0.028 - 0.031"
	2	5.515"	0.029 - 0.030"
	3	5.515"	0.028 - 0.029"
(After Polarization)	1	5.517"	0.031"
	2	5.520"	0.030"
	3	5.520"	0.030"
(After Formation)	1	5.520"	0.030"
	2	5.520"	0.030"
	3	5.519"	0.030"
LOT 152			
(Start)	1	5.520"	0.029" - 0.031"
	2	5.525"	0.029 - 0.030"
	3	5.525"	0.028 - 0.029"
(After Polarization)	1	5.520"	0.033"
	2	5.518"	0.034"
	3	5.521"	0.033"
(After Formation)	1	5.517"	0.032"
	2	5.515"	0.031"
	3	5.516"	0.030"
LOT 153			
(Start)	1	5.518"	0.027 - 0.030"
	2	5.518"	0.027 - 0.030"
	3	5.525"	0.025 - 0.030"
(After Polarization)	1	5.517"	0.030"
	2	5.525"	0.032"
	3	5.520"	0.030"
(After Formation)	1	5.519"	0.031"
	2	5.520"	0.030"
	3	5.520"	0.030"

NEGATIVE EXPERIMENT 2

		LENGTH	THICKNESS
LOT 151			
(Start)	1	5.515"	0.028"
	2	5.515"	0.028"
	3	5.515"	0.028"
(After Polarization)	1	5.519"	0.030"
	2	5.518"	0.030"
	3	5.519"	0.029"
(After Formation)	1	5.520"	0.030"
	2	5.516"	0.030"
	3	5.519"	0.030"
LOT 152			
(Start)	1	5.515"	0.029"
	2	5.515"	0.029"
	3	5.518"	0.030"
(After Polarization)	1	5.520"	*
	2	5.518"	
	3	5.520"	
(After Formation)	1	5.518"	*
	2	5.518"	
	3	5.518"	
LOT 153			
(Start)	1	5.518"	0.029"
	2	5.518"	0.029"
	3	5.518"	0.030"
(After Polarization)	1	5.520"	0.030"
	2	5.519"	0.030"
	3	5.520"	0.030"
(After Formation)	1	5.520"	0.030"
	2	5.519"	0.031"
	3	5.516"	0.031"

*The impregnated plaques of Lot 152 were so badly warped that an accurate thickness measurement could not be taken.

A P P E N D I X C

POSITIVE IMPREGNATION/POLARIZATION EXPERIMENT

VARIABLE LEVELS

EXPERIMENT NUMBER 1

	VARIABLE	LEVEL
1.	Specific Gravity of Nitrate	1.70
2.	Free Acid (Controlled By Addition of HNO_3)	1.0 gms/liter
3.	Temperature of Nitrate (In I/P Tank)	132 to 137°F
4.	Time of Impregnation	1 Hour
5.	Vacuum	15 Inches
6.	Wash Time	30 Minutes
7.	Wash (Number of Cycles)	1 Cycle
8.	Wash Water Temperature	59°F
9.	pH of Wash Water (Measured pH Paper)	4.5 to 5.3
10.	Type of Caustic	NaOH
11.	Specific Gravity of Caustic	1.30
12.	Temperature of Caustic (In I/P Tank)	64 to 74°F
13.	Amount of NH_3 in Caustic	0.021 to 0.037 N
14.	Amount of CO_3 in Caustic	0.2 N
15.	Amount of OH in Caustic	9.2 N
16.	Polarization Current	0.4 amps/in^2
17.	Polarization Time	1 Hour
18.	Voltage of Plaque to Reference	See Appendix
19.	Amount of Cycles with Same Caustic	1 Cycle
20.	Number of Total Cycles	4 Cycles
21.	Type of Plaque	3 Types

EXPERIMENT NUMBER 2

	VARIABLE	LEVEL
1.	Specific Gravity of Nitrate	1.70
2.	Free Acid (Controlled By Addition of HNO_3)	1.2 to 1.4 gms/liter
3.	Temperature of Nitrate (In I/P Tank)	136 to 145°F
4.	Time of Impregnation	15 Minutes
5.	Vacuum	0 Inches
6.	Wash Time	10 Minutes
7.	Wash (Number of Cycles)	1 Cycle
8.	Wash Water Temperature	64 to 70°F
9.	pH of Wash Water (Measured pH Paper)	4.5 to 5.0
10.	Type of Caustic	KOH
11.	Specific Gravity of Caustic	1.20
12.	Temperature of Caustic (In I/P Tank)	140 to 151°F
13.	Amount of NH_3 in Caustic	0.008 to 0.013 N
14.	Amount of CO_3 in Caustic	0.24 to 0.44 N
15.	Amount of OH in Caustic	0.50 to 0.55 N
16.	Polarization Current	0.4 amps/in^2
17.	Polarization Time	1 Hour
18.	Voltage of Plaque to Reference	See Appendix
19.	Amount of Cycles with Same Caustic	4 Cycles
20.	Number of Total Cycles	4 Cycles
21.	Type of Plaque	3 Types

EXPERIMENT NUMBER 3

VARIABLE	LEVEL
1. As shown for previous experiments	1.70
2. " " " " "	1.0 gms/liter
3. " " " " "	175 to 189°F
4. " " " " "	15 Minutes
5. " " " " "	15 Inches
6. " " " " "	10 Minutes
7. " " " " "	3 Cycles
8. " " " " "	52 to 54°F
9. " " " " "	4.5 to 5.3
10. " " " " "	KOH
11. " " " " "	1.30
12. " " " " "	150 to 158°F
13. " " " " "	0.010 to 0.015 N
14. " " " " "	0.84 to 1.40 N*
15. " " " " "	7.1 to 7.4 N
16. " " " " "	0.4 amps/in^2
17. " " " " "	15 Minutes
18. " " " " "	See Appendix
19. " " " " "	4 Cycles
20. " " " " "	4 Cycles
21. " " " " "	3 Types

*The high carbonate contamination indicated here is suspected to be the result of the use of carbonate contaminated deionized water.

EXPERIMENT NUMBER 4

	VARIABLE	LEVEL
1.	As shown for previous experiments	1.70
2.	" " " " "	1.0 gms/liter
3.	" " " " "	180 to 188°F
4.	" " " " "	1 Hour
5.	" " " " "	15 Inches
6.	" " " " "	10 Minutes
7.	" " " " "	3 Cycles
8.	" " " " "	50 to 56°F
9.	" " " " "	4.5
10.	" " " " "	KOH
11.	" " " " "	1.30
12.	" " " " "	150 to 156°F
13.	" " " " "	0.010 to 0.016 N
14.	" " " " "	0.44 to 0.60 N
15.	" " " " "	7.0 to 7.4 N
16.	" " " " "	0.4 amps/in^2
17.	" " " " "	1 Hour
18.	" " " " "	See Appendix
19.	" " " " "	4 Cycles
20.	" " " " "	4 Cycles
21.	" " " " "	3 Types

EXPERIMENT NUMBER 5A

VARIABLES	LEVEL
1. As shown for previous experiments	1.70
2. " " " " "	0.80 to 1.0 gm/liter
3. " " " " "	178 to 186°F
4. " " " " "	1 Hour
5. " " " " "	0 Inches
6. " " " " "	10 Minutes
7. " " " " "	3 Cycles
8. " " " " "	50 to 52°F
9. " " " " "	4.5
10. " " " " "	NaOH
11. " " " " "	1.30
12. " " " " "	150 to 160°F
13. " " " " "	0.007 to 0.018 N
14. " " " " "	0.28 to 0.44 N
15. " " " " "	9.4 to 9.8 N
16. " " " " "	0.4 amp/in^2
17. " " " " "	1 Hour
18. " " " " "	See Appendix
19. " " " " "	4 Cycles
20. " " " " "	4 Cycles
21. " " " " "	3 Types

EXPERIMENT NUMBER 6A

	VARIABLE	LEVEL
1.	As shown for previous experiments	1.80
2.	" " " " "	3.8 gms/liter
3.	" " " " "	182 to 190°F
4.	" " " " "	1 Hour
5.	" " " " "	0 Inch
6.	" " " " "	10 Minutes
7.	" " " " "	3 Cycles
8.	" " " " "	48 to 50°F
9.	" " " " "	4.5
10.	" " " " "	NaOH
11.	" " " " "	1.30
12.	" " " " "	150 to 160°F
13.	" " " " "	0.009 to 0.024 N
14.	" " " " "	0.16 to 0.24 N
15.	" " " " "	9.6 to 9.9 N
16.	" " " " "	0.4 amps/in^2
17.	" " " " "	1 Hour
18.	" " " " "	See Appendix
19.	" " " " "	4 Cycles
20.	" " " " "	4 Cycles
21.	" " " " "	3 Types

EXPERIMENT NUMBER 7A

	VARIABLE	LEVEL
1.	As shown for previous experiments	1.80
2.	" " " " "	3.4 to 4.4 gms/liter
3.	" " " " "	188 to 194°F
4.	" " " " "	15 Minutes
5.	" " " " "	0 Inches
6.	" " " " "	10 Minutes
7.	" " " " "	3 Cycles
8.	" " " " "	46 to 48°F
9.	" " " " "	4.5
10.	" " " " "	KOH
11.	" " " " "	1.30
12.	" " " " "	150 to 160°F
13.	" " " " "	0.006 N
14.	" " " " "	0.12 N
15.	" " " " "	7.6 N
16.	" " " " "	0.4 amps/in^2
17.	" " " " "	15 Minutes
18.	" " " " "	See Appendix
19.	" " " " "	4 Cycles
20.	" " " " "	4 Cycles
21.	" " " " "	3 Types

EXPERIMENT NUMBER 8B

	VARIABLE	LEVEL
1.	As shown for previous experiments	1.80
2.	" " " " "	0.8 to 1.0 gms/liter
3.	" " " " "	188 to 196°F
4.	" " " " "	15 Minutes
5.	" " " " "	0 Inches
6.	" " " " "	10 Minutes
7.	" " " " "	3 Cycles
8.	" " " " "	48 to 49°F
9.	" " " " "	4.5
10.	" " " " "	NaOH
11.	" " " " "	1.30
12.	" " " " "	150 to 170°F
13.	" " " " "	0.014 to 0.026 N
14.	" " " " "	0.20 to 0.44 N
15.	" " " " "	9.2 to 9.7 N
16.	" " " " "	0.4 amps/in^2
17.	" " " " "	1 Hour
18.	" " " " "	See Appendix
19.	" " " " "	4 Cycles
20.	" " " " "	4 Cycles
21.	" " " " "	3 Types

EXPERIMENT NUMBER 9A

	VARIABLE	LEVEL
1.	As shown for previous experiments	1.80
2.	" " " " "	1.0 to 1.2 gms/liter
3.	" " " " "	186 to 190°F
4.	" " " " "	1 Hour
5.	" " " " "	0 Inch
6.	" " " " "	10 Minutes
7.	" " " " "	3 Cycles
8.	" " " " "	49°F
9.	" " " " "	4.5
10.	" " " " "	NaOH
11.	" " " " "	1.30
12.	" " " " "	138 to 156°F
13.	" " " " "	0.012 to 0.014 N
14.	" " " " "	0.32 to 0.36 N
15.	" " " " "	9.2 to 9.5 N
16.	" " " " "	0.4 amp/in^2
17.	" " " " "	15 Minutes
18.	" " " " "	See Appendix
19.	" " " " "	4 Cycles
20.	" " " " "	4 Cycles
21.	" " " " "	3 Types

3

EXPERIMENT NUMBER 10B

VARIABLE	LEVEL
1. As shown for previous experiments	1.70
2. " " " " "	1.0 to 1.8 gms/liter
3. " " " " "	182 to 195°F
4. " " " " "	15 Minutes
5. " " " " "	0 Inch
6. " " " " "	10 Minutes
7. " " " " "	3 Cycles
8. " " " " "	48°F
9. " " " " "	4.0
10. " " " " "	NaOH
11. " " " " "	1.30
12. " " " " "	135 to 148°F
13. " " " " "	0.009 to 0.010 N
14. " " " " "	0.32N
15. " " " " "	8.9 N
16. " " " " "	0.4 amps/in^2
17. " " " " "	15 Minutes
18. " " " " "	See Appendix
19. " " " " "	4 Cycles
20. " " " " "	4 Cycles
21. " " " " "	3 Types

A P P E N D I X   D

NEGATIVE IMPREGNATION/POLARIZATION EXPERIMENT

VARIABLE LEVELS

EXPERIMENT NUMBER 1

VARIABLES	LEVELS
1. As shown for previous experiments	1.90
2. " " " " "	0.4 to 0.5 gms/liter
3. " " " " "	130 to 138°F
4. " " " " "	15 Minutes
5. " " " " "	0 Inches
6. " " " " "	10 Minutes
7. " " " " "	3 Cycles
8. " " " " "	48 to 52°F
9. " " " " "	4.5
10. " " " " "	NaOH
11. " " " " "	1.30
12. " " " " "	78 to 88°F
13. " " " " "	0.012 to 0.017 N
14. " " " " "	0.20 to 0.28 N
15. " " " " "	8.6 to 9.1 N
16. " " " " "	0.4 amps/in^2
17. " " " " "	1 Hour
18. " " " " "	See Appendix
19. " " " " "	3 Cycles
20. " " " " "	3 Cycles
21. " " " " "	3 Types

EXPERIMENT NUMBER 2

	VARIABLES	LEVEL
1.	As shown for previous experiments	1.90
2.	" " " " "	0.5 to 0.6 gms/liter
3.	" " " " "	132 to 140°F
4.	" " " " "	1 Hour
5.	" " " " "	0 Inches
6.	" " " " "	10 Minutes
7.	" " " " "	3 Cycles
8.	" " " " "	50°F
9.	" " " " "	4.5
10.	" " " " "	NaOH
11.	" " " " "	1.30
12.	" " " " "	78 to 94°F
13.	" " " " "	0.007 N
14.	" " " " "	0.16 N
15.	" " " " "	8.3 N
16.	" " " " "	0.4 amps/in^2
17.	" " " " "	15 Minutes
18.	" " " " "	See Appendix
19.	" " " " "	3 Cycles
20.	" " " " "	3 Cycles
21.	" " " " "	3 Types

EXPERIMENT NUMBER 3

VARIABLES	LEVELS
1. As shown for previous experiments	1.80
2. " " " " "	0.4 to 0.6 gms/liter
3. " " " " "	130 to 138°F
4. " " " " "	1 Hour
5. " " " " "	0 Inches
6. " " " " "	10 Minutes
7. " " " " "	3 Cycles
8. " " " " "	48°F
9. " " " " "	4.5
10. " " " " "	NaOH
11. " " " " "	1.30
12. " " " " "	92 to 103°F
13. " " " " "	0.009 N
14. " " " " "	0.20 to 0.92 N*
15. " " " " "	9.0 to 9.3 N
16. " " " " "	0.4 amps/in^2
17. " " " " "	1 Hour
18. " " " " "	See Appendix
19. " " " " "	3 Cycles
20. " " " " "	3 Cycles
21. " " " " "	3 Types

*Suspect high carbonate indication is the result of the use of carbonate contaminated deionized water.

EXPERIMENT NUMBER 4

VARIABLES		LEVELS
1.	As shown for previous experiments	1.80
2.	" " " " "	0.5 gms/liter
3.	" " " " "	128 to 135°F
4.	" " " " "	15 Minutes
5.	" " " " "	0 Inches
6.	" " " " "	10 Minutes
7.	" " " " "	3 Cycles
8.	" " " " "	52 to 54°F
9.	" " " " "	4.5
10.	" " " " "	NaOH
11.	" " " " "	1.30
12.	" " " " "	92 to 110°F
13.	" " " " "	0.009 N
14.	" " " " "	0.16 to 0.20 N
15.	" " " " "	7.8 to 8.7 N
16.	" " " " "	0.4 $amps/in^2$
17.	" " " " "	15 Minutes
18.	" " " " "	See Appendix
19.	" " " " "	3 Cycles
20.	" " " " "	3 Cycles
21.	" " " " "	3 Types

APPENDIX E

INDIVIDUAL PLAQUE RESPONSE MEASUREMENTS

POSITIVE RESPONSES (EXPERIMENT 1)

1. Pickup Weight

PLAQUE AFTER I/P	AFTER FORMATION	LOSS
LOT 151		
1. 64.4 gms	59.9	-4.5
2. 63.3	58.1	-5.2
3. 65.1	55.1	-10.0
LOT 152		
1. 51.9 gms	43.4	-8.5
2. 50.6	43.3	-7.3
3. 47.4	41.6	-5.8
LOT 153		
1. 55.0 gms	50.5	-4.5
2. 57.5	51.0	-6.5
3. 59.0	53.5	-5.5

2. Capacity

Two terms are used to express electrical capacity: The first term is ampere-hours/plate which is the capacity of a single standard (approximately 15 in^2) plate used throughout this work. The second term is ampere-hours/gram which may be considered an efficiency factor. The actual grams of active material impregnated in a test plate is determined and the ampere-hours capacity is expressed in terms of this quantity.

PLAQUE	PLATE	AMP-HOURS/PLATE	AMP-HOURS/GRAM
LOT 151			
1	2	2.42	0.228
2	4	2.40	0.226
3	2	2.42	0.228
LOT 152			
1	2	1.98	0.213
2	2	1.92	0.218
3	2	1.83	0.229
LOT 153			
1	2	2.07	0.284
2	4	1.98	0.305
3	2	2.10	0.276

Lot 153 impregnated plaques exhibited an unusually high efficiency factor in relation to the other lots in this experiment. No explanation can be given at this time to satisfactorily explain this peculiar result.

3. Plaque Characterization

All three lots of plaques in this experiment exhibited a very rough surface texture. Active material appeared to be caked on the outside surface of the plaque. This observation is supported by the plaque weight loss associated with the formation process which to a certain extent affects the removal of an unimpregnated surface layer.

POSITIVE RESPONSES (EXPERIMENT 2)

1. Pickup Weight

LOT 151

PLAQUE AFTER I/P	AFTER FORMATION	LOSS
1. 42.2 gms	41.5	-0.7
2. 42.0	41.5	-0.5
3. 41.0	40.0	-1.0
LOT 152		
1. 47.2 gms	44.2	-3.0
2. 44.8	42.3	-2.5
3. 46.3	43.3	-3.0
LOT 153		
1. 42.6 gms	42.6	0.0
2. 41.1	40.6	-0.5
3. 41.8	41.8	0.0

2. Capacity

LOT 151

PLAQUE	PLATE	AMP-HOURS/PLATE	AMP-HOURS/GRAM
1	2	1.44	0.218
2	4	1.38	0.216
3	2	1.41	0.216
LOT 153			
1	2	1.44	0.218
2	4	1.40	0.209
3	2	1.29	0.239

3. Plaque Characterization

The surface texture of the three groups of plaques in this experiment was much smoother than the previous experiment, but all surfaces were badly cracked. Lot 152 plaques were in such poor condition that they were not subjected to the capacity test.

POSITIVE RESPONSES (EXPERIMENT 3)

1. Pickup Weight

LOT 151

PLAQUE	AFTER I/P	AFTER FORMATION	LOSS
1	47.5	43.5	-4.0
2	51.0	47.0	-4.0
3	49.5	47.5	-2.0

2. Capacity

LOT 151

PLAQUE	PLATE	AMP-HOURS/PLATE	AMP-HOURS/GRAM
1	2	1.78	0.234

Test equipment failure resulted in the loss of the capacity data for plaques 2 and 3.

3. Plaque Characterization

The results of this experiment were very poor. The surface of all plaques appeared to be blistered. In the case of Lots 152 and 153, the sintered nickel was removed from the body of the plaque during the wash procedure following the formation operation. This prevented the evaluation of pickup weight and capacity for these two lots.

POSITIVE RESPONSES (EXPERIMENT 4)

As in the previous experiment, the surfaces of all plaques were blistered, but to a much greater extent. The condition of the plaque was so poor that they were not subjected to the formation operation and the experiment was discontinued.

POSITIVE RESPONSES (EXPERIMENT 5A)

1. Pickup Weight

LOT 151

PLAQUE	AFTER I/P	AFTER FORMATION	LOSS
1	54.5	54.0	-0.5
2	58.0	57.5	-0.5
3	56.0	56.0	0.0

LOT 152

PLAQUE	AFTER I/P	AFTER FORMATION	LOSS
1	70.5	66.5	-4.0
2	68.5	65.5	-3.0
3	64.5	56.5	-8.0

LOT 153

PLAQUE	AFTER I/P	AFTER FORMATION	LOSS
1	54.5	54.0	-0.5
2	60.0	59.5	-0.5
3	60.0	59.0	-1.0

2. Capacity

LOT 151

PLAQUE	PLATE	AMP-HOURS/PLATE	AMP-HOURS/GRAM
1	2	2.37	0.263
2	4	2.59	0.254
3	2	2.37	0.279

LOT 152

PLAQUE	PLATE	AMP-HOURS/PLATE	AMP-HOURS/GRAM
1	2	3.23	0.243
2	4	2.95	0.268
3	2	2.97	0.260

LOT 153

PLAQUE	PLATE	AMP-HOURS/PLATE	AMP-HOURS/GRAM
1	2	2.16	0.251
2	4	2.54	0.226
3	2	2.54	0.249

3. Plaque Characterization

Lots 151 and 153 were very good. The plaques exhibited smooth clean surfaces without cracks. There was some material flaking associated with Lot 152 but no blistering.

POSITIVE RESPONSES (EXPERIMENT 6A)

1. Pickup Weight

LOT 151

PLAQUE	AFTER I/P	AFTER FORMATION	LOSS
1	*	57.5	--
2	*	58.0	--
3	*	65.0	--
LOT 153			
1	*	60.0	--
2	*	60.5	--
3	*	64.5	--

*The pickup weights of the plaques after completion of the impregnation/polarization process were inadvertently missed during this experiment.

2. Capacity

LOT 151

PLAQUE	PLATE	AMP-HOURS/PLATE	AMP-HOURS/GRAM
1	2	3.00	0.289
2	4	3.00	0.297
3	2	3.23	0.296
LOT 153			
1	2	3.00	0.286
2	4	2.88	0.280
3	2	3.15	0.281

3. Plaque Characterization

Lot 151 was good with fairly smooth and clean surfaces. Lot 152 was poor with active material flaking off. This lot was not weighed or subjected to the capacity test. Lot 153 was also poor with rough pitted surfaces.

POSITIVE RESPONSES (EXPERIMENT 7A)

This experiment was discontinued after completion of the third impregnation/polarization cycle because of poor plaque condition. All three groups of plaques were badly blistered and exhibited flaking material.

POSITIVE RESPONSES (EXPERIMENT 8B)

1. Pickup Weight

LOT 151

PLAQUE	AFTER I/P	AFTER FORMATION	LOSS
1	58.0	56.0	-2.0
2	59.5	57.0	-2.5
3	57.5	56.5	-1.0
LOT 152			
1	56.0	48.5	-7.5
2	59.5	52.0	-7.5
3	61.5	54.5	-7.0
LOT 153			
1	57.5	56.5	-1.0
2	57.5	57.0	-0.5
3	56.5	55.5	-1.0

2. Capacity

LOT 151

PLAQUE	PLATE	AMP-HOURS/PLATE	AMP-HOURS/GRAM
1	2	2.41	0.257
2	4	2.47	0.257
3	2	2.36	0.268
LOT 152			
1	2	2.05	0.256
2	2	2.28	0.235
3	2	2.43	0.250
LOT 153			
1	2	2.17	0.236
2	4	2.32	0.242
3	2	2.12	0.252

3. Plaque Characterization

Lot 151 was very good with smooth and clean surfaces. Lot 152 was poor with material flaking off. Lot 153 was good, but exhibited a few cracks.

POSITIVE RESPONSES (EXPERIMENT 9A)

1. Pickup Weight

LOT 151

PLAQUE	AFTER I/P	AFTER FORMATION	LOSS
1	69.0	67.0	-2.0
2	67.5	65.5	-2.0
3	68.0	67.0	-1.0

LOT 153

PLAQUE	AFTER I/P	AFTER FORMATION	LOSS
1	72.0	68.0	-4.0
2	73.0	66.0	-7.0
3	71.0	69.5	-1.5

2. Capacity

LOT 151

PLAQUE	PLATE	AMP-HOURS/PLATE	AMP-HOURS/GRAM
1	4	2.82	0.274
2	2	2.97	0.275
3	4	2.94	0.272

3. Plaque Characterization

Lot 151 was fair, but had a rough surface texture. Lot 152 was again very poor with flaking material. Lot 153 was also poor with a rough surface and cracks. Lots 152 and 153 were not subjected to the capacity test.

POSITIVE RESPONSES (EXPERIMENT 10B)

1. Pickup Weight

LOT 151

PLAQUE	AFTER I/P	AFTER FORMATION	LOSS
1	47.5	46.5	-1.0
2	48.0	46.5	-1.5
3	48.0	47.5	-0.5
LOT 153			
1	45.0	45.5	0.5
2	47.0	46.0	-1.0
3	44.5	43.5	-1.0

2. Capacity

LOT 151

PLAQUE	PLATE	AMP-HOURS/PLATE	AMP-HOURS/GRAM
1	2	1.93	0.254
2	4	2.02	0.250
3	2	1.85	0.243
LOT 153			
1	2	1.70	0.233
2	4	1.65	0.226
3	2	1.53	0.235

3. Plaque Characterization

Lot 151 was good with a smooth and clean surface texture. Lot 152 was as usual, poor with flaking material. Lot 153 was fair, but the plaque surfaces contained a lot of cracks.

NEGATIVE RESPONSES (EXPERIMENT 1)

1. Pickup Weight

LOT 151

PLAQUE	AFTER I/P	AFTER FORMATION	LOSS
1	49.2	47.2	-2.0
2	49.3	47.8	-1.5
3	45.9	43.9	-2.0
LOT 152			
1	55.9	54.9	-1.0
2	57.3	55.3	-2.0
3	53.9	51.4	-2.5
LOT 153			
1	49.0	48.0	-1.0
2	50.6	49.1	-1.5
3	48.6	46.6	-2.0

2. Capacity

LOT 151

PLAQUE	PLATE	AMP-HOURS/PLATE	AMP-HOURS/GRAMS
1	2	1.98	0.268
2	4	2.08	0.274
3	2	1.84	0.267
LOT 152			
1	2	2.42	0.260
2	4	2.39	0.254
3	2	2.17	0.244
LOT 153			
1	2	2.12	0.279
2	4	2.15	0.262
3	2	1.89	0.255

3. Plaque Characterization

All three groups of plaques looked very good in this experiment. There was some cracking at the edges of the plaques associated with Lot 152.

NEGATIVE RESPONSES (EXPERIMENT 2)

1. Pickup Weight

LOT 151

PLAQUE	AFTER I/P	AFTER FORMATION	LOSS
1	69.1	64.1	-5.0
2	67.5	63.0	-4.5
3	66.2	62.2	-4.0
LOT 152			
1	78.5	73.0	-5.5
2	80.6	75.1	-5.5
3	79.7	73.7	-6.0
LOT 153			
1	67.0	62.0	-5.0
2	67.0	63.0	-4.0
3	69.0	64.5	-4.5

2. Capacity

LOT 151

PLAQUE	PLATE	AMP-HOURS/PLATE	AMP-HOURS/GRAM
1	2	2.71	0.244
2	4	2.63	0.248
3	2	2.56	0.248
LOT 152			
1	2	3.00	0.240
2	4	3.12	0.238
3	2	3.18	0.221
LOT 153			
1	2	2.64	0.266
2	4	2.90	0.244
3	2	2.85	0.261

3. Plaque Characterization

The three groups of plaques in this experiment also looked very good. Again, there was some cracking at the edges of the plaques associated with Lot 152.

NEGATIVE RESPONSES (EXPERIMENT 3)

1. Pickup Weight

LOT 151

PLAQUE	AFTER I/P	AFTER FORMATION	LOSS
1	69.5	65.0	-4.5
2	70.0	66.5	-3.5
3	71.0	67.0	-4.0
LOT 152			
1	79.0	70.5	-8.5
2	78.5	70.0	-8.5
3	78.5	69.0	-9.5
LOT 153			
1	54.0	49.0	-5.0
2	58.5	53.5	-5.0
3	66.0	61.5	-4.5

2. Capacity

LOT 151

PLAQUE	PLATE	AMP-HOURS/PLATE	AMP-HOURS/GRAM
1	2	3.07	0.258
2	4	3.04	0.262
3	2	3.01	0.255
LOT 152			
1	3	3.48	0.268
2	4	3.09	0.258
3	1	3.29	0.259
LOT 153			
1	2	1.98	0.257
2	4	2.37	0.282
3	2	2.57	0.270

3. Plaque Characterization

Lot 151 exhibited a slightly rough surface texture. Lot 152 was for the first time during these negative experiments very poor. The blistering phenomenon so common with the positive plaques occurred on the surface of this lot of plaques which resulted in material flaking off. Lot 153 was good with smooth clean surfaces.

NEGATIVE RESPONSES (EXPERIMENT 4)

1. Pickup Weight

LOT 151

PLAQUE	AFTER I/P	AFTER FORMATION	LOSS
1	41.0	38.0	-3.0
2	55.0	52.0	-3.0
3	54.0	51.5	-2.5
LOT 152			
1	66.0	63.0	-3.0
2	67.5	62.0	-5.5
3	60.0	56.5	-3.5
LOT 153			
1	52.5	50.5	-2.5
2	40.0	39.0	-1.0
3	41.5	39.5	-2.0

2. Capacity

LOT 151

PLAQUE	PLATE	AMP-HOURS/PLATE	AMP-HOURS/GRAM
1	2	1.61	0.259
2	4	2.65	0.276
3	2	2.63	0.289
LOT 152			
1	2	2.93	0.279
2	2	2.92	0.278
3	4	2.62	0.276
LOT 153			
1	2	2.30	0.291
2	4	1.84	0.279
3	2	1.85	0.308

3. Plaque Characterization

Lot 151 was good, but it exhibited a slightly rough surface texture. Lot 152 was fair, but it exhibited a rough surface. Lot 153 was good with a smooth and clean surface.