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An In-Depth Look At Ionic Cleanliness Testing

RR0013

Tim Crawford

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Electronics Manufacturing Productivity Facility *714 North Senate Avenue* *Indianapolis, IN 46202-3112*

Phone: 317-655-3673 *Fax: 317-655-3699*

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Kester Solder
London Chemical
Protonique
Westek

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Thank You.

Tim Crawford
EMPF

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EXECUTIVE SUMMARY

Testing performed at the Electronics Manufacturing Productivity Facility has shown that as technology advances and printed wiring assembly (PWA) surface areas get smaller, surface residues will become harder to measure accurately. On small surface areas, variables such as probe limitations, solvent volume, and even carbon dioxide from the air will influence ionic contamination measurements.

Most systems have what is termed a "deadband". The resistivity probe used in each system has a maximum measurement capability. For example, if the maximum capability of the probe is 100 megohm-cm and the resistivity of the solvent is actually 150 megohm-cm, the display will continue to read 100 megohm-cm. Any ionic residues that lower the resistance of the solvent from 150 to 100 megohms-cm will not be measured. Resistivity, however, is not linear, and the amount of residue it takes to drop the resistivity from 150 megohm-cm to 140 megohm-cm is much less than the amount of residue it takes to drop the resistivity from 50 megohm-cm to 40 megohm-cm. It has been argued that the amount of ionic residue it takes to drop the resistivity from the deadband to the visible range is insignificant in most cases. This argument would depend on surface area as well as the need for accuracy. To maintain accuracy, it is important that the operator of the cleanliness test equipment not leave the system in a clean/filter mode for an extended period of time. If the operator inadvertently deionized the solvent to a higher than normal level, the solvent should be artificially contaminated and then recleaned to an acceptable level.

Carbon dioxide can dissolve in water to form carbonic acid. This can weakly ionize into H^+ and HCO_3^- ions which can/will then affect ionic readings. The presence of this ionic build-up during a static extraction will contribute to the overall ionic reading. In most instances, such contributions will be small, representing only a relatively small error in the measured results. If, however, we are measuring a small sample in a large volume of extracting solution, the effective total micrograms of NaCl represented by the CO_2 build-up in solution will be divided by the smaller surface area of the sample giving rise to a larger relative error in the reading expressed as $\mu g/in^2$. Extractions which are made for longer times will also show higher CO_2 errors, since more CO_2 will dissolve in the longer period of exposure to the atmosphere. Testing indicated that the problem was not detectable for all of the static systems; and there did not appear to be any correlation for spray versus no spray, or spray above immersion versus spray below immersion. The dynamic systems are continually deionizing the solvent, therefore removing the small amounts of CO_2 before it has a chance to accumulate a measurable amount. Further testing, however, would be required to fully characterize the effects of CO_2.

The temperature of the solvent used in ionic cleanliness test systems will increase but eventually stabilize over time in operation. This was true for all of the test equipment, even the systems without heating elements. Due to pumps moving the solvent and friction in the plumbing, solvent temperatures would typically increase in an unheated system 10 to 15° F from initial room temperature. Only the Icom 5000 and the Omegameter 600SMD could be run with the heaters in the "on" or "off" position. Both systems showed higher results when the solvent was heated. In addition, the heated systems when crossed with the solution volume, indicated that the volume variable was more significant.

Throughout all of the testing, there appeared to be a disagreement, or a separation, between the "dynamic" and the more popular "static" families of cleanliness test equipment. Additional testing, not outlined in the original test plan, showed that there appear to be limitations associated with the "static" process that hinder the ability of the solvent to ionize, and thus measure contamination.

Not surprisingly, the most significant variable that influenced the final result, when altered for both "in solution" and "test coupon" testing, was the residue quantity. When all of the 5 microgram data is compared to all of the 55 microgram data, the change is significant. The dynamic systems and the static systems were grouped separately and the dynamic systems measured a more significant change when going from 5 to 55 micrograms. Though grouped, the dynamic processes had a data spread of about 8 micrograms when measuring the 55 microgram concentration, and the static systems had a spread of about 15 micrograms. It can also be noted that the static systems read similar or higher than the dynamics at 5 micrograms, but then read lower at 55 micrograms.

The next most significant variable was the IPA effect. As the alcohol content in the solvent was increased from 70% to 80%, the results dropped. This too is not surprising, knowing that it is the water that ionizes the contamination and that the alcohol is there merely to dissolve the nonionic (rosin) material to get access to any trapped ionic contamination. The 70%

solution contains more water than the 80% solution, thereby giving this solution more ionizing capabilities. Again, there was a definite grouping associated with the static versus dynamic systems, and the dynamic systems seem to be most affected by the change in alcohol.

The effect of standoff height was not as great as anticipated for the static systems. The static systems were equally effective at removing contamination from under both standoffs; however, residue was being left under both standoff heights. Standoff height seemed to affect the dynamic systems more than the static systems, meaning that a larger percent of residue was removed from under the 9 mil standoff than that of the 3 mil standoff. Statistically, the only system that measured the channel depth as being significant was the Ionograph 500M. Temperature and sprays seem to enhance the solvent's ability to penetrate smaller areas (3 mils) and dissolve surface residues, but was not a significant variable at 9 mils.

In comparing weakly ionizable flux to strongly ionizable flux during "in solution" testing, three out of the four dynamic systems showed the variable to be insignificant, while the Ionograph 500SMD and all of the static systems showed that the variable was significant. Though the weakly ionizable and strongly ionizable fluxes appeared to be different from each other, the trends that occurred when changing other variables were similar. Once the fluxes were introduced to the test coupons and baked, however, a wide variance in the strongly ionizable flux data began to appear. Because of these wide variances, and also since the trends were similar to weakly ionizable flux during "in solution" testing, the Ionic Conductivity Task Group (ICTG) decided not to perform extensive coupon testing on the strongly ionizable flux. Though the variable was not found to be significant in the dynamic systems, all had a negative effect as the flux shifted from weak to strong, whereas in the static systems all measured a positive effect.

The volume effect was perhaps the most unusual observation made in this study. When the volume was increased during the "in solution" testing, the results also tended to increase. But for some reason, when the volume was increased during the board testing, the ionic results tended to drop. This trend was noted on most of the systems, and at this point, there is no explanation for this observance.

Volume influence has been noted and explained in previous studies conducted by Jack Brous of Alpha Metals. Originally, the extraction procedures were developed for the measurement of ionic materials present in fully activated rosin flux residues. These ionic materials are usually strongly ionized salts such as amine hydrochlorides. It was shown that such materials give linear response with concentration.[1] If, however, we try to measure residues of materials which are weakly ionized, the response is extremely concentration-dependent. An extraction of a quantity of a weakly ionized material into a large volume of a water/alcohol mixture will, therefore, indicate a much greater ionic response than for the same amount of materials extracted in a smaller volume (higher concentration).[1,2] As we approach higher dilutions (larger volumes), the degree of ionization approaches 100% and the reading is more truly proportionately representative of amounts of extracted ionic material. Weakly ionized organic acids are typically found in water-soluble (OA type) fluxes and the low-solids "no-clean" flux types. Caution should be used, therefore, in applying these ionic extract techniques to these flux types.

It will be hard to answer the age old question "How clean is clean?" without attaching an analytical quantity to a certain level of reliability. Understanding the effect of the variables was the first step in determining whether existing equipment design accommodates that need. It is important to note that this equipment was never meant to be used for analytical purposes; instead, it was intended to be used for process control. Though there are variables that influence final ionic readings, these systems will detect equipment failures, materials handling and processing errors. For now, use this equipment consistently and routinely; most importantly, use it as the creators intended - as a process control tool.

INTRODUCTION

Many printed wiring assembly (PWA) failures that occur in the field can be attributed to manufacturing residues that were not properly removed. It is essential that the cleaning process be monitored to ensure proper removal of contaminants that may, when exposed to time, temperature, and humidity, lead to high defect rates.

The most common method for evaluating the cleanliness level of a PWA is a method called the Resistivity Of Solvent Extract (ROSE) test. The original procedure, developed in the early 1970s, used a laboratory squeeze bottle filled with a 75% isopropanol (IPA) and 25% deionized water solution to dissolve ionic contamination from the PWA into a beaker. The resistivity of the extract solution was then measured and assigned a value based on a sodium chloride (NaCl) standard. In the last 20 years, several manufacturers have developed and marketed equipment to perform this type of testing. During that time, radical changes have been made to the systems, such as the addition of solvent heaters, sprays and microprocessors. Recent studies have shown discrepancies among not only the different manufacturers, but also among different parameters such as solvent temperature and volume. To continue using this test to manage a process or to make decisions on what cleaning alternative works best, it became necessary to investigate what variables influence final results and standardize a test procedure.

The goal of this project is to give users of cleanliness test equipment a better understanding of ionic cleanliness testing. How much does solvent temperature influence the final cleanliness results? How critical is the 75% isopropanol to 25% water ratio? Is spraying the solvent important? Will today's systems remove contamination from under a component with a .005" standoff height? Is static or dynamic the more efficient or effective process? This project has explored these questions and has determined what variables most influence ionic cleanliness test results.

BACKGROUND

Residual contamination left on a printed wiring assembly (PWA) is generally classed into one of two categories: ionic or non-ionic. Ionic residues derived from plating salts, flux activators, and human perspiration, for example, have the ability to conduct electrical current. In the presence of moisture, these residues can cause short circuits and corrosion of solder joints. Non-ionic residues, such as rosin, oil, or grease, act as insulators and do not conduct electricity. This type of residue can inhibit current flow across edge connectors or some other communications port. Fluxes used in the manufacturing process contain both ionic and non-ionic materials.

It is obvious that a "clean" PWA has a greater chance for reliability. In 1972, the Naval Air Warfare Center (NAWC) in Indianapolis (formerly Naval Avionics Facility Indianapolis) conducted a study to find a technique for evaluating how "clean" a PWA is after the manufacturing process.[3] Though the test measured ionic residues only, a good assessment of the cleaning process could still be made. The test procedure used a squeeze bottle filled with 75% isopropanol and 25% water solution with a minimum resistivity of 6 megohms-cm to rinse residue off a circuit board. The extract solution was funneled into a beaker until 10 milliliters per square inch of PWA surface area was collected and the resistivity was again measured. A minimum pass/fail limit was set at 2 megohm-cm, which was later interpreted into a sodium chloride equivalent and calculated in micrograms per square inch ($\mu g/in^2$) or per square centimeter ($\mu g/cm^2$) of board surface area. However, there were many unspecified parameters in the pioneer test, and different authorities calculated different results.

Once the test method and the pass/fail criteria were established, equipment manufacturers began designing and building systems to do this type of testing. Due to efficiency, or perhaps the slightly different measuring process, it was noted that the new equipment would typically give higher results than that of the beaker/funnel technique. In 1978, a second study was performed at NAWC[4] to establish "equivalency factors" for some of the new equipment which would be incorporated into various military standards, such as MIL-P-28809 and WS-6536. The theory behind the "equivalency factors" was that the same PWA that measured 10.06 $\mu g/in^2$ using the beaker/funnel test would have measured 14.00 $\mu g/in^2$ in a static system, and 20.00 $\mu g/in^2$ in a dynamic system under the conditions of the study. As the years progressed, more advances were made to the equipment such as the incorporation of solvent heaters, microprocessors, and sprays. As the efficiency of the systems increased, it became increasingly apparent that the equivalency factors established for the 1978 equipment did not apply to current equipment. In addition, equipment introduced to the market after the study are not mentioned, even in the revised standards, and erroneously not considered as accepted test equipment by potential users.

The problem was further complicated when Motorola documented that the temperature of the solvent significantly influenced the final result of a test[5]. An earlier study performed at DuPont[6] showed that solution temperatures could increase by as much as 14° F over the course of a work day, increasing the results by as much as 20%. One ionic cleanliness tester could give two different answers for the same PWA depending on the temperature of the solvent. Other studies with similar results led members of the Institute for Interconnecting and Packaging of Electronic Circuits (IPC) to form an Ionic Conductivity Task Group (ICTG) to investigate temperature and other variables involved with ionic test equipment.

Resistivity vs Conductivity

The ROSE test uses the solvent's ability to conduct electricity to determine how much ionic contamination is present. The ability to conduct electricity can be measured in either conductivity (siemens/cm or mhos/cm) or by its reciprocal, resistivity (ohms-cm). Pure water/IPA solvent is an extremely poor conductor of electricity, so the resistance is high and the conductance is low. Pure water conducts electricity slightly better, and is capable of showing a resistivity of about 19 megohm-cm or 0.0526 microsiemens/cm measured at 20°C. This is attributed to water's self-ionization enhanced by its own high polarity. As ionic contamination is removed from the PWA and passed to the solvent, the resistivity drops while the conductivity increases. It is the measurement of this enhanced electrical conductivity of water (or mixtures containing water) that is the basis of all ion extract conductivity testing being studied in this program.

If we examine the conductivity values for strongly ionized materials in an aqueous solution, we find that they are linearly proportional to the concentrations of the salt in solution as shown in Figure 1. However, a plot of the resistivity vs. sodium chloride concentration will yield a hyperbolic function as shown in Figure 2. This type of response curve has two major drawbacks for ionic measurement. First, the mathematical calculation of ionic differences becomes considerably more complicated when using the non-linear calculation of resistivity as compared to conductivity. Second, the sensitivity of the resistivity measurement, as represented by the slope of the curve, decreases significantly as concentration builds. This can be a particular problem in using the static method of extraction, since the final readings are taken after most of the ionic materials have been extracted and accumulated in solution. The readings at maximum concentration are taken at the point where sensitivity of response (slope) is the least thereby limiting the ability of the system to detect small amounts of ions still being extracted from the sample.

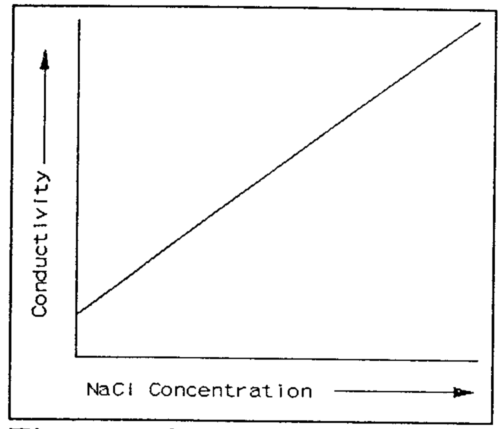


Figure 1 Conductivity Curve

In his original work in the early 70's, Tom Egan of Bell Laboratories very succinctly stated the case for using conductivity exclusively in measurements of extracted ionic contaminants.[7] This was later expanded by Jack Brous.[8] Most chemists prefer the use of the conductivity function over resistivity. Many engineers, on the other hand, use the resistance and resistivity value in areas related to water purity measurement. Though some of the cleanliness test equipment used in this study measure conductivity, most systems measure resistivity. For this reason, resistivity was chosen to describe changes in electrical current flow in this document.

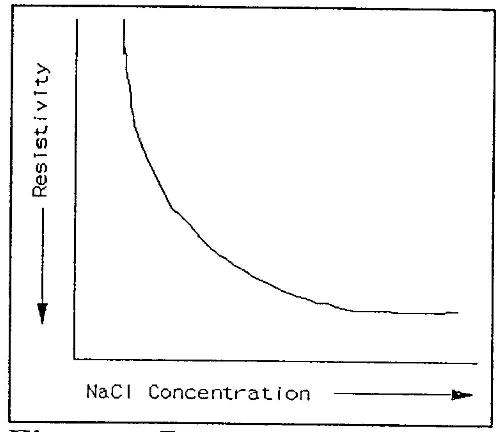


Figure 2 Resistivity Curve

Units of Measure

The EMPF and IPC acknowledge the fact that much of the world uses the metric system of measurement, therefore correlating contamination to micrograms per square centimeter ($\mu g/cm^2$) of surface area. However, for the purpose of this report, micrograms per square inch ($\mu g/in^2$) is a more accepted term in the United States. The formula for converting $\mu g/in^2$ into $\mu g/cm^2$ is as follows:

$$\mu g/in^2 \ \text{X} \ 0.1550 = \mu g/cm^2$$

TEST PROCEDURE

Objective

This project was **not** intended to select a "best system". This study used a statistically designed experiment to examine the different variables that are associated with ionic cleanliness test equipment and their effects on ionic measurement (see Appendix A). In addition, various concentrations of different flux types were used to measure how accurate each system was at detecting specific residues. Finally, stainless steel plates machined to yield known standoff heights were used to determine the efficiency of each system/variable at removing residue from tight spaces.

One of the primary goals established by the ICTG was to evaluate how the different system variables affect the removal of ionic residues from under known standoff heights. Our intent was to be able to determine that "System A", for example, with no heat and no sprays was 88% efficient at removing residue from under a 9 mil standoff, only 60% efficient at 6 mil standoff, and 30% efficient at 3 mil. This data could then be compared to "System B" with heat and sprays that was 100% efficient at 9 mil, 98% efficient at 6 mil, and 85% efficient at 3 mil standoffs.

A future target for this project may be to examine the validity of the equivalency factors assigned to some of the testers in various military standards. There is a need to correlate the newer, more efficient systems to somehow relate their results to other equipment as well as to the original beaker/funnel method, but how accurate are the equivalency factors? Have the factors changed over the years? How do equivalency factors and the overall pass/fail criteria relate to long-term reliability? These questions may be answered by determining which, and to what degree, variables influence the equivalency factors.

Equipment

Equipment vendors agreed to loan their ionic cleanliness test equipment to the EMPF for the duration of the study. All of the equipment used in this study is commercially available from Alpha Metals, Kester Solder, London Chemical, Protonique, Westek and Zero Systems. The equipment is classed into one of four categories; Static/ No Heat, Static/ With Heat, Dynamic/ No

TABLE 1 EQUIPMENT CLASSIFICATIONS					
COMPANY	MODEL	TYPE	HEAT	VOLUME CONTROL	SPRAY
Alpha Metals	Ionograph 500SMD	Dynamic	Yes	No	Yes
	Ionograph 500M	Dynamic	No	No	No
Zero Systems**	Zero Ion	Dynamic	No	No	Yes
Protonique*	Contaminometer CM-5	Dynamic	No	No	No
Alpha Metals	Omegameter 600SMD	Static	Yes	Yes	Yes
	Omegameter 600R	Static	No	Yes	No
Kester	Ionex 2000 System 100	Static	No	Yes	Yes
Protonique*	Contaminometer CM-5	Static	No	No	No
Westek	Icom 5000	Static	Yes	Yes	Yes

* Distributed in United States by Multicore Solder
** Distributed worldwide by London Chemical (Lonco)

Heat, Dynamic/ With Heat (see Table 1). The term "static" is really a misnomer in that static usually refers to something as being stagnant, or motionless. In this case, the term "static" refers to the fixed volume that is used for testing. In the clean/fill mode, the static system will deionize solvent from the reservoir and fill the test cell with a known volume (see Figure 3). While in the test mode, the static system will continually circulate solvent from the test cell, past a resistivity probe, then back into the test cell. Ionic residues are dissolved and distributed throughout a set volume, so the resistivity of the

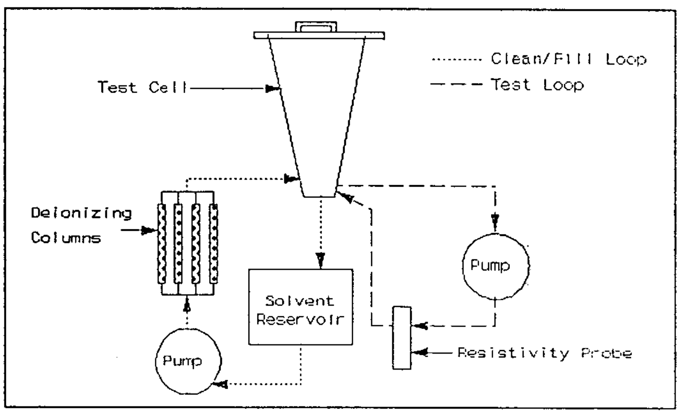


Figure 3 Static Process

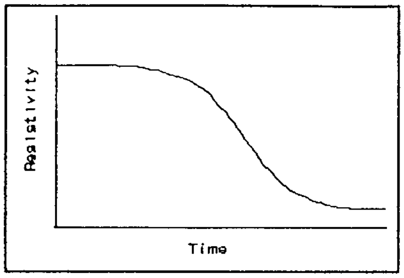


Figure 4 Static Curve

solvent will drop and then level off (see Figure 4). The final resistivity measurement is compared to the initial starting resistivity, and the change is correlated to the total ionic contamination. When testing is complete, the clean/fill loop is again used to clean, or regenerate, the solvent back to a high resistivity before starting the next test.

The "dynamic" process takes solvent from the test cell (see Figure 5), measures the resistivity, deionizes, then puts the solvent back into the test cell. Because contaminated solvent is being replaced with clean solvent, the volume is effectively infinite. The resistivity reading for the dynamic process starts at a high baseline, drops as the residue is removed, then returns to that baseline as the solvent is deionized (see Figure 6). The area under the curve is then related to the total ionic contamination.

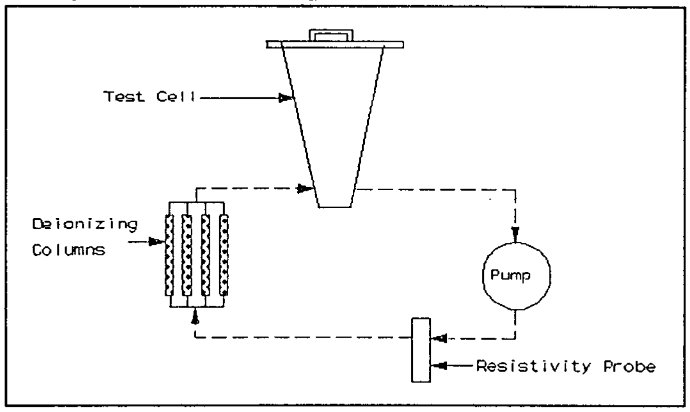


Figure 5 Dynamic Process

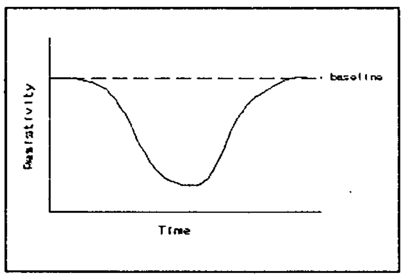


Figure 6 Dynamic Curve

Operation of the equipment was based upon standard operating conditions set by the manufacturers and some preliminary work done at the EMPF. Any changes to the operating procedures were recommended by either the manufacturer, or the EMPF, with final approval coming from the ICTG and the manufacturer.

Test Vehicle

The test vehicle used to determine the ability of a system to remove ionic contamination from under known standoff heights is pictured in Figures 7 and 8. The board (Figure 7) consisted of an FR4, epoxy/glass laminate with 0.5 ounce copper patterns. Other board materials were considered in preliminary testing; however, FR4 was chosen as the standard. Stainless steel plates (Figure 8) were machined to yield a known standoff height of 0.003, 0.006, or 0.009 (+/- 0.0005) inch.

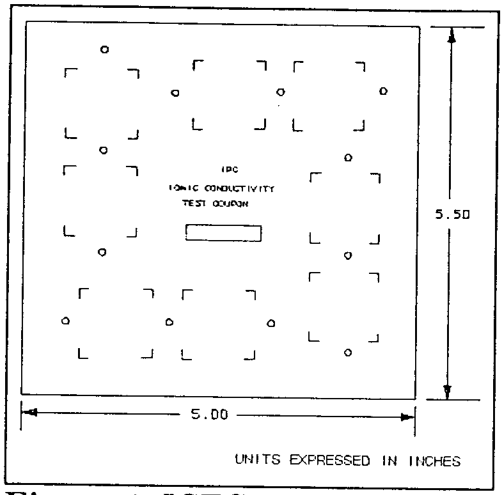


Figure 7 ICTG Test Board

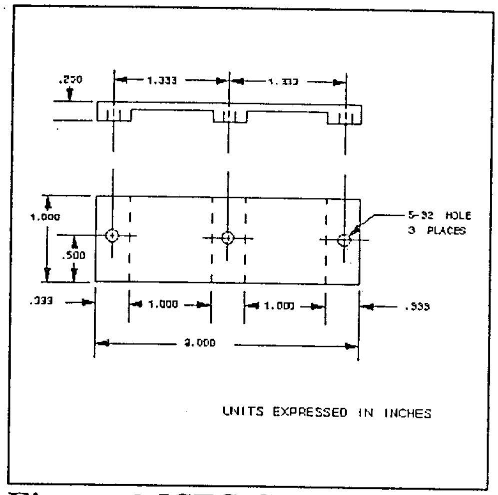


Figure 8 ICTG Cover Plate

Flux Types

The consensus of the ICTG was to exclude commercially available fluxes from this study since all fluxes dissociate and ionize differently based on their chemistries. There was considerable discussion concerning the ionizable source. Preliminary testing of specific synthetic contaminants was unsuccessful, and it was decided to use synthetic "fluxes". Two formulations of fluxes were used to represent the strongly ionizable and the weakly ionizable flux types in comparing the test equipment. A third contaminant was made from NaCl in IPA/water solution. The three formulations were as follows:

Strongly Ionizable "Flux":

60% Isopropyl Alcohol, technical grade
5% Diethylamine Hydrochloride
5% Malic Acid
5% Triton™ X100
15% Polyethylene Glycol 600
10% Deionized Water

Weakly Ionizable "Flux": 75% Isopropyl Alcohol, technical grade
20% Water White Rosin
5% Adipic Acid

NaCl Solution: 75% Isopropyl Alcohol, technical grade
25% Deionized Water
6 grams NaCl/liter

A microliter syringe was used to dispense the flux within the boundaries of the eight 1" x 1" squares printed on the board. Volume was kept constant at 5 microliters per 1 inch square (40 microliters total) throughout the testing. The concentration, however, was diluted with isopropanol to give three different contamination levels. The three levels defined were 5, 30 and 55 $\mu g/in^2$, which equates to 40, 240, and 440 total micrograms per board, respectively.

Variables

Again, this project was **not** intended to select a "best system". The test plan was statistically designed to best see the influences of each variable upon the final cleanliness results. An in-depth explanation of how the test was designed is given in Appendix A of this document. The equipment variables examined are given in Table 2 along with their high, medium, and low settings.

TABLE 2 EQUIPMENT VARIABLES

Variable	Low Setting	Center Point	High Setting	Units
Flux Residue	5	30	55	Micrograms per Inch^2
Alcohol Content	70	75	80	% Isopropanol
Solution Temperature	OFF	ON	ON	Degrees Fahrenheit
Solution Volume	33	66	100	% Test Cell Volume
Standoff Height	.003	.006	.009	Inches

The flux variable used three different quantities of each flux type. It was decided by the ICTG to keep the volume of flux dispensed onto the test coupon consistent, but dilute the stock solution three different ways to yield the 55, 30 and 5 $\mu g/in^2$ of NaCl equivalent specified in the test plan.

The alcohol content was calculated by measuring specific gravity and temperature of the test solution. The three settings used were 70, 75 and 80% alcohol, with the balance of each solution being deionized water.

Preliminary testing found that the temperature of the solvent used in all systems, even the non-heated, will increase due to pump temperature and friction in the plumbing. If a system had the capability of heating the solvent, this variable was either "ON" or "OFF". In either case, the solvent was allowed to reach equilibrium temperature prior to testing.

The dynamic systems do not use a fixed volume; therefore, volume was not a controlled variable to them. Since all of the static systems had different size tanks, it was not possible to specify three different volumes. Instead, a percentage of each system's total tank volume was set. This worked for all of the systems except for the Icom 5000, which uses a volume based on 10, 20 or 40 milliliters per square inch of board surface area. The minimum volume required to operate the Icom 5000, without cavitating the pumps, was 160 milliliters. So with an 8 square inch area, the system could only be run at 20 and 40 milliliters per square inch or 160 and 320 milliliters.

Standoff height was controlled using the stainless steel coupons described earlier in the "Test Vehicle" section of this document. Four stainless steel coupons, all with the same standoff, were mounted to the test board using stainless steel nuts and bolts. For consistency, all of the nuts used to hold the plates to the test boards were torqued to 5 inch/pounds.

INITIAL OBSERVATIONS

The intent of the study was to establish how accurate, reproducible, and effective each system was at removing residues from under known standoff heights and to determine how much each system variable would influence the final ionic results. In order to do this type of testing and draw legitimate conclusions, it was essential that all test assemblies had exactly the same quantity of residue to begin with, and it was necessary to know what that amount was. This posed significant problems. A known volume of residue could be deposited onto the substrate using a microliter syringe, but what volume of "flux" does it take to make 440 micrograms of sodium chloride (NaCl) equivalent?

To investigate this, the Omegameter 600R was randomly selected. A NaCl standard was made so that 40 microliters would equal 80 micrograms of NaCl (10 $\mu g/in^2$ based on an 8 square inch area). A static system was selected because the plan was to clean the solvent to an acceptable resistivity, inject 40 microliters of solution directly into the test tank, and measure the change in resistivity. This change in resistivity would represent 80 micrograms of NaCl equivalent. The solvent in the system would be returned to the same starting resistivity, and the "flux" titrated into the test cell to that same ending resistivity. The volume of "flux" titrated would be 80 micrograms of NaCl equivalent.

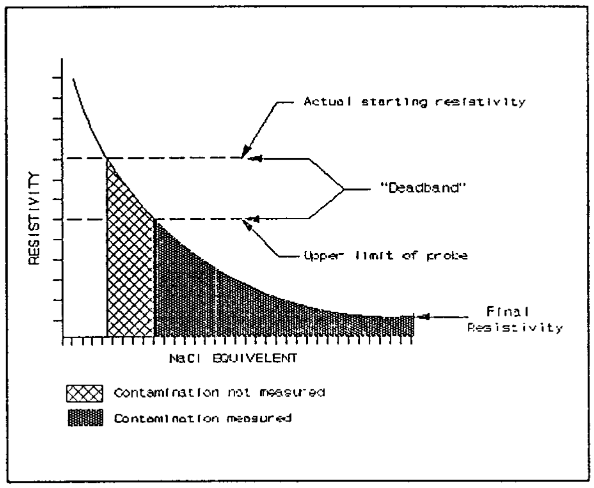


Figure 9 "Deadband"

The first measurements taken were lower than expected and not repeatable. Further research showed that the Omegameter 600R has what was termed a "deadband" (see Figure 9). The maximum measurement capability of the resistivity probe was only 60.35 megohms-cm, and though the solvent could be cleaned to a higher resistance level, the system would continue to read 60.35 megohms-cm. Although the starting resistivity read 60.35 megohms-cm, the actual starting resistivity of the solvent was much higher. Any ionic residues that lowered the resistance from this higher value to 60.35 megohms-cm was not being measured. This problem was not unique to the Omegameter 600R, but instead was typical for most of the equipment that was tested. Some exhibited this problem to a lesser degree than others; for example, the Zero Ion is capable of measuring resistances up to 245 megohms-cm, but even it has a deadband. Some systems avoid the deadband by using computer software to stop the circulation of the solvent once the resistivity reaches the upper range limit of the probe. The effect of the deadband is unsure on some of the systems since the starting resistivities are not always displayed. As mentioned earlier in this document, resistivity is not linear. The amount of residue it takes to drop the resistivity from 150 megohm-cm to 140 megohm-cm is much less than the amount of residue it takes to drop the resistivity from 50 megohm-cm to 40 megohm-cm. It has been argued that the amount of ionic residue it takes to drop the resistivity from the deadband to the visible range is insignificant in most cases. This argument would depend on surface area as well as the need for accuracy.

This problem was more noticeable in systems that use resistivity than those that use conductivity. But the deadband could influence the readings of all of the equipment if the operator was not careful or was not aware of the problem. It is important that the operator of the cleanliness test equipment not leave the system in a clean/filter mode for an extended period of time. If the operator inadvertently deionized the solvent to a higher than normal level, the solvent should be artificially contaminated and then recleaned to an acceptable level.

With the deadband understood, another series of tests were initiated on the Omegameter 600R using a resistivity less than 60.35 megohms-cm as a starting point. The readings were now slightly higher than the expected 10 $\mu g/in^2$ NaCl equivalent. The first theory regarding the higher readings was that the IPA/water from the standard was contributing to the resistivity, therefore adding to the contamination. It was noted, however, that the results seemed to be volume dependent. Three different volumes were used in the test cell and the results averaged 12.5, 14.8, and 16.2 μ/in^2 NaCl equivalent. The Omegameter 600SMD was used to verify the results of the Omegameter 600R, and it was noted that volume did not influence the results; however, the results were nearly twice what they should have been (about 20 $\mu g/in^2$ NaCl equivalent). A blank was run on the Omegameter 600R and the result was 0.0 $\mu g/in^2$ NaCl equivalent. The blank for the Omegameter 600SMD was 20 $\mu g/in^2$ NaCl equivalent and a subsequent run adding nothing to the test cell resulted in 20 $\mu g/in^2$ NaCl equivalent. By examining the printout of the Omegameter 600SMD over three separate runs, the graphs showed that the results were 0.0 $\mu g/in^2$ NaCl equivalent for the first minute of testing, but then jumped anywhere from 8 to 12 $\mu g/in^2$ NaCl equivalent (see Figure 10). In addition, the graphs showed that the results slowly and steadily increased from that point throughout the duration of the test and leveled off at 20 $\mu g/in^2$ NaCl equivalent. Three questions were raised:

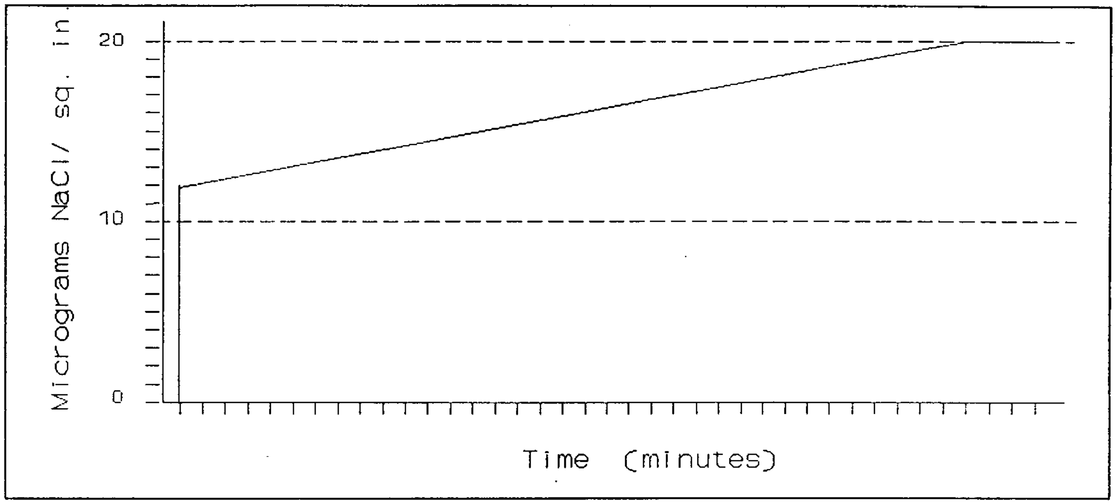


Figure 10 Carbon Dioxide Absorption

1. Why did the results gradually climb?
2. Why did the results jump at one minute?
3. Why did the climb stop at 20 $\mu g/in^2$ NaCl equivalent?

The gradual climb addressed in the first question was theorized to be caused by carbon dioxide (CO_2) absorption. Carbon dioxide can dissolve in water to form carbonic acid. This can weakly ionize into H^+ and HCO_3^- ions which can/will affect ionic readings. The presence of this ionic build-up during a static extraction contributes to the overall ionic reading. In most instances, such contributions are small, representing only a relatively small error in the measured results. If, however, we are measuring a small sample in a large volume of extracting solution, the effective total micrograms of NaCl represented by the CO_2 build-up in solution are divided by the smaller surface area of the sample giving rise to a larger relative error in the reading expressed as $\mu g/in^2$. Extractions which are made for longer times will also show higher CO_2 errors since more CO_2 will dissolve in the longer period of exposure to the atmosphere.

To test this theory, nitrogen was fed into the Omegameter 600SMD test cell to form an inert atmosphere over the solvent/air interface. A second series of tests were initiated and the results showed that the gradual climb had been eliminated, indicating that CO_2 did indeed cause the climb. The jump at one minute, however, remained. The results jumped anywhere from 3.0 to 7.4 $\mu g/in^2$ NaCl equivalent even though no contamination was being introduced into the test cell. The jump was not consistent and after closer examination of the data, it appeared that the jump was dependent on the starting resistivity of the solvent; therefore, the answer to the second question is that, unlike the Omegameter 600R which subtracts the ending resistivity from the starting resistivity and calculates contamination based on that change, the Omegameter 600SMD measures the resistivity at one minute, subtracts that resistivity from an *assumed* starting resistivity (60.35 megohm-cm), then calculates the contamination based on that difference. To verify this theory, the actual solvent resistivity was adjusted to that assumed starting resistivity under a nitrogen blanket. Finally, a reading of 0.0 $\mu g/in^2$ NaCl equivalent was obtained by adding nothing to the system.

The third question was answered when it was learned that the termination of the test is dependent on the range entered in the software at the start of the test. If the results of the test go higher than that range (in this case 20 $\mu g/\ in^2$ NaCl equivalent), the test will terminate. So it was no coincidence that all of our NaCl standards and the blank all resulted in a reading of 20 $\mu g/in^2$ NaCl equivalent. The CO_2 drove the reading up off scale and terminated the test at that point.

This test was repeated on all of the remaining systems to determine the effects of CO_2 absorption. Testing indicated that the problem was not detectable for all of the static systems, and there did not appear to be any correlation for spray versus no spray, or spray above immersion versus spray below immersion. The dynamic systems are continually deionizing the solvent, therefore removing the small amounts of CO_2 before it has a chance to accumulate a measurable amount. Further testing, however, would be required to fully characterize the effects of CO_2.

But if testing thus far has been accurate, why have these problems not been noticed before? As mentioned earlier, the surface area of the test vehicle was set at 8.0 square inches. This small surface area magnifies all of the little imperfections of all of the test equipment. For example, if the surface area of a PWA is 100 square inches and the change in resistivity correlates to 100 micrograms, the end result would be 1 $\mu g/in^2$. An accuracy tolerance of plus or minus 50 micrograms would change the end result only 0.5 $\mu g/in^2$. If that same change in resistivity was measured on a PWA with a surface area of 1 square inch, the resulting contamination reading would be 100 $\mu g/in^2$. Since a variance of plus or minus 50 micrograms significantly influences the final reading, any variable that influences the resistivity of the solvent (CO_2, temperature, deadband, etc.) will be much more noticeable on PWAs with smaller surface areas.

Another observation made in the initial test setup was that the temperature of the solvent increased over time in operation. This was true for all of the test equipment, even the systems without heating elements. Due to pumps moving the solvent and friction in the plumbing, solvent temperatures would typically increase 10 to 15° F from initial room temperature. This correlates with the study performed at DuPont[6]. The original Ionex 2000, which has no heating elements and is classed as a non-heated system, increased the temperature of its solvent above 125° F in just over one hour. This issue was rectified by Kester so that the solvent temperature now stabilizes at about 110° F. Since temperature was one of the variables being investigated, it was necessary to investigate at what temperature each system was stable, and perform all testing at that point.

Once the deadband, CO_2, and temperature effects were identified, testing resumed with the sodium chloride standard. Using a microliter syringe with an accuracy of ±0.1 microliters, a 40 microliter sample containing 80 micrograms of sodium chloride was injected directly into each of the cleanliness testers. By entering a surface area of eight square inches, the final result should have been 10 $\mu g/in^2$ NaCl equivalent.

The results were still slightly higher than expected. A blank was run to see how much, if any, the IPA/water contributed to the final results. The sodium chloride standard, the blank, and the corrected final results are listed in Table 3.

The plan was to have three different quantities of both types of fluxes. Though the test plan specified 55, 30 and 5 $\mu g/in^2$ of NaCl equivalent, there was no way of knowing how much flux would be required to achieve these results. For example, if the flux sample was diluted so 40 microliters measured 55 $\mu g/in^2$ in one system, and a second system measured that same sample as 51 $\mu g/in^2$ and a third system measured 58 $\mu g/in^2$, there was no way of knowing which system was correct. A chemical titration could not be used since NaCl was not actually being measured. Since the measurement was based on a change in resistivity, there was no way of injecting a quantity of flux that represented a known change in resistivity. There was good correlation on all of the equipment when using NaCl, so one tester was randomly selected to aid in the dilution of the two fluxes.

TABLE 3 SODIUM CHLORIDE STANDARDS							
	Omegameter 600R	Omegameter 600SMD	Ionex 2000	Icom 5000	Zero Ion	Ionograph 500M	Ionograph 500SMD
	11.2	11.6	13.7	11.15	11.70	12.84	11.91
	11.2	11.4	13.1	11.50	12.57	12.57	11.98
	11.3	11.6	13.4	11.15	12.03	12.50	12.11
	11.2	11.6	12.6	12.07	12.43	13.00	11.95
	11.4	11.6	13.59		12.61	12.51	11.91
standard average	11.27	11.56	13.28	11.47	12.26	12.68	11.97
	ISOPROPANOL BLANKS						
	0.3	0.2	1.4	1.00	0.82	0.73	0.41
	0.3	0.2	1.4	1.00	0.66	0.86	0.27
	0.3	0.3	1.4	1.00	0.80	0.80	0.29
	0.3	0.3	1.4	1.00	0.72	0.90	0.34
	0.4	0.4	1.4	1.00	0.68	0.92	0.23
blank average	0.32	0.28	1.40	1.00	0.74	0.84	0.31
correct average	10.95	11.28	11.88	10.47	11.52	11.84	11.66

Note: The Contaminometer was not available at the time of this testing.

The Zero Ion system was selected as a benchmark to determine how much each flux type had to be diluted to yield 55, 30 and 5 $\mu g/in^2$ of NaCl equivalent. The dilutions were then checked on all of the other systems to verify the Zero Ion results. At this point, it was noted that although the dynamic and static families were similar when measuring NaCl (see Table 3), there was a big difference between the two groups when measuring flux residues. Though the same sample type and volume was being injected into all of the test cells, members of the static family consistently gave lower results than those of the dynamic family. Two theories were presented, but it was decided to proceed with testing and stay with the Zero Ion dynamic system to aide with the dilutions. **This did not mean the dynamic systems were correct**, but instead allowed the test to proceed with a high ($\approx$55 $\mu g/in^2$), medium ($\approx$30 $\mu g/in^2$) and a low ($\approx$5 $\mu g/in^2$) quantity of flux.

The next hurdle came when it was observed that, although the flux "in solution" was fairly reproducible, the results became much lower and widely varied for the strongly ionizable flux once the build process was added. The original process selected to bake the flux onto the test vehicle was infrared (IR) reflow with a thermal profile similar to that of the IPC Chlorofluorocarbon

Alternative study. Test results with this thermal process proved to be inconsistent and lower than expected. A total of 40 microliters of strongly ionizable flux was deposited on each of ten different bare boards. The boards were reflowed on a Vitronics Infrared Reflow machine at identical thermal profiles, yet the results varied considerably. Further modifications to the thermal profile, including the addition of one and two prebake steps, found that the results were very dependent on time and temperature (see Table 4).

TABLE 4 IONIC CONTAMINATION VS TEMPERATURE			
PROCESS	AVERAGE TOTAL μGRAMS	RANGE	STANDARD DEVIATION
Wet Flux, Directly into Test Cell	2802.1	35.6	.0127
Wet Flux on Board, No Heat	2805.2	236.3	.0842
Flux on Board, 1 Hour at 45°C	2436.8	150.4	.0617
Flux on Board,1 Hour at 45°C, 1 Hour at 100°C	1607.0	426.5	.2654
Flux on Board, IR Reflow Only	471.1	309.0	.6559
Flux on Board,, 1 Hour at 45°C, IR Reflow	356.8	414.0	1.1603
Flux on Board, 1 Hour at 45°C, 1 Hour at 100°C, IR Reflow	279.8	107.8	.3853
Flux on Board, 2 Hours at 45°C, 2 Hours at 100°C, IR Reflow	0	0	0

Depending on how the flux is heated, results varied from 0 to 2800 total micrograms using the same ionic tester with the same variable settings.

Glass slides were then used as a test vehicle to evaluate the possibility that the porosity of the copper-clad, etched, FR4 laminate was contributing to the wide variances in results. Four systems were randomly selected and all variables were set at their center points. Each slide containing 40 microliters of flux was baked at 100° C for 1 hour and the test was repeated four times for each system. Table 5 shows a comparison between the strongly ionizable flux in solution versus after bake and the weakly ionizable flux in solution versus after bake. The results are an average reading in $\mu g/in^2$ NaCl equivalent for each system.

TABLE 5 STRONG FLUX IN SOLUTION vs GLASS SLIDE WEAK FLUX IN SOLUTION vs GLASS SLIDE				
	IONOGRAPH 500SMD	OMEGAMETER 600R	ICOM 5000	OMEGAMETER 600SMD
Strong Flux, In Solution	40.79	49.70	44.10	37.53
Strong Flux, On Glass Slide	13.31	4.17	12.18	0.2
Weak Flux, In Solution	59.22	29.93	12.32	28.70
Weak Flux, On Glass Slide	65.10	27.47	11.74	28.20

The data shows that the ionic results for the strongly ionizable flux changed significantly after baking, whereas the weakly ionizable flux stayed fairly consistent.

Testing thus far proved that temperature had a significant influence on the strongly ionizable flux. In addition, the standard deviation was much greater than with the weakly ionizable flux. Testing also showed that temperature did not significantly affect the weakly ionizable results compared to in solution results. An additional test was conducted to determine if other board substrates would affect the weakly ionizable flux data. The test was run using 1) original FR4 laminate, 2) FR4 with a solder mask, 3) alumina ceramic and 4) glass.

Table 6 shows that boards with a solder mask yield higher ionic contamination measured than the other substrates. Though the mask smoothed the surface topography, the mask itself leached ionic contamination. The other substrates were not significantly different. Testing of these materials proved that it was the thermal profile, and not the materials, that was causing the deviations.

After consulting with industry flux experts, consensus was that constituents of the strongly ionizable flux will volatilize, oxidize and polymerize to different degrees depending on a number of different variables. Though 40 microliters was dispensed on each board (5 microliters per square), each deposit has its own geometric shape (see Figure 11). A 5 microliter spot that spreads thin, as shown in example #1 of Figure 11, will completely volatilize and, if given enough time and/or temperature, will polymerize and become insoluble

TABLE 6 WEAKLY IONIZABLE FLUX vs SUBSTRATE vs IN SOLUTION				
SUBSTRATE	IONOGRAPH 500SMD	OMEGAMETER 600R	ICOM 5000	OMEGAMETER 600SMD
In Solution	59.22	29.93	12.32	28.70
Original FR4	70.16	22.37	12.64	24.32
FR4 with Solder Mask	101.40	30.97	18.98	44.57
Alumina Ceramic	66.54	18.57	11.73	26.50
Glass	65.10	27.47	11.74	28.20

in alcohol/water. On the other hand, a spot that does not spread, as shown in example #2, may polymerize a "shell" over the surface of the flux, and trap wet flux inside. Once this "shell" is dissolved, the rest of the flux would break down and ionize more easily.

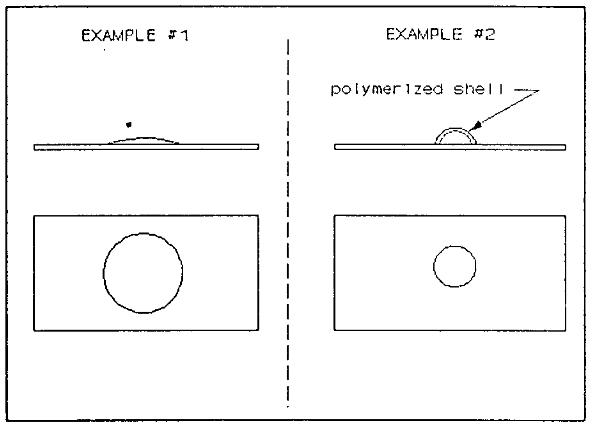


Figure 11 Flux Geometry

In addition to the physical geometry of the sample, the chemistry of flux changes when exposed to elevated temperatures, due to volatilization of the weak acids. These weak acids would normally contribute to ionic contamination readings when the flux is wet, but as these acids evaporate, the resulting NaCl equivalent is lowered. The degree to which this volatilization influences the final result is dependent on how thick the "shell" is and how quickly that "shell" is formed. These theories for the wide variances and lower than expected results were merely put forward as possible explanations and were not investigated any further.

Test Coupon Preparation

The process that seemed to be the most consistent, while still offering a removal challenge to the equipment, was to bake the coupons at 100° C (+/- 5) for one hour. It was also found that a minimum cool time of 10 minutes and a maximum of 1 hour was found to be optimum, which meant that the maximum number of boards that could be processed at one time was four. Much care was needed to assure that the board racks and the handling tongs were scrupulously clean and each part was handled with clean, powder-free gloves. It also took a very conscientious effort on the part of the technician to assure each coupon was prepared in the same manner.

PRESENTATION OF DATA

The first part of the results section will discuss the "in solution" general observations and trends which includes a table of effects and graphical analysis for all systems together. The data for each individual system will then be presented in the following order:

1) Raw data
2) Table of effects
3) Graphical analysis
4) Statistical analysis

The spreadsheet containing the raw data lists the randomized sequence that each variable was set per the test plan. Also listed on the spreadsheet is the actual result measured at each particular setting. This data was then analyzed and organized into a table of effects. The table examines all of the systems and determines the main effects and the interactions of each variable considered. To help give a better understanding of the effects, several graphs are given to show visually the effects and interactions. Finally, the statistical analysis gives more information on the data listed in the table of effects including the standard deviation, the t-ratio and a "p" value which is used to determine the rate of "chance". A low "p" value denotes a high confidence level and a low likelihood the result was obtained merely by chance. Also contained in the statistical analysis is an analysis of variance (ANOVA).

Once the "in solution" data is presented, the next section will discuss general observations and trends from testing with the coupon. The individual system data will then be presented in the same order stated above.

Statistical Design

Before presenting the test data, the reader must have a basic understanding of the statistically designed experiment. Appendix A contains an in-depth explanation of the experimental design and discusses the statistical tools used to display and interpret the data. Briefly, a main effect is the difference in output when a factor is changed from low level to high level. When the design is balanced, this is the average of all runs at the low level subtracted from the average of all runs at the high level of a factor. For example, the main effect graph for "RESIDUE" averages all data at 5 micrograms, irrelevant of the alcohol content, solvent volume, temperature, flux type and channel depth, and subtracts that average from the average of all data measured at 55 micrograms. The main effect data for "IPA" averages all data at 70% alcohol, irrelevant of the residue quantity, solvent volume, temperature, flux type and channel depth, and subtracts that average from the average of all data measured at 80% alcohol. In the hypothetical example given in Figure 12, the main effect for RESIDUE and IPA would be:

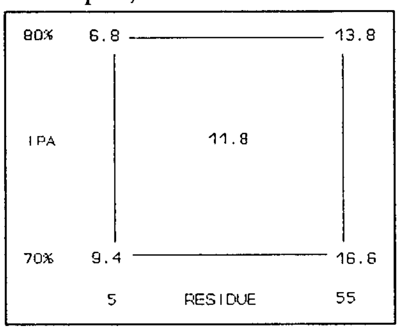


Figure 12
Simple Factorial Example

RESIDUE = (13.8+16.6)/2 - (6.8+9.4)/2 = 15.2 - 8.1 = 7.1
IPA = (6.8+13.8)/2 - (9.4+16.6)/2 = 10.3 - 13.0 = -2.7

The negative effect for IPA means that the response decreases as percent IPA is changed from low level (70%) to high level (80%). Main effects are also graphically presented by plotting the average response at each level (see Figure 13). The response at the center point is plotted on the same graph to visually check for curvature (non-linearity). In this case, each factor has a consistent effect, regardless of the level of the other factor. The effect of RESIDUE is 7.0 when IPA is at the high level (13.8 - 6.8) and it is 7.2 when IPA is at the low level (16.6 - 9.4).

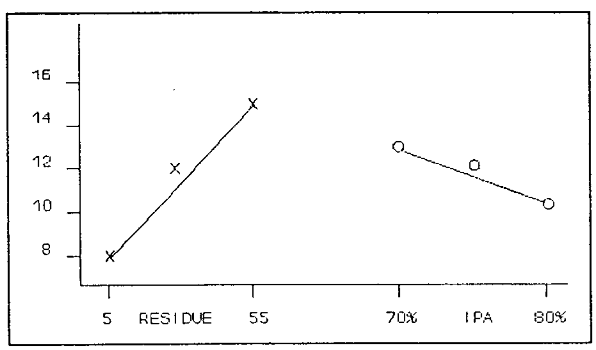


Figure 13 Main Effects Plot

Similarly, the effect of IPA is -2.8 when RESIDUE is at the high level and -2.6 when RESIDUE is at the low level. The effects of these factors are independent and there is no interaction.

When the effect of a factor is dependent on the level of one or more other factors, then an interaction exists. In this case, the effects of these factors cannot be interpreted separately. Consider the hypothetical example in Figure 14. The effect of HEAT is 10.6 when VOLUME is at the high level, but it is only 2.6 when VOLUME is at the low level. Similarly the effect of VOLUME is 3.4 when HEAT is at the high level, and it is in the opposite direction when HEAT is at the low level (-4.6). This is called a two-way interaction and the usual notation is with an asterisk (*) or H*V.

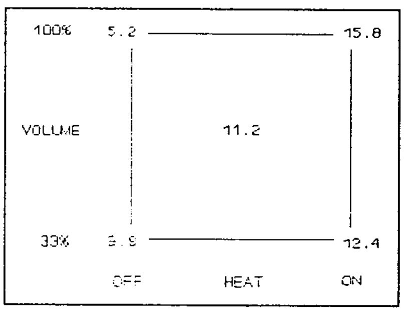


Figure 14 Example of an Interaction

The interaction effect is calculated by subtracting the effect of HEAT at the low level of VOLUME from the effect of HEAT at the high level of VOLUME and divided by two, which is (10.6 - 2.6)/2 = 4.0. Note that the same value is achieved using the effect of VOLUME at the two levels of HEAT (3.4 - {-4.6})/2 = 4.0). Also note that the R*I interaction effect in the other example is only -0.1.

The calculated value for the effect of an interaction is used to determine whether the effect is significant, but it has little intuitive meaning. The best way to understand the effects is with an interaction plot (see Figure 15), which is simply graphing the effect of one factor at each level of the other. A difference in slopes is characteristic of an interaction. Parallel or near parallel lines indicate no interaction.

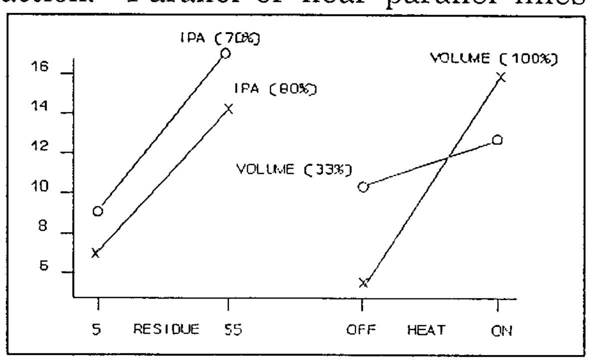


Figure 15 Interaction Plot

There are several statistical tests that determine if an effect is significant. Each of these tests is based on the probability of observing, during the experiment, an effect of that magnitude or greater if the true value of the effect were zero. In other words, what is the probability of observing an effect of that size just by chance, completely due to experimental error? If that probability is low, then the "p-value" should be less than 0.05 (5%). If this is the case, it can also be said that there is 95% confidence that the effect is significant.

"IN SOLUTION" TEST RESULTS

"IN SOLUTION" GENERAL TRENDS AND OBSERVATIONS

When in the dynamic mode, the Contaminometer CM-5 exhibited behavior outside that of all other dynamic systems and is not included in the discussions or conclusions in this report. After the data was analyzed and made available to Protonique, it was realized that an inappropriate model was sent to the EMPF for this study. The model delivered was engineered for larger (greater than 45 in^2) surface areas and was not sensitive enough for the small surface area that the test program required. Protonique requested that a more concentrated flux be used along with a larger surface area that equated to the same 55, 30 and 5 $\mu g/in^2$. The ICTG, however, decided that the test program could not be modified for one system without compromising the statistical design of the test. Time did not allow the manufacturer the opportunity to provide a different model.

The easiest way to determine the significance of a variable is to examine the slope of the lines on the graphs. The steeper the slope, the more significant the variable. The graph on page 34 shows the most significant variable, which, not surprisingly, is the residue effect. When all of the 5 microgram data is compared to all of the 55 microgram data, the change is significant. As mentioned earlier, these residues were **not necessarily** 5 and 55 micrograms. **Do not** look at the graphs and assume the Zero Ion system is correct and all of the others were incorrect to some degree. The Zero Ion system was randomly selected as a benchmark to aid in the dilutions of the flux standards. In reality, the Zero Ion **may** have been reading high, with actual standards of 3 and 45 micrograms or 2 and 28 micrograms. What can be derived from this graph, with the exception of the Contaminometer (dynamic), is that the dynamic systems and the static systems were grouped separately and the dynamic systems measured a more significant change when going from 5 to 55 micrograms. Though grouped, the dynamic processes had a data spread of about 8 micrograms when measuring the 55 microgram concentration, and the static systems had a spread of about 15 micrograms. It can also be noted that the static systems read similar or higher than the dynamics at 5 micrograms, but then read lower at 55 micrograms.

The next most significant variable was the IPA effect. As the alcohol content in the solvent was increased from 70% to 80%, the results dropped. This, too, is not surprising, knowing that it is the water that ionizes the contamination; the alcohol is there merely to dissolve the nonionic (rosin) material to get access to any trapped ionic contamination. The 70% solution contains more water than the 80% solution, thereby giving this solution more ionizing capabilities. Again, there is a definite grouping associated with the static versus dynamic systems, and the dynamics seem to be most affected by the change in alcohol.

The flux effect was not statistically significant in three out of four of the dynamic systems, but it was significant in the Ionograph 500SMD and all of the static systems. In addition, it is interesting to note that the dynamic systems, though not all significant, had a negative effect as the flux shifted from weak to strong, whereas the static systems all measured a positive effect.

As we examine the interaction effect between the flux type variable and the IPA variable, it can be noted that the alcohol content affected the weak flux more than the strong flux on all of the systems. In fact, the measurements of the strong flux in the static systems were somewhat similar to the measurements made in the dynamic systems. It can also be noted that the weak flux tended to measure lower than the strong flux at both 70% and 80% IPA in the static systems. In the dynamic systems, however, strongly ionizable flux measured higher than weakly ionizable flux at 80% IPA, but lower than weakly ionizable flux at 70% IPA.

The final variable examined in the "in solution" test was solvent volume in the static systems. If the system was capable of heating the solvent, this test was conducted with the heat on. As stated earlier, the Icom 5000 does not use a tank volume, but instead, pumps a volume (10, 20 or 40 milliliters) per square inch of board surface area into the test cell. Since our surface area was only 8 square inches, 80 milliliters would have been the minimum (33%) setting. This volume was less than the minimum required to circulate the solvent. For this reason, the Icom 5000 was run at 360 milliliters (high or 100%), 160 milliliters (medium or 66%) and 160 milliliters (low or 33%). Most of the test results showed that as the volume of solvent contained in the test cell increased, so did the test results. Testing also found that the volume variable seemed to be more significant in the heated systems than the non-heated systems. The only exception to this trend was in the Ionex 2000. This system appeared to be able to compensate for the change in volume.

Figure 16 shows the ionic readings for each system when a standard sodium chloride solution was injected into each system's test chamber. The standard solution consisted of 240 micrograms sodium chloride, and the surface area used for the testing was 8 square inches. Ionic readings should be 30

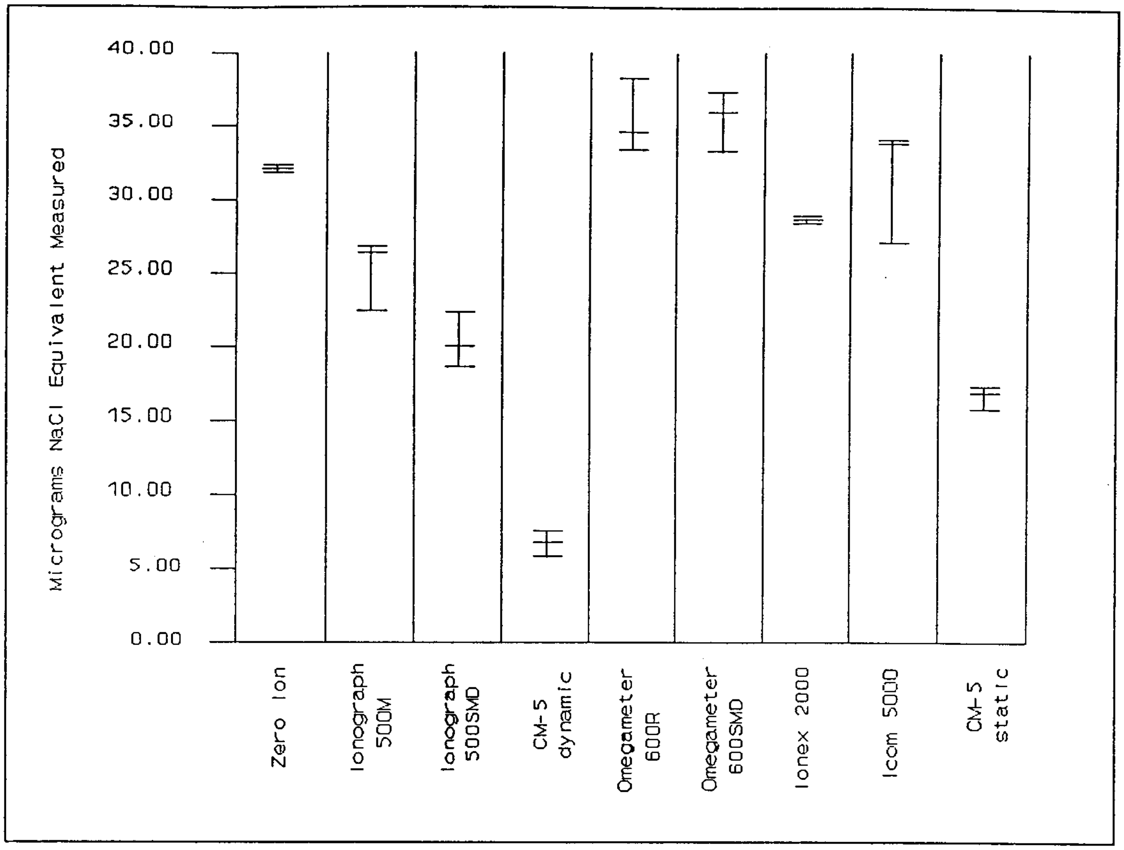


Figure 16 "In Solution" NaCl Measurements

$\mu g/in^2$ NaCl equivalent. Three separate readings were obtained for each system using the standard solution and the equipment operating at center point values (75% IPA, 66% volume). The graph in Figure 16 shows each of the three measurements (horizontal line) made for each piece of equipment and the spread between the high and the low (vertical line). As seen, readings varied from 16.8 to 38.4 $\mu g/in^2$. In addition, note the relative spread of the three data points, which varied system to system.

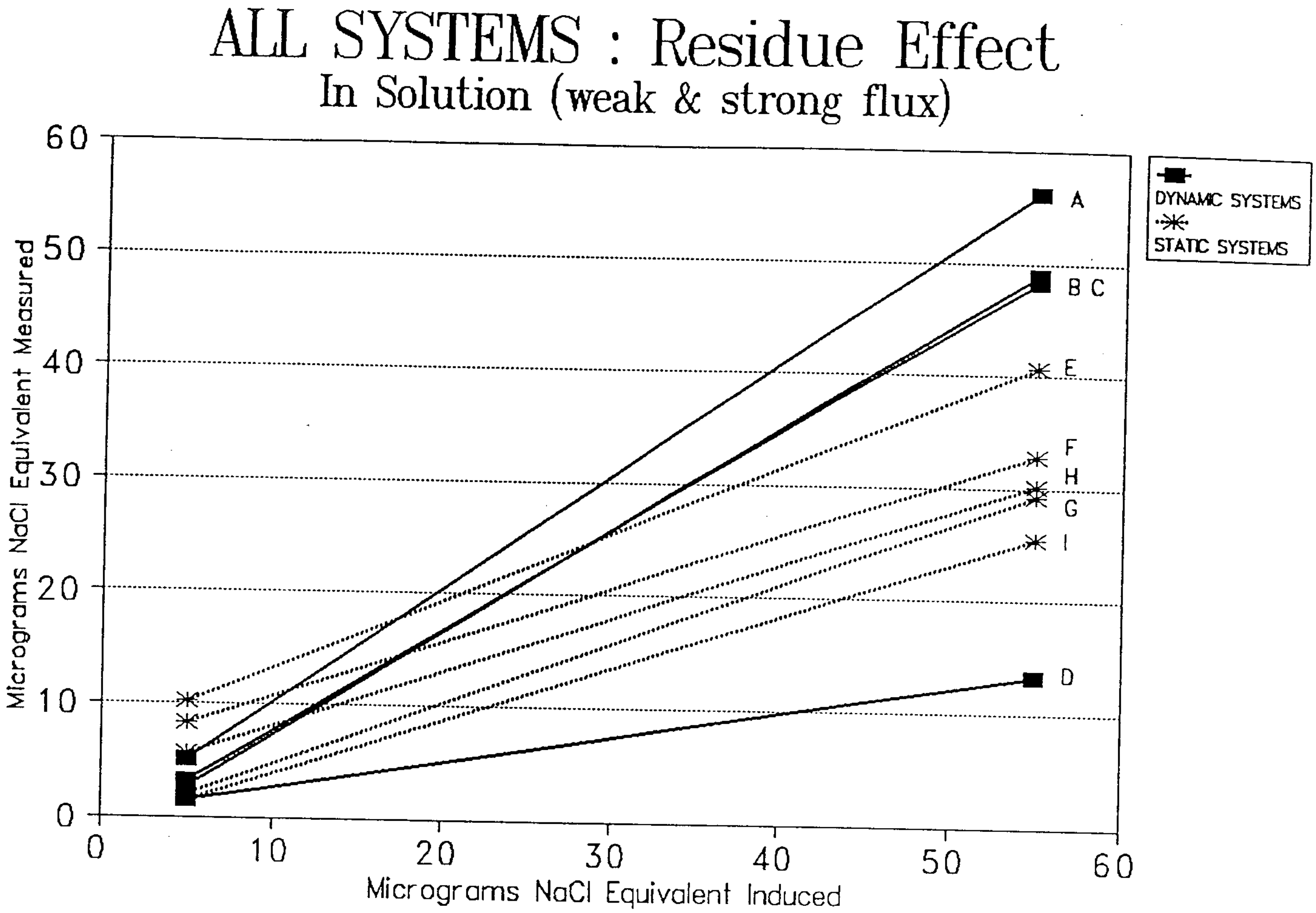
This raises questions regarding the accuracy associated with the current ionic conductivity/resistivity test methods and equipment. This is data for a standard solution of sodium chloride. One might expect such data for an assembly with flux residues, where differences in equipment variables such as operating temperatures and design (sprays, heat, etc...) would be expected to be strong influences; however, these results are for the solution which is used to "calibrate" the systems.

Accuracy problems are not usually noted when calibrating the systems during normal operation, so why are we seeing this behavior in this study? The amount of sodium chloride used for this evaluation was much smaller than that used industry-wide for calibration. A typical calibration uses 5 ml of a 750 μg/ml solution. This results in 3,750 micrograms total NaCl being added to the test chamber. In comparison to the 240 total micrograms NaCl used in this evaluation, the calibration concentration is much higher, and according to the equipment manufacturers, in a better area of the equipment's sensitivity/accuracy curve. The smaller amount of sodium chloride accentuates the inherent inaccuracy of the test method and equipment.

TABLE OF EFFECTS
In Solution Testing

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN RESPONSE	30.89*	27.20*	26.38*	7.00*	25.33*	20.53*	16.10*	17.98*	13.75*
MAIN EFFECTS									
Residue (R)	51.18*	46.58*	47.26*	11.10*	30.57*	25.91*	28.31*	24.56*	24.11*
IPA (I)	-20.33*	-22.84*	-22.29*	-1.40	-10.0*	-7.60*	-7.85*	-7.19*	-6.69*
Flux (F)	-1.55	-1.49	-9.88*	2.23	10.07*	7.51*	18.46*	19.37*	5.16*
Volume (V)					4.7*	7.45*	-1.01	3.61*	
INTERACTIONS									
R*I	-14.13*	-15.18*	-18.48*	-1.00	-2.35*	-3.29	-6.86*	-3.29*	-4.28*
R*F	0.65	0.70	-8.55*	2.63*	8.07*	3.78*	16.15*	16.47*	4.84*
R*V					1.55*	3.89*	0.72	6.56*	
I*F	11.00*	10.52*	10.28*	1.48	5.75*	2.79	1.63	0.74	2.42*
I*V					1.77*	-1.63	-0.04	-2.88*	
F*V					-0.85	-2.16	-1.60	5.24*	
R*I*F	8.00*	8.06*	8.83*	0.98	5.15*	4.15*	1.05	0.10	1.77
R*I*V					-0.52	-1.39	-1.05	-1.89*	
R*F*V					-1.0	0.38	-1.04	5.35*	
I*F*V					0.87	2.49	0.90	-2.65*	
R*I*F*V					0.12	-0.33	1.04	-2.22*	
CENTER POINT	1.74*	5.42	-0.64	4.48*	2.91	2.00	-0.15	2.22*	1.41

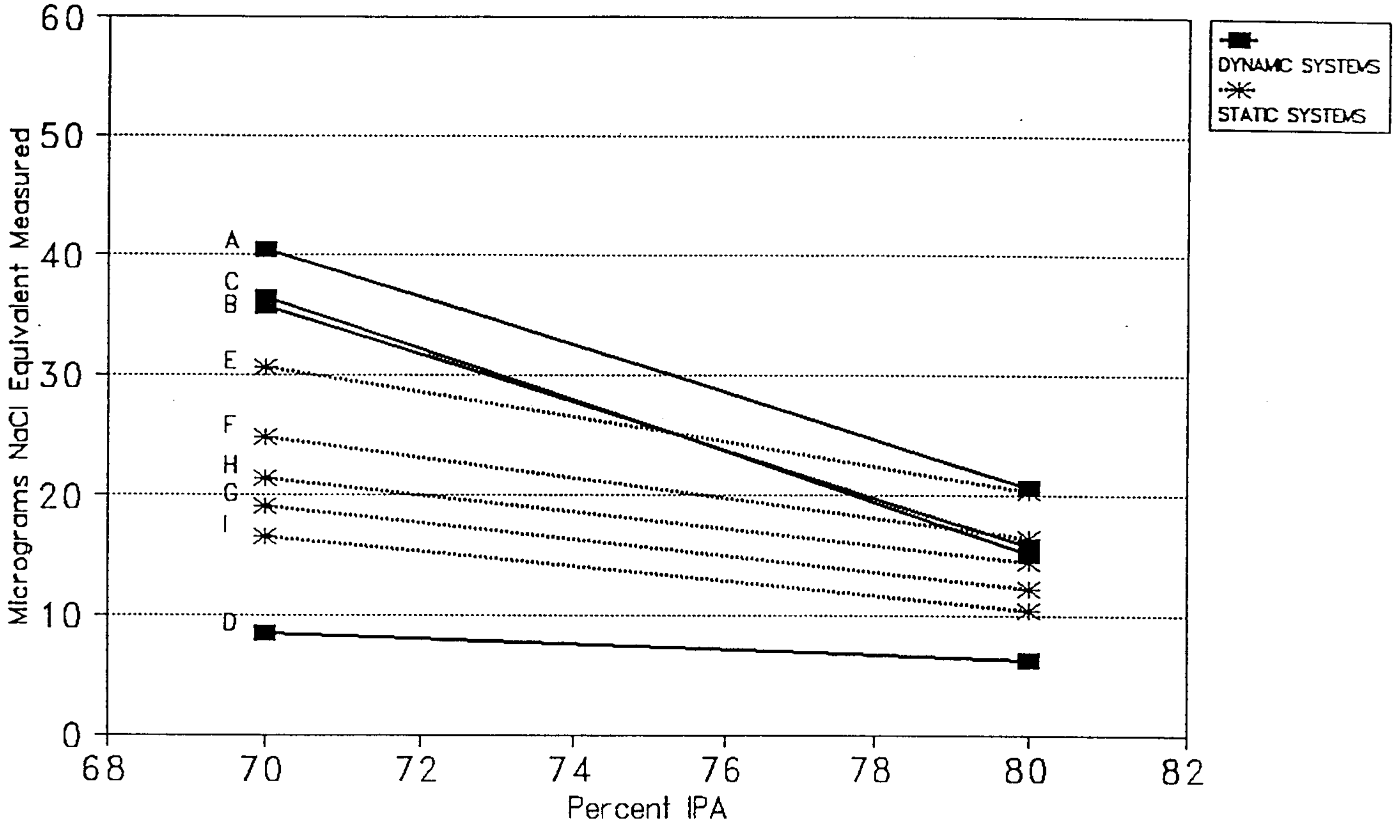
Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.



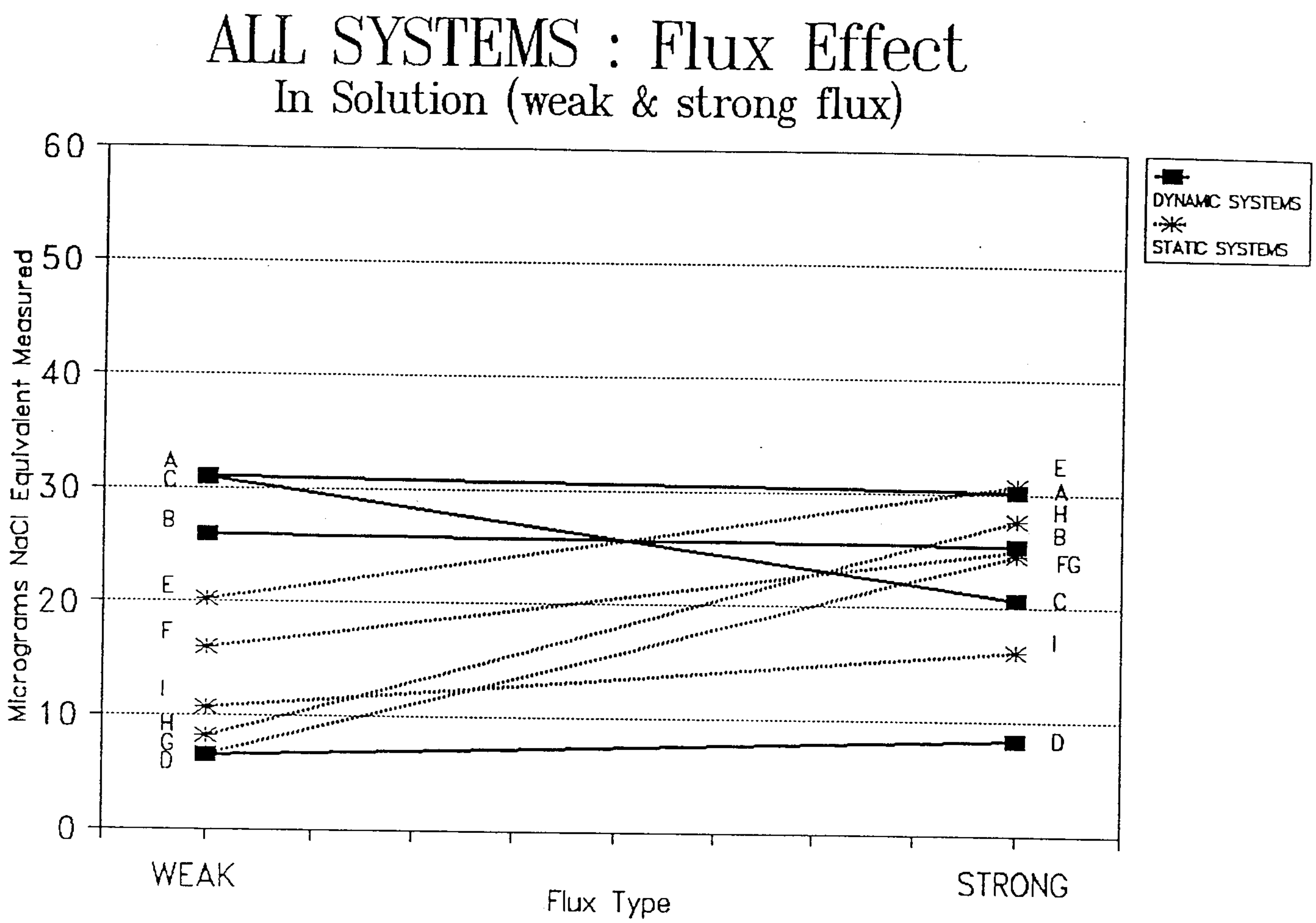
A = Zero Ion
B = Ionograph 500M
C = Ionograph 500SMD
D = Contaminometer CM-5
E = Omegameter 600R
F = Omegameter 600SMD
G = Ionex 2000
H = Icom 5000
I = Contaminometer CM-5

ALL SYSTEMS : IPA Effect

In Solution (weak & strong flux)



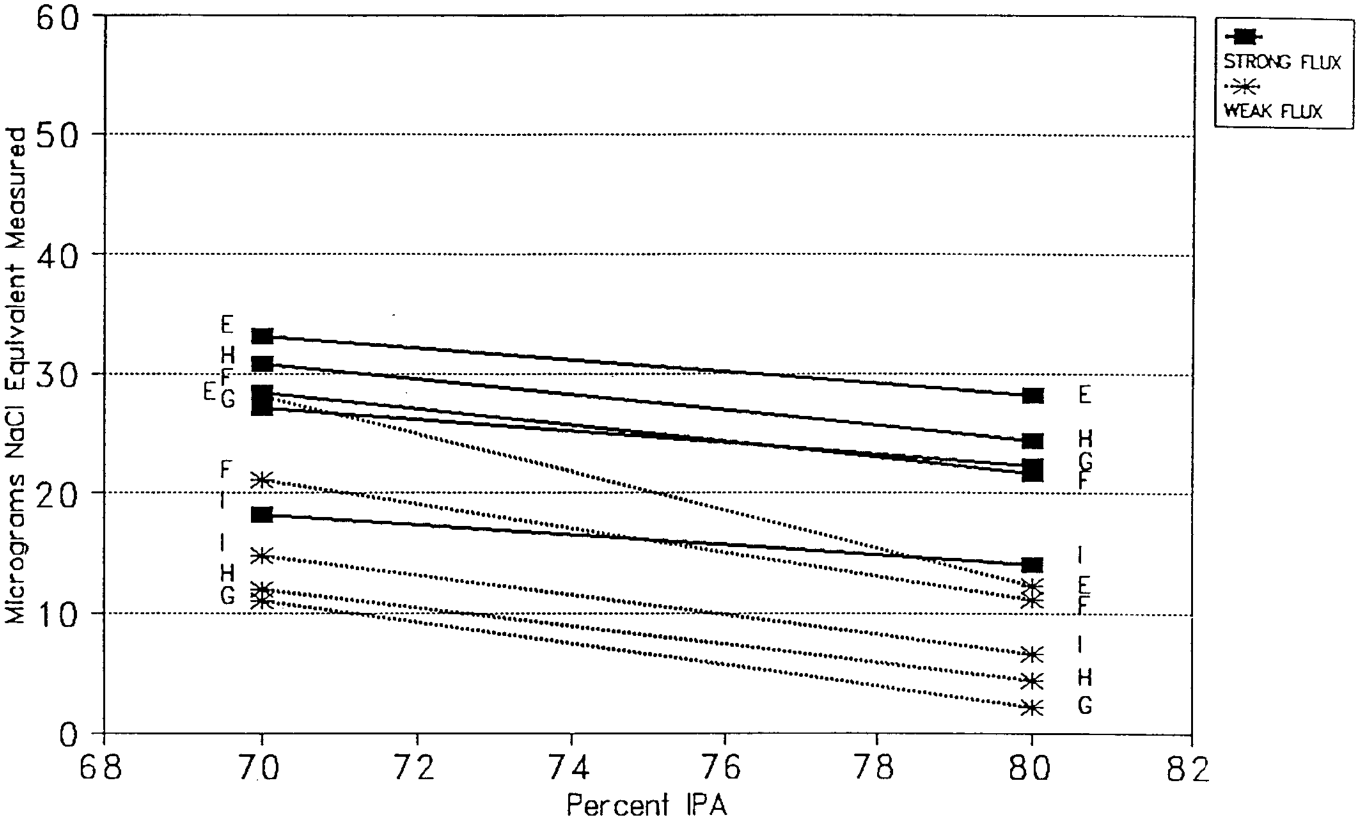
A = Zero Ion
B = Ionograph 500M
C = Ionograph 500SMD
D = Contaminometer CM-5
E = Omegameter 600R
F = Omegameter 600SMD
G = Ionex 2000
H = Icom 5000
I = Contaminometer CM-5



A = Zero Ion
B = Ionograph 500M
C = Ionograph 500SMD
D = Contaminometer CM-5
E = Omegameter 600R
F = Omegameter 600SMD
G = Ionex 2000
H = Icom 5000
I = Contaminometer CM-5

STATIC SYSTEMS : IPA*Flux Interaction

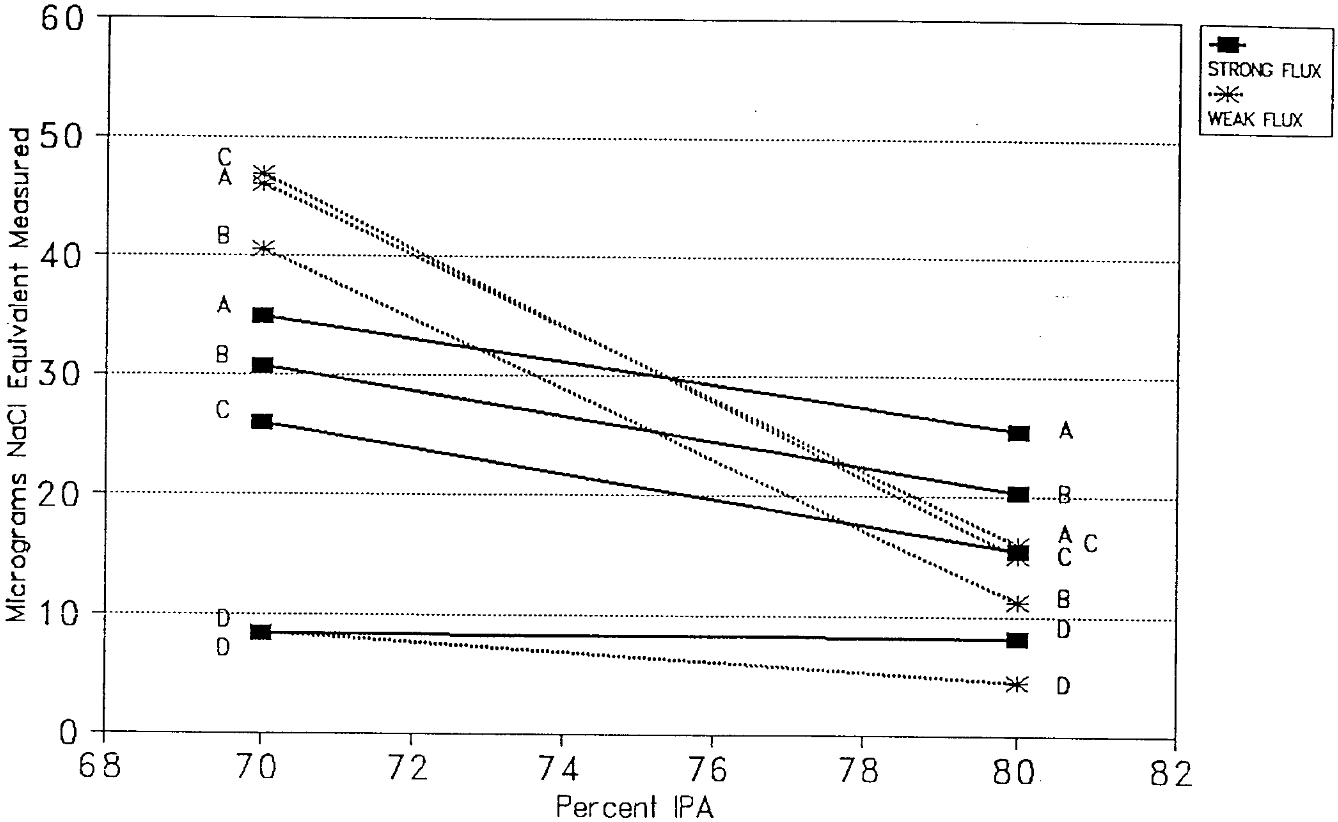
In Solution (weak & strong flux)



A = Zero Ion
B = Ionograph 500M
C = Ionograph 500SMD
D = Contaminometer CM-5
E = Omegameter 600R
F = Omegameter 600SMD
G = Ionex 2000
H = Icom 5000
I = Contaminometer CM-5

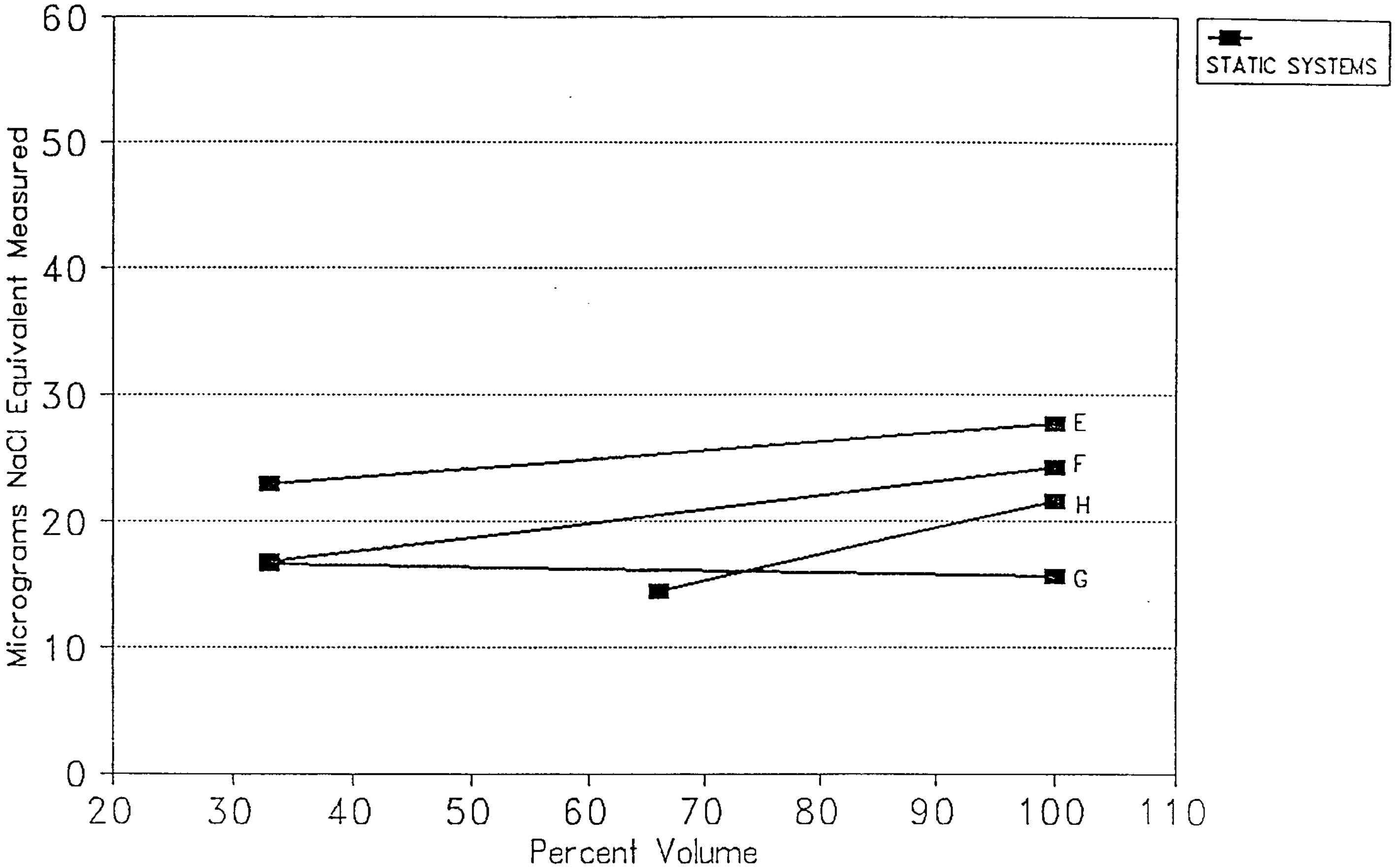
DYNAMIC SYSTEMS : IPA*Flux Interaction

In Solution (weak & strong flux)



A = Zero Ion
B = Ionograph 500M
C = Ionograph 500SMD
D = Contaminometer CM-5
E = Omegameter 600R
F = Omegameter 600SMD
G = Ionex 2000
H = Icom 5000
I = Contaminometer CM-5

STATIC SYSTEMS : Volume Effect
In Solution (weak & strong flux)



A = Zero Ion
B = Ionograph 500M
C = Ionograph 500SMD
D = Contaminometer CM-5
E = Omegameter 600R
F = Omegameter 600SMD
G = Ionex 2000
H = Icom 5000
I = Contaminometer CM-5

LONDON CHEMICAL

ZERO ION

Dynamic
Unheated
Spray below immersion

ZERO ION SYSTEM
RANDOMIZED EXPERIMENTAL MATRIX
"IN SOLUTION" TESTS

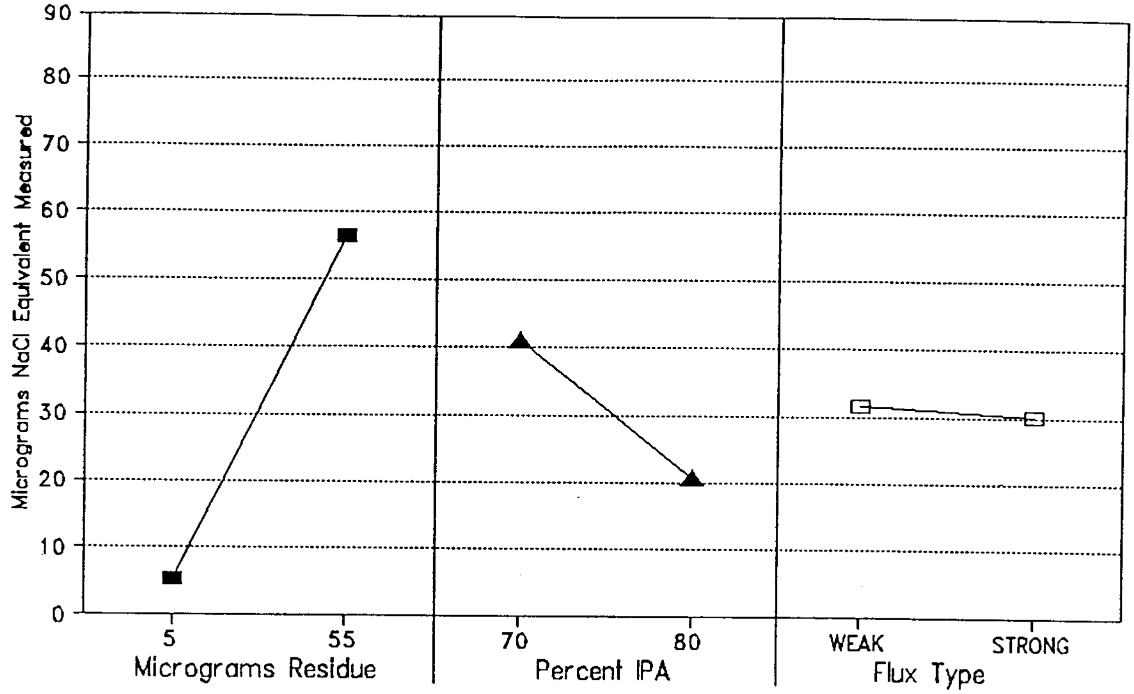
RANDOMIZED RUN SEQUENCE	STANDARD ORDER	A B C	A AMOUNT OF RESIDUE (μGR/IN²)	B IPA (VOL%)	C FLUX TYPE	IONIC READING	TEST DURATION	TEST CELL TEMP.
BLANK		BLANK	BLANK			0.0	0:14	88°F
1	5	- - +	5	70	STRONG	6.4	1:14	87°F
2	2	+ - -	55	70	WEAK	82.5	4:34	88°F
3	1	- - -	5	70	WEAK	9.6	1:30	88°F
4	6	+ - +	55	70	STRONG	63.7	3:39	89°F
5		0 0 -	30	75	WEAK	36.7	2:49	88°F
6	11	0 0 0	30	75	NaCl	32.0	2:29	88°F
7		0 0 +	30	75	STRONG	28.9	2:16	88°F
8	9	0 0 0	30	75	NaCl	32.2	2:24	88°F
9		0 0 -	30	75	WEAK	36.5	2:47	88°F
10	10	0 0 0	30	75	NaCl	32.4	2:24	88°F
11		0 0 +	30	75	STRONG	28.4	2:16	88°F
12	3	- + -	5	80	WEAK	1.8	0:35	87°F
13	7	- + +	5	80	STRONG	2.6	0:37	87°F
14	8	+ + +	55	80	STRONG	48.3	2:37	87°F
15	4	+ + -	55	80	WEAK	30.2	2:19	87°F
16	5	- - +	5	70	STRONG	5.2	1:20	91°F
17	2	+ - -	55	70	WEAK	84.8	4:43	91°F
18	1	- - -	5	70	WEAK	12.4	1:48	91°F
19	6	+ - +	55	70	STRONG	63.8	3:52	91°F
BLANK		BLANK	BLANK			0.0	0:15	91°F

TABLE OF EFFECTS
In Solution Testing

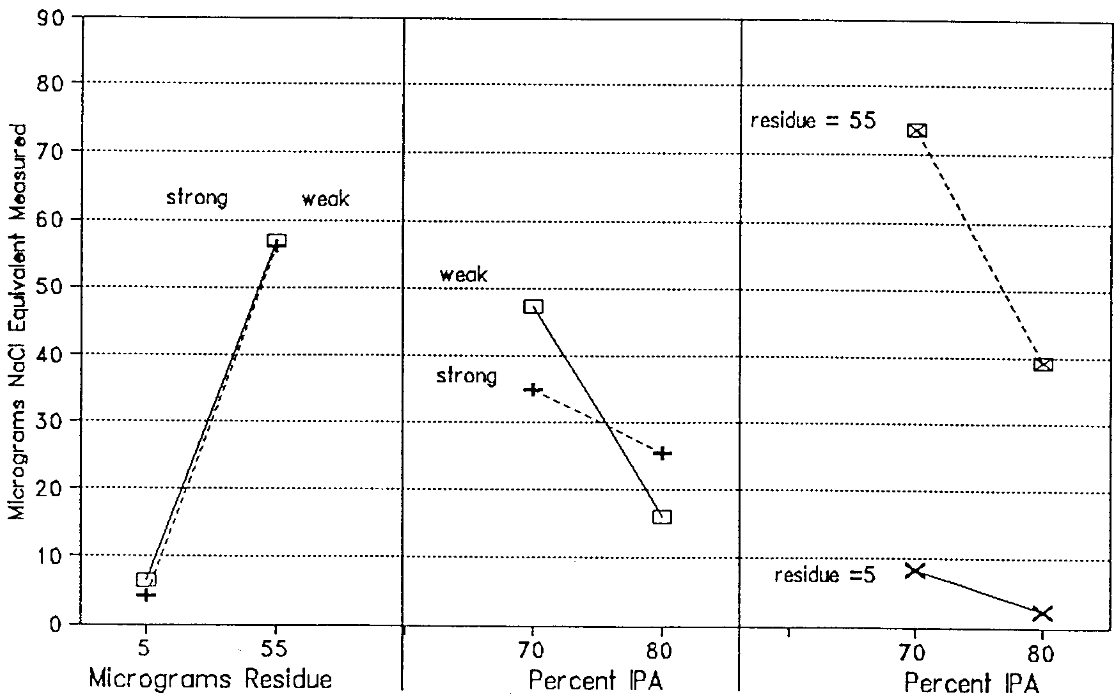
	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN RESPONSE	30.89*	27.20*	26.38*	7.00*	25.33*	20.53*	16.10*	17.98*	13.75*
MAIN EFFECTS									
Residue (R)	51.18*	46.58*	47.26*	11.10*	30.57*	25.91*	28.31*	24.56*	24.11*
IPA (I)	-20.33*	-22.84*	-22.29*	-1.40	-10.0*	-7.60*	-7.85*	-7.19*	-6.69*
Flux (F)	-1.55	-1.49	-9.88*	2.23	10.07*	7.51*	18.46*	19.37*	5.16*
Volume (V)					4.7*	7.45*	-1.01	3.61*	
INTERACTIONS									
R*I	-14.13*	-15.18*	-18.48*	-1.00	-2.35*	-3.29	-6.86*	-3.29*	-4.28*
R*F	0.65	0.70	-8.55*	2.63*	8.07*	3.78*	16.15*	16.47*	4.84*
R*V					1.55*	3.89*	0.72	6.56*	
I*F	11.00*	10.52*	10.28*	1.48	5.75*	2.79	1.63	0.74	2.42*
I*V					1.77*	-1.63	-0.04	-2.88*	
F*V					-0.85	-2.16	-1.60	5.24*	
R*I*F	8.00*	8.06*	8.83*	0.98	5.15*	4.15*	1.05	0.10	1.77
R*I*V					-0.52	-1.39	-1.05	-1.89*	
R*F*V					-1.0	0.38	-1.04	5.35*	
I*F*V					0.87	2.49	0.90	-2.65*	
R*I*F*V					0.12	-0.33	1.04	-2.22*	
CENTER POINT	1.74*	5.42	-0.64	4.48*	2.91	2.00	-0.15	2.22*	1.41

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

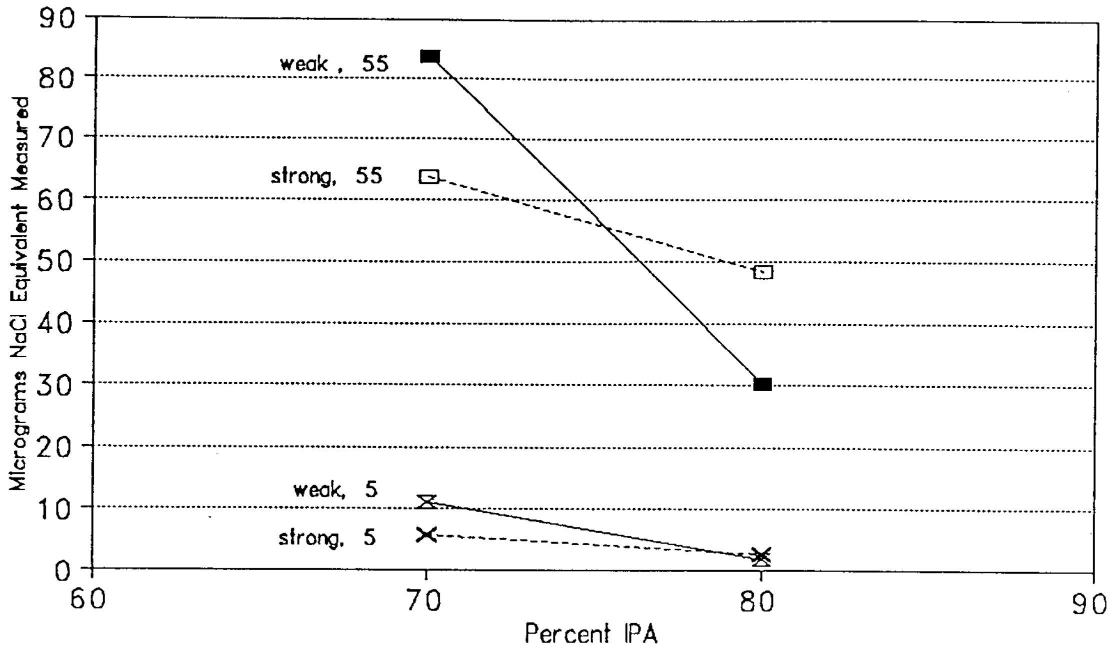
ZERO ION
MAIN EFFECTS



ZERO ION
2-WAY INTERACTIONS



ZERO ION
3-WAY INTERACTION



ZERO ION
IN SOLUTION TEST

Predictor	Coef	Stdev	t-ratio	p	
Constant	30.8875	0.3408	90.62	0.000	*
R	25.5875	0.3408	75.07	0.000	*
I	-10.1625	0.3408	-29.82	0.000	*
F	-0.7750	0.3408	-2.27	0.063	
R*I	-7.0625	0.3408	-20.72	0.000	*
R*F	0.3250	0.3408	0.95	0.377	
I*F	5.5000	0.3408	16.14	0.000	*
R*I*F	4.0000	0.3408	11.74	0.000	*
CTR.PT	1.7375	0.6527	2.66	0.037	*
CTR*F	-3.2000	0.6527	-4.90	0.003	*

s = 1.113 R-sq = 99.9% R-sq(adj) = 99.8%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	9	11661.0	1295.7	1045.60	0.000
Error	6	7.4	1.2		
Total	15	11668.5			

SOURCE	DF	SEQ SS
R	1	9368.8
I	1	1101.0
F	1	139.2
R*I	1	532.0
R*F	1	12.2
I*F	1	298.5
R*I*F	1	170.7
CTR.PT	1	8.8
CTR*F	1	29.8

ALPHA METALS

IONOGRAPH 500M

Dynamic
Unheated
Spray below immersion

IONOGRAPH 500M
RANDOMIZED EXPERIMENTAL MATRIX
"IN SOLUTION" TESTS

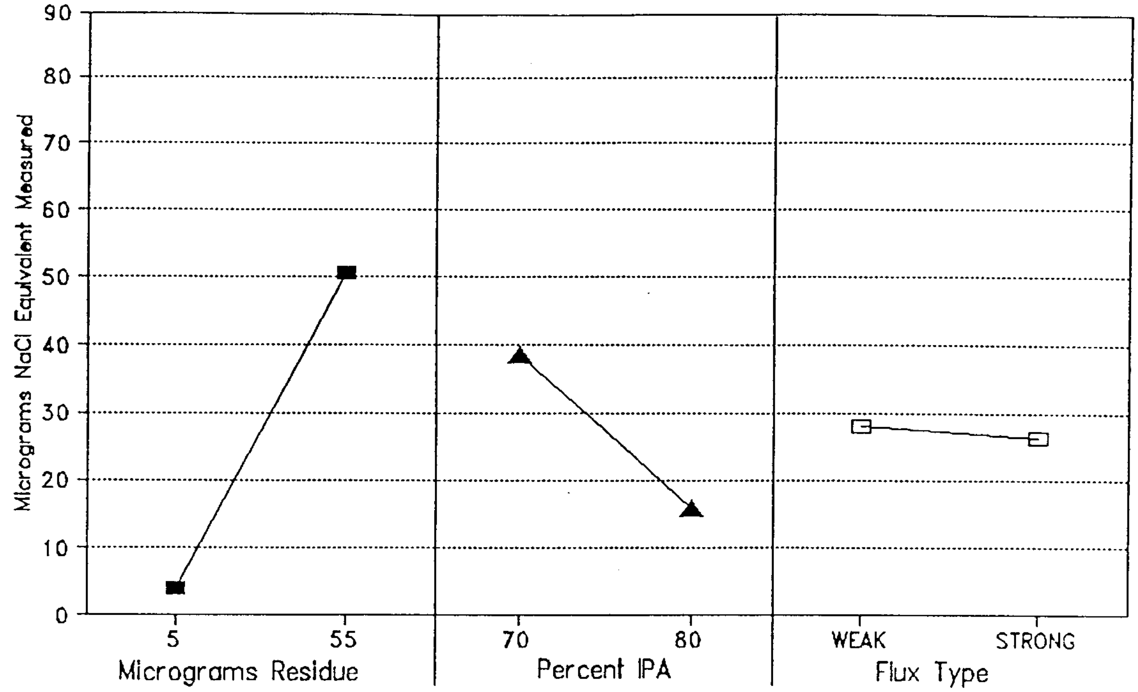
RANDOMIZED RUN SEQUENCE	STANDARD ORDER	A B C	A AMOUNT OF RESIDUE ($\mu GR/IN^2$)	B IPA (VOL%)	C FLUX TYPE	IONIC READING	TEST DURATION	TEST CELL TEMP.
1	5	- - +	5	70	STRONG	4.64	2:00	33.2°C
2	1	- - -	5	70	WEAK	6.72	2:00	33.2°C
3	6	+ - +	55	70	STRONG	56.83	6:00	33.2°C
4	2	+ - -	55	70	WEAK	74.58	6:00	33.4°C
5		0 0 +	30	75	STRONG	23.29	4:00	34.8°C
6	9	0 0 0	30	75	NaCl	22.54	4:00	34.8°C
7		0 0 -	30	75	WEAK	34.23	6:00	34.7°C
8	10	0 0 0	30	75	NaCl	26.12	4:00	34.7°C
9		0 0 +	30	75	STRONG	22.32	4:00	34.7°C
10	11	0 0 0	30	75	NaCl	26.93	4:00	34.7°C
11		0 0 -	30	75	WEAK	32.71	6:00	34.7°C
12	7	- + +	5	80	STRONG	0.72	2:00	35.0°C
13	8	+ + +	55	80	STRONG	39.88	4:00	34.9°C
14	4	+ + -	55	80	WEAK	22.09	4:00	34.9°C
15	3	- + -	5	80	WEAK	0.45	2:00	34.9°C
16	5	- - +	5	70	STRONG	6.63	2:00	34.0°C
17	1	- - -	5	70	WEAK	6.76	2:00	34.0°C
18	6	+ - +	55	70	STRONG	54.39	6:00	34.1°C
19	2	+ - -	55	70	WEAK	87.53	8:00	34.0°C

TABLE OF EFFECTS
In Solution Testing

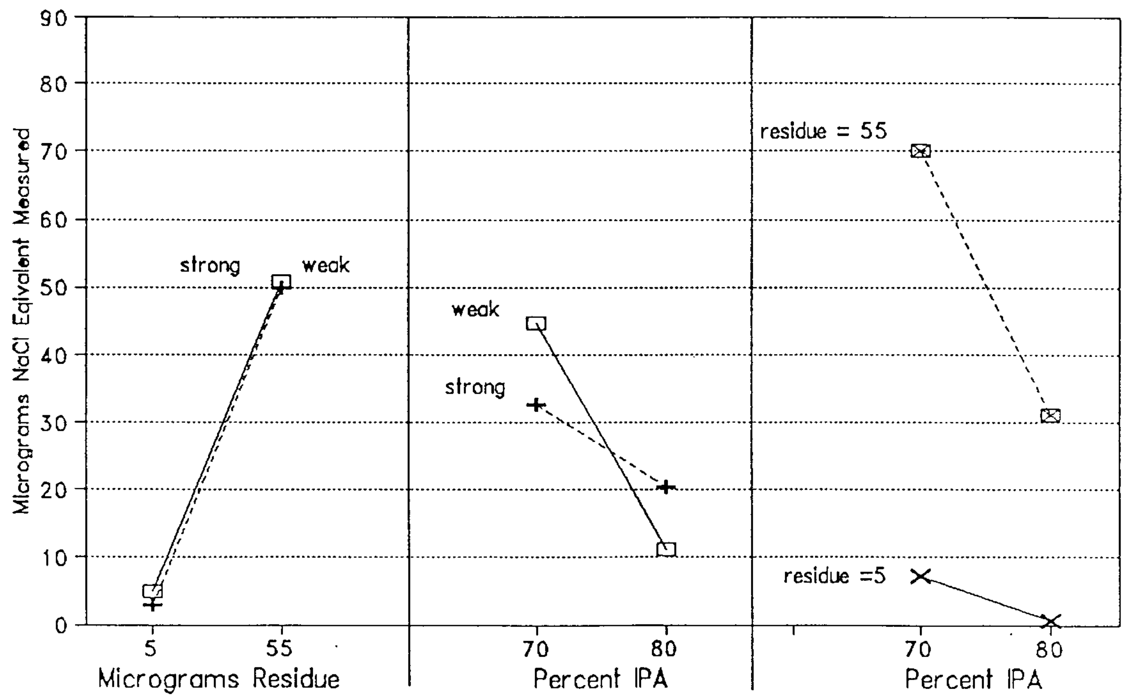
	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN RESPONSE	30.89*	27.20*	26.38*	7.00*	25.33*	20.53*	16.10*	17.98*	13.75*
MAIN EFFECTS									
Residue (R)	51.18*	46.58*	47.26*	11.10*	30.57*	25.91*	28.31*	24.56*	24.11*
IPA (I)	-20.33*	-22.84*	-22.29*	-1.40	-10.0*	-7.60*	-7.85*	-7.19*	-6.69*
Flux (F)	-1.55	-1.49	-9.88*	2.23	10.07*	7.51*	18.46*	19.37*	5.16*
Volume (V)					4.7*	7.45*	-1.01	3.61*	
INTERACTIONS									
R*I	-14.13*	-15.18*	-18.48*	-1.00	-2.35*	-3.29	-6.86*	-3.29*	-4.28*
R*F	0.65	0.70	-8.55*	2.63*	8.07*	3.78*	16.15*	16.47*	4.84*
R*V					1.55*	3.89*	0.72	6.56*	
I*F	11.00*	10.52*	10.28*	1.48	5.75*	2.79	1.63	0.74	2.42*
I*V					1.77*	-1.63	-0.04	-2.88*	
F*V					-0.85	-2.16	-1.60	5.24*	
R*I*F	8.00*	8.06*	8.83*	0.98	5.15*	4.15*	1.05	0.10	1.77
R*I*V					-0.52	-1.39	-1.05	-1.89*	
R*F*V					-1.0	0.38	-1.04	5.35*	
I*F*V					0.87	2.49	0.90	-2.65*	
R*I*F*V					0.12	-0.33	1.04	-2.22*	
CENTER POINT	1.74*	5.42	-0.64	4.48*	2.91	2.00	-0.15	2.22*	1.41

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

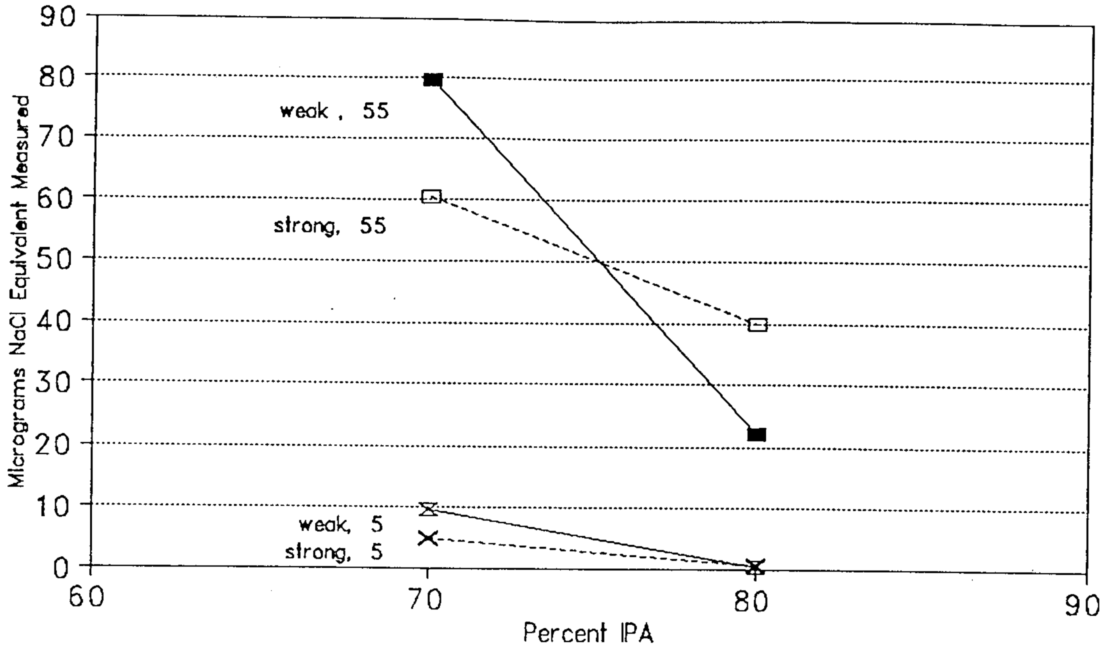
IONOGRAPH 500M
MAIN EFFECTS



IONOGRAPH 500M
2-WAY INTERACTIONS



IONOGRAPH 500M
3-WAY INTERACTION



IONOGRAPH 500M
IN SOLUTION TEST

Predictor	Coef	Stdev	t-ratio	p	
Constant	27.203	1.205	22.57	0.000	*
R	23.291	1.205	19.33	0.000	*
I	-11.418	1.205	-9.47	0.000	*
F	-0.744	1.205	-0.62	0.559	
R*I	-8.091	1.205	-6.71	0.001	*
R*F	0.348	1.205	0.29	0.782	
I*F	5.259	1.205	4.36	0.005	*
R*I*F	4.032	1.205	3.35	0.016	*
CTR.PT	5.422	2.308	2.35	0.057	
CTR*F	-3.231	2.308	-1.40	0.211	

s = 3.936 R-sq = 99.1% R-sq(adj) = 97.9%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	9	10819.3	1202.1	77.60	0.000
Error	6	92.9	15.5		
Total	15	10912.3			

SOURCE	DF	SEQ SS
R	1	8104.2
I	1	1313.0
F	1	131.5
R*I	1	698.2
R*F	1	11.9
I*F	1	271.2
R*I*F	1	173.4
CTR.PT	1	85.5
CTR*F	1	30.4

ALPHA METALS

IONOGRAPH 500SMD

Dynamic
Heated
Spray below immersion

IONOGRAPH 500M SMD
RANDOMIZED EXPERIMENTAL MATRIX
"IN SOLUTION" TESTS

RANDOMIZED RUN SEQUENCE	STANDARD ORDER	A B C	A AMOUNT OF RESIDUE (μGR/IN^2)	B IPA (VOL%)	C FLUX TYPE	IONIC READING	TEST DURATION	TEST CELL TEMP.
1	5	- - +	5	70	STRONG	2.90	2:00	44.6°C
2	2	+ - -	55	70	WEAK	87.73	8:00	44.4°C
3	1	- - -	5	70	WEAK	6.21	2:00	44.1°C
4	6	+ - +	55	70	STRONG	49.01	6:00	45.0°C
5		0 0 -	30	75	WEAK	29.93	4:00	44.2°C
6	11	0 0 0	30	75	NaCl	20.23	4:00	44.2°C
7		0 0 +	30	75	STRONG	18.21	4:00	44.1°C
8	9	0 0 0	30	75	NaCl	19.38	4:00	44.7°C
9		0 0 -	30	75	WEAK	33.77	4:00	44.9°C
10	10	0 0 0	30	75	NaCl	22.42	4:00	44.8°C
11		0 0 +	30	75	STRONG	21.06	4:00	44.6°C
12	3	- + -	5	80	WEAK	0.79	2:00	44.4°C
13	7	- + +	5	80	STRONG	0.90	2:00	44.8°C
14	8	+ + +	55	80	STRONG	29.96	4:00	45.0°C
15	4	+ + -	55	80	WEAK	29.28	6:00	44.2°C
16	5	- - +	5	70	STRONG	3.62	2:00	44.2°C
17	2	+ - -	55	70	WEAK	90.59	2:00	45.0°C
18	1	- - -	5	70	WEAK	5.88	2:00	44.8°C
19	6	+ - +	55	70	STRONG	54.24	6:00	44.2°C

TABLE OF EFFECTS
In Solution Testing

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN RESPONSE	30.89*	27.20*	26.38*	7.00*	25.33*	20.53*	16.10*	17.98*	13.75*
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Residue (R)	51.18*	46.58*	47.26*	11.10*	30.57*	25.91*	28.31*	24.56*	24.11*
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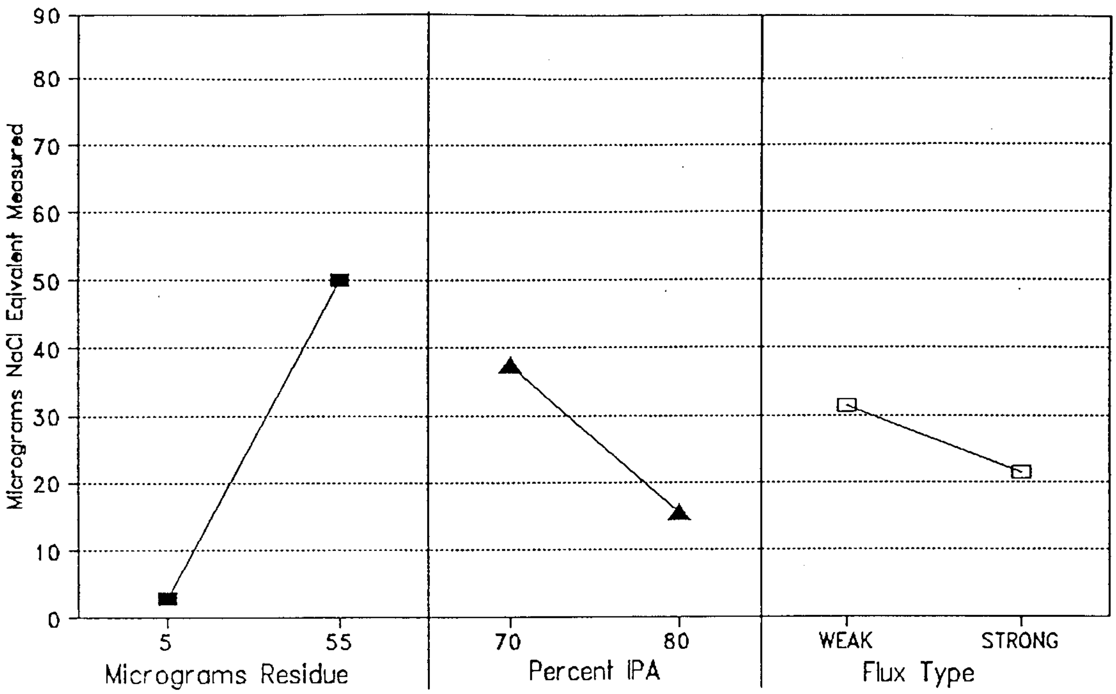
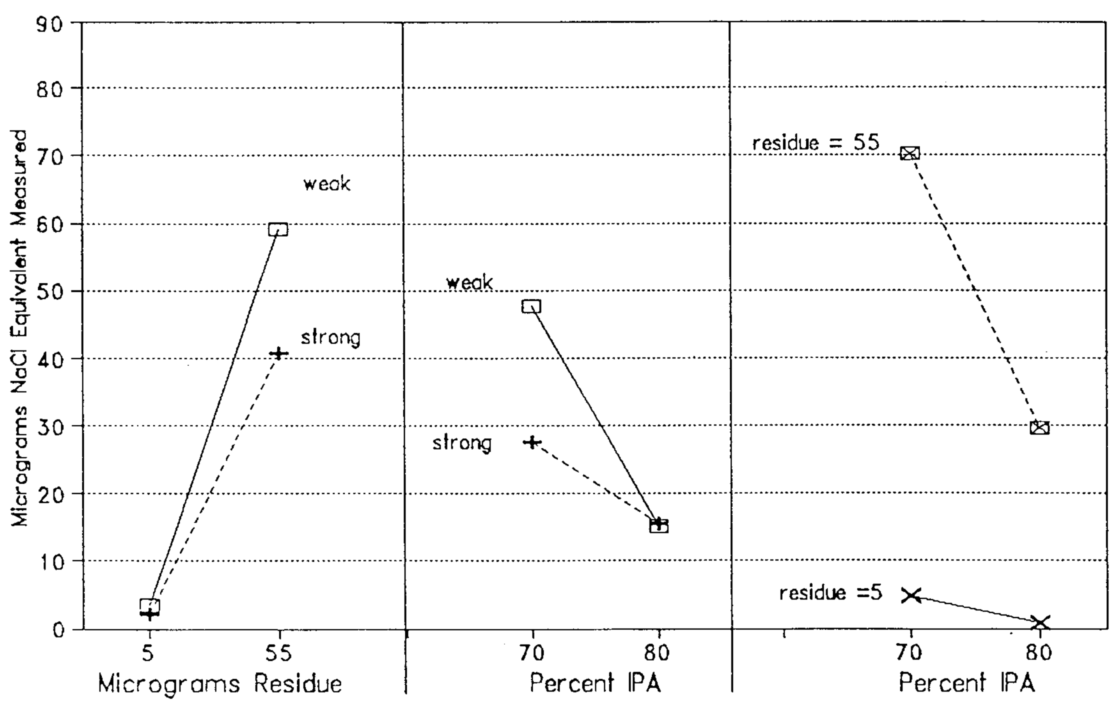
Flux (F)	-1.55	-1.49	-9.88*	2.23	10.07*	7.51*	18.46*	19.37*	5.16*
Volume (V)					4.7*	7.45*	-1.01	3.61*	
INTERACTIONS									
R*I	-14.13*	-15.18*	-18.48*	-1.00	-2.35*	-3.29	-6.86*	-3.29*	-4.28*
R*F	0.65	0.70	-8.55*	2.63*	8.07*	3.78*	16.15*	16.47*	4.84*
R*V					1.55*	3.89*	0.72	6.56*	
I*F	11.00*	10.52*	10.28*	1.48	5.75*	2.79	1.63	0.74	2.42*
I*V					1.77*	-1.63	-0.04	-2.88*	
F*V					-0.85	-2.16	-1.60	5.24*	
R*I*F	8.00*	8.06*	8.83*	0.98	5.15*	4.15*	1.05	0.10	1.77
R*I*V					-0.52	-1.39	-1.05	-1.89*	
R*F*V					-1.0	0.38	-1.04	5.35*	
I*F*V					0.87	2.49	0.90	-2.65*	
R*I*F*V					0.12	-0.33	1.04	-2.22*	
CENTER POINT	1.74*	5.42	-0.64	4.48*	2.91	2.00	-0.15	2.22*	1.41

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

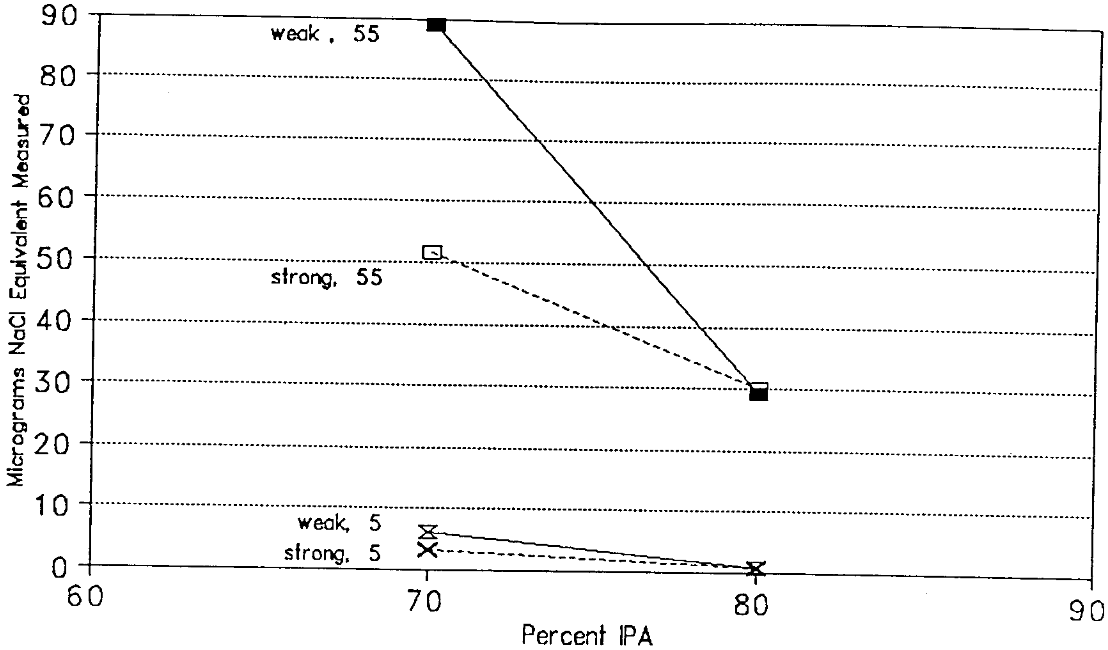
IONOGRAPH 500SMD
MAIN EFFECTS



IONOGRAPH 500SMD
2-WAY INTERACTIONS



IONOGRAPH 500SMD
3-WAY INTERACTION



IONOGRAPH 500SMD
IN SOLUTION TEST

Predictor	Coef	Stdev	t-ratio	p	
Constant	26.3775	0.6791	38.84	0.000	*
R	23.6287	0.6791	34.80	0.000	*
I	-11.1450	0.6791	-16.41	0.000	*
F	-4.9413	0.6791	-7.28	0.000	*
R*I	-9.2413	0.6791	-13.61	0.000	*
R*F	-4.2725	0.6791	-6.29	0.001	*
I*F	5.1387	0.6791	7.57	0.000	*
R*I*F	4.4150	0.6791	6.50	0.001	*
CTR.PT	-0.635	1.300	-0.49	0.643	
CTR*F	-1.166	1.300	-0.90	0.404	

s = 2.218   R-sq = 99.8%   R-sq(adj) = 99.4%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	9	12419.3	1379.9	280.53	0.000
Error	6	29.5	4.9		
Total	15	12448.8			

SOURCE	DF	SEQ SS
R	1	8560.6
I	1	1380.5
F	1	679.6
R*I	1	910.9
R*F	1	395.9
I*F	1	278.6
R*I*F	1	207.9
CTR.PT	1	1.2
CTR*F	1	4.0

PROTONIQUE

CONTAMINOMETER CM5 (dynamic)

Dynamic
Unheated
No Spray

CONTAMINOMETER CM5/DYNAMIC MODE
RANDOMIZED EXPERIMENTAL MATRIX
"IN SOLUTION" TESTS

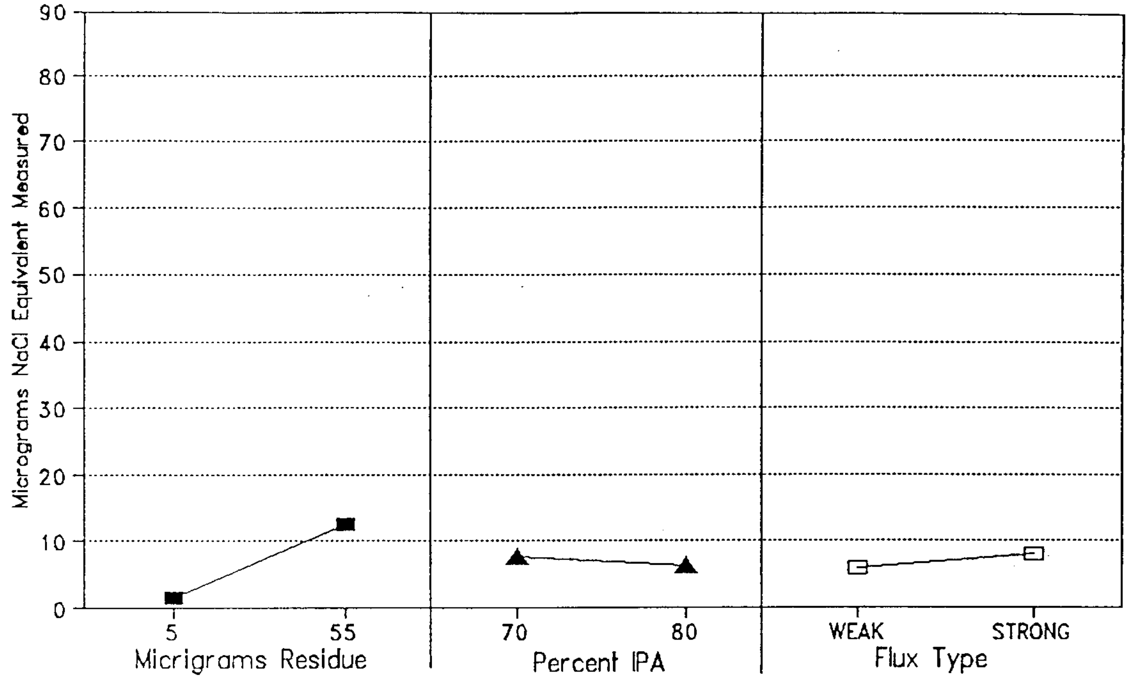
RANDOMIZED RUN SEQUENCE	STANDARD ORDER	A B C	A AMOUNT OF RESIDUE (μGR/IN^2)	B IPA (VOL%)	C FLUX TYPE	IONIC READING	TEST DURATION	TEST CELL TEMP.
1	2	+ - -	55	70	WEAK	15.1	3:16	71°F
2	5	- - +	5	70	STRONG	1.4	1:36	71°F
3	6	+ - +	55	70	STRONG	15.5	3:16	72°F
4	1	- - -	5	70	WEAK	2.0	1:36	72°F
5		0 0 +	30	75	STRONG	10.4	3:16	72°F
6	11	0 0 0	30	75	NaCl	7.7	3:16	72°F
7		0 0 -	30	75	WEAK	12.1	3:16	72°F
8	9	0 0 0	30	75	NaCl	5.9	1:36	72°F
9		0 0 +	30	75	STRONG	10.9	3:16	72°F
10	10	0 0 0	30	75	NaCl	6.8	3:16	72°F
11		0 0 -	30	75	WEAK	12.5	3:16	72°F
12	8	+ + +	55	80	STRONG	15.0	3:16	72°F
13	7	- + +	5	80	STRONG	1.3	1:36	72°F
14	3	- + -	5	80	WEAK	1.2	1:36	72°F
15	4	+ + -	55	80	WEAK	7.7	3:16	72°F
16	2	+ - -	55	70	WEAK	10.0	3:16	72°F
17	5	- - +	5	70	STRONG	1.0	1:36	73°F
18	6	+ - +	55	70	STRONG	14.4	3:16	73°F
19	1	- - -	5	70	WEAK	2.2	1:36	73°F

TABLE OF EFFECTS
In Solution Testing

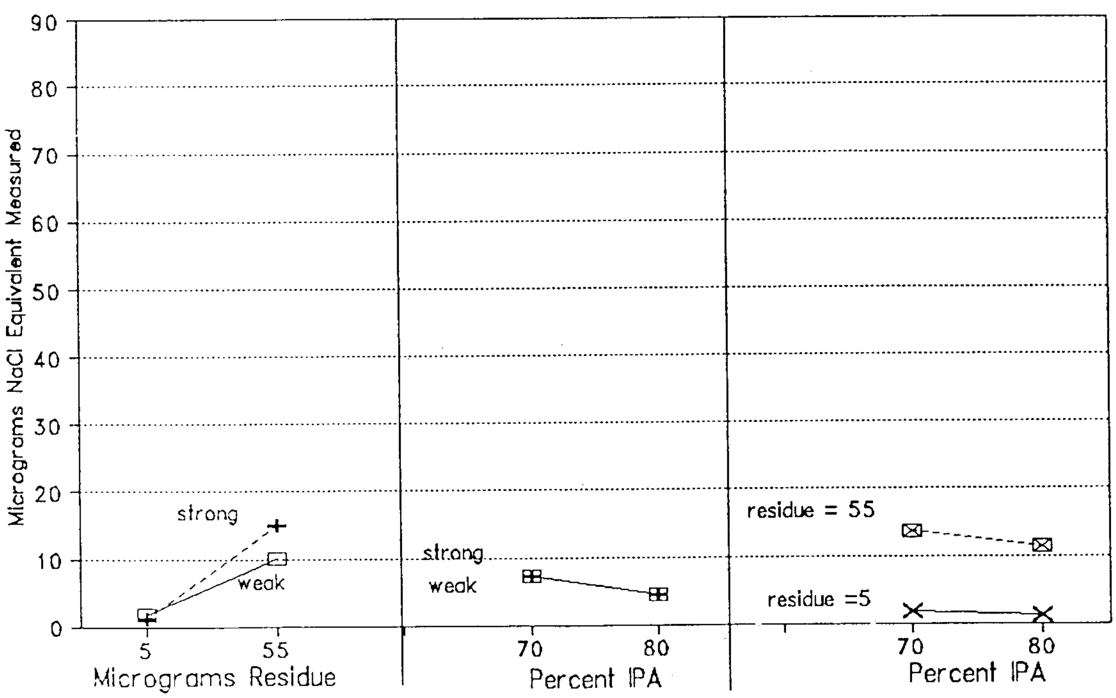
	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN RESPONSE	30.89*	27.20*	26.38*	7.00*	25.33*	20.53*	16.10*	17.98*	13.75*
MAIN EFFECTS									
Residue (R)	51.18*	46.58*	47.26*	11.10*	30.57*	25.91*	28.31*	24.56*	24.11*
IPA (I)	-20.33*	-22.84*	-22.29*	-1.40	-10.0*	-7.60*	-7.85*	-7.19*	-6.69*
Flux (F)	-1.55	-1.49	-9.88*	2.23	10.07*	7.51*	18.46*	19.37*	5.16*
Volume (V)					4.7*	7.45*	-1.01	3.61*	
INTERACTIONS									
R*I	-14.13*	-15.18*	-18.48*	-1.00	-2.35*	-3.29	-6.86*	-3.29*	-4.28*
R*F	0.65	0.70	-8.55*	2.63*	8.07*	3.78*	16.15*	16.47*	4.84*
R*V					1.55*	3.89*	0.72	6.56*	
I*F	11.00*	10.52*	10.28*	1.48	5.75*	2.79	1.63	0.74	2.42*
I*V					1.77*	-1.63	-0.04	-2.88*	
F*V					-0.85	-2.16	-1.60	5.24*	
R*I*F	8.00*	8.06*	8.83*	0.98	5.15*	4.15*	1.05	0.10	1.77
R*I*V					-0.52	-1.39	-1.05	-1.89*	
R*F*V					-1.0	0.38	-1.04	5.35*	
I*F*V					0.87	2.49	0.90	-2.65*	
R*I*F*V					0.12	-0.33	1.04	-2.22*	
CENTER POINT	1.74*	5.42	-0.64	4.48*	2.91	2.00	-0.15	2.22*	1.41

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

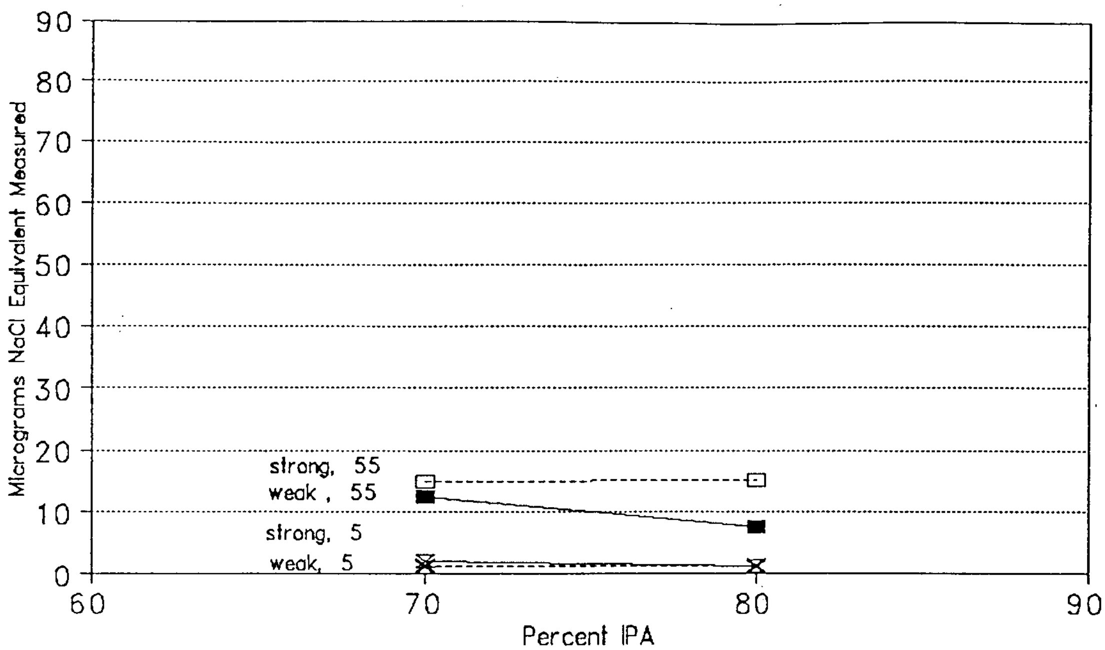
CONTAMINOMER CM-5 (dynamic)
MAIN EFFECTS



CONTAMINOMETER CM-5 (dynamic)
2-WAY INTERACTIONS



CONTAMINOMETER CM-5 (dynamic)
3-WAY INTERACTION



CONTAMINOMETER CM-5 (dynamic)
IN SOLUTION TEST

Predictor	Coef	Stdev	t-ratio	p	
Constant	7.0000	0.4663	15.01	0.000	*
R	5.5500	0.4663	11.90	0.000	*
I	-0.7000	0.4663	-1.50	0.184	
F	1.1125	0.4663	2.39	0.054	
R*I	-0.5000	0.4663	-1.07	0.325	
R*F	1.3125	0.4663	2.81	0.031	*
I*F	0.7375	0.4663	1.58	0.165	
R*I*F	0.4875	0.4663	1.05	0.336	
CTR.PT	4.4750	0.8929	5.01	0.002	*
CTR*F	-1.9375	0.8929	-2.17	0.073	

s = 1.523   R-sq = 97.2%   R-sq(adj) = 93.1%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	9	489.974	54.442	23.47	0.001
Error	6	13.915	2.319		
Total	15	503.889			

SOURCE	DF	SEQ SS
R	1	392.163
I	1	0.946
F	1	3.151
R*I	1	2.667
R*F	1	15.870
I*F	1	3.466
R*I*F	1	2.535
CTR.PT	1	58.256
CTR*F	1	10.920

Unusual Observations

Obs.	R	D	Fit	Stdev.Fit	Residual	St.Resid
1	1.00	15.100	12.550	1.077	2.550	2.37R
13	1.00	10.000	12.550	1.077	-2.550	-2.37R

R denotes an obs. with a large st. resid.

ALPHA METALS

OMEGAMETER 600R

Static
Unheated
No spray

OMEGAMETER 600R
RANDOMIZED EXPERIMENTAL MATRIX
"IN SOLUTION" TESTS

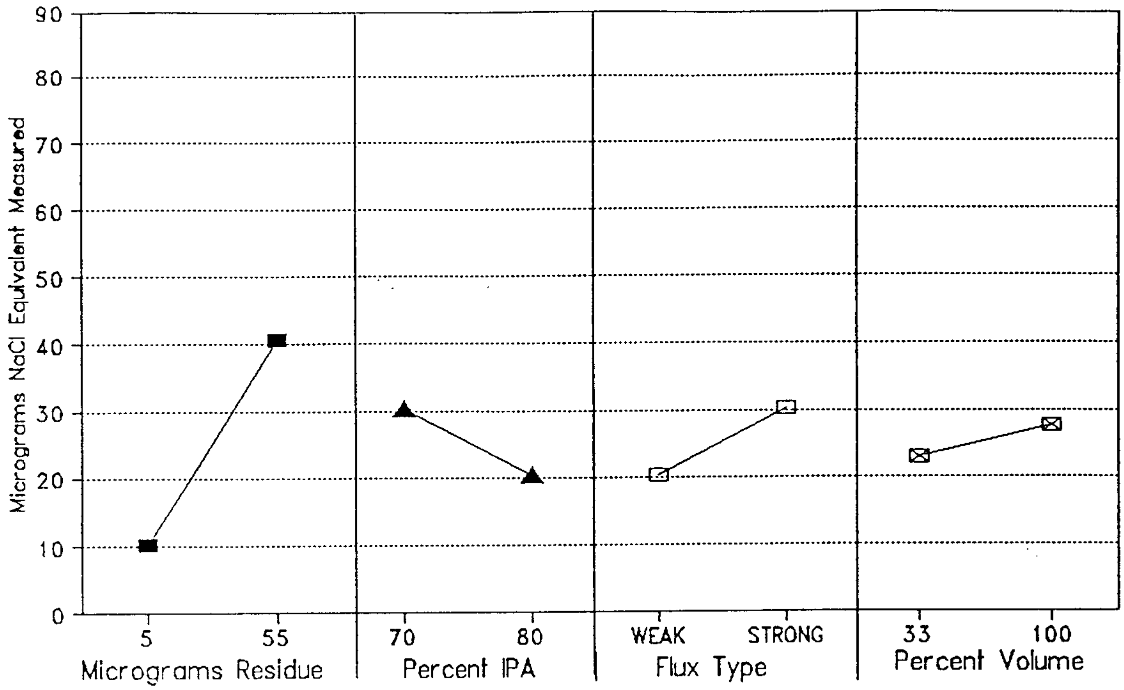
RANDOMIZED RUN SEQUENCE	STANDARD ORDER	A B C D	A AMOUNT OF RESIDUE (µGR/IN²)	B IPA (VOL%)	C TEST CELL VOLUME (% FULL)	D FLUX TYPE	IONIC READING	TEST DURATION	TEST CELL TEMP.
1	5	- - + -	5	70	33	STRONG	13.0	23:10	82°F
2	1	- - - -	5	70	33	WEAK	10.4	22:40	82°F
3	2	+ - - -	55	70	33	WEAK	37.1	4:20	81°F
4	6	+ - + -	55	70	33	STRONG	50.2	4:20	81°F
5	9	- - - +	5	70	100	WEAK	16.0	33:00	81°F
6	14	+ - + +	55	70	100	STRONG	52.6	4:20	80°F
7	13	- - + +	5	70	100	STRONG	17.0	37:00	80°F
8	10	+ - - +	55	70	100	WEAK	48.7	4:20	80°F
9		0 0 + 0	30	75	66	STRONG	26.0	5:30	81°F
10	18	0 0 0 0	30	75	66	NaCl	34.6	14:40	81°F
11		0 0 - 0	30	75	66	WEAK	18.1	6:30	81°F
12	17	0 0 0 0	30	75	66	NaCl	33.6	11:40	80°F
13		0 0 + 0	30	75	66	STRONG	27.4	5:60	80°F
14	19	0 0 0 0	30	75	66	NaCl	38.4	20:50	80°F
15		0 0 - 0	30	75	66	WEAK	18.2	8:40	80°F
16	8	+ + + -	55	80	33	STRONG	47.4	8:10	82°F
17	3	- + - -	5	80	33	WEAK	4.4	12:30	81°F
18	15	- + + +	5	80	100	STRONG	8.9	22:30	80°F
19	11	- + - +	5	80	100	WEAK	5.4	12:30	80°F
20	12	+ + - +	55	80	100	WEAK	22.3	4:10	78°F
21	7	- + + -	5	80	33	STRONG	6.1	9:00	80°F
22	16	+ + + +	55	80	100	STRONG	50.5	4:00	79°F
23	4	+ + - -	55	80	33	WEAK	17.5	4:00	79°F
24	5	- - + -	5	70	33	STRONG	12.4	24:10	80°F
25	1	- - - -	5	70	33	WEAK	11.0	21:40	81°F
26	2	+ - - -	55	70	33	WEAK	37.9	5:40	81°F
27	6	+ - + -	55	70	33	STRONG	45.0	4:10	83°F
28	9	- - - +	5	70	100	WEAK	15.4	33:20	80°F
29	14	+ - + +	55	70	100	STRONG	54.0	4:10	79°F
30	13	- - + +	5	70	100	STRONG	16.0	37:20	80°F
31	10	+ - - +	55	70	100	WEAK	49.1	10:40	79°F

TABLE OF EFFECTS
In Solution Testing

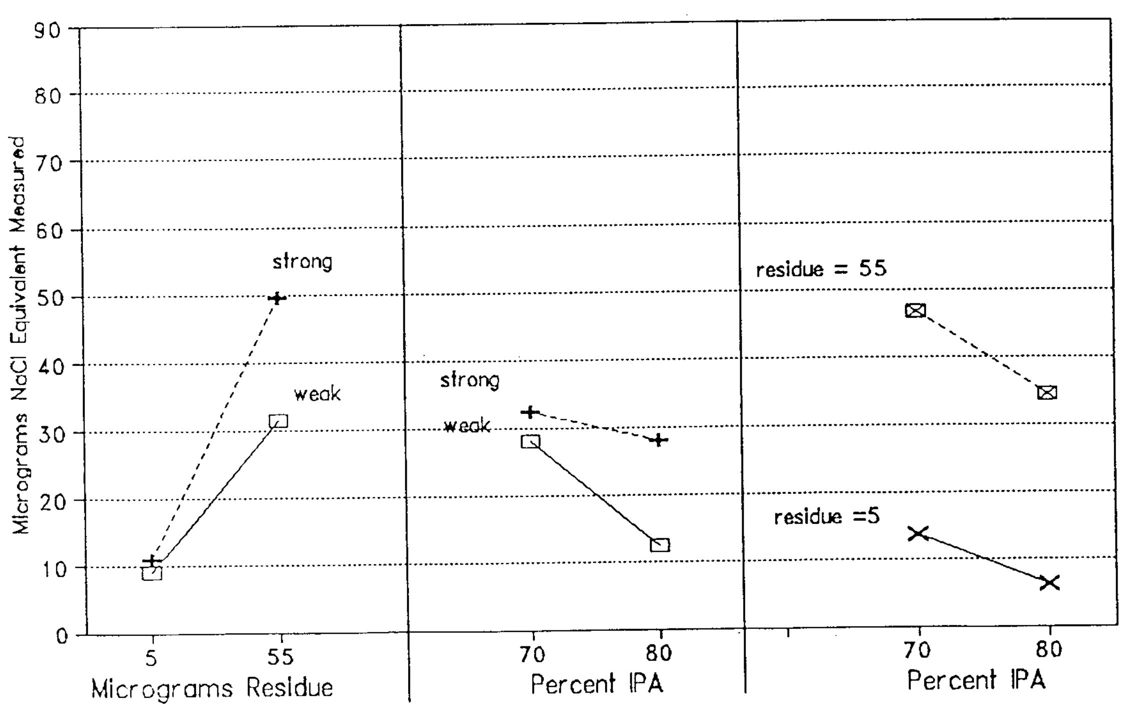
	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	Cm-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN RESPONSE	30.89*	27.20*	26.38*	7.00*	25.33*	20.53*	16.10*	17.98*	13.75*
MAIN EFFECTS									
Residue (R)	51.18*	46.58*	47.26*	11.10*	30.57*	25.91*	28.31*	24.56*	24.11*
IPA (I)	-20.33*	-22.84*	-22.29*	-1.40	-10.0*	-7.60*	-7.85*	-7.19*	-6.69*
Flux (F)	-1.55	-1.49	-9.88*	2.23	10.07*	7.51*	18.46*	19.37*	5.16*
Volume (V)					4.7*	7.45*	-1.01	3.61*	
INTERACTIONS									
R*I	-14.13*	-15.18*	-18.48*	-1.00	-2.35*	-3.29	-6.86*	-3.29*	-4.28*
R*F	0.65	0.70	-8.55*	2.63*	8.07*	3.78*	16.15*	16.47*	4.84*
R*V					1.55*	3.89*	0.72	6.56*	
I*F	11.00*	10.52*	10.28*	1.48	5.75*	2.79	1.63	0.74	2.42*
I*V					1.77*	-1.63	-0.04	-2.88*	
F*V					-0.85	-2.16	-1.60	5.24*	
R*I*F	8.00*	8.06*	8.83*	0.98	5.15*	4.15*	1.05	0.10	1.77
R*I*V					-0.52	-1.39	-1.05	-1.89*	
R*F*V					-1.0	0.38	-1.04	5.35*	
I*F*V					0.87	2.49	0.90	-2.65*	
R*I*F*V					0.12	-0.33	1.04	-2.22*	
CENTER POINT	1.74*	5.42	-0.64	4.48*	2.91	2.00	-0.15	2.22*	1.41

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

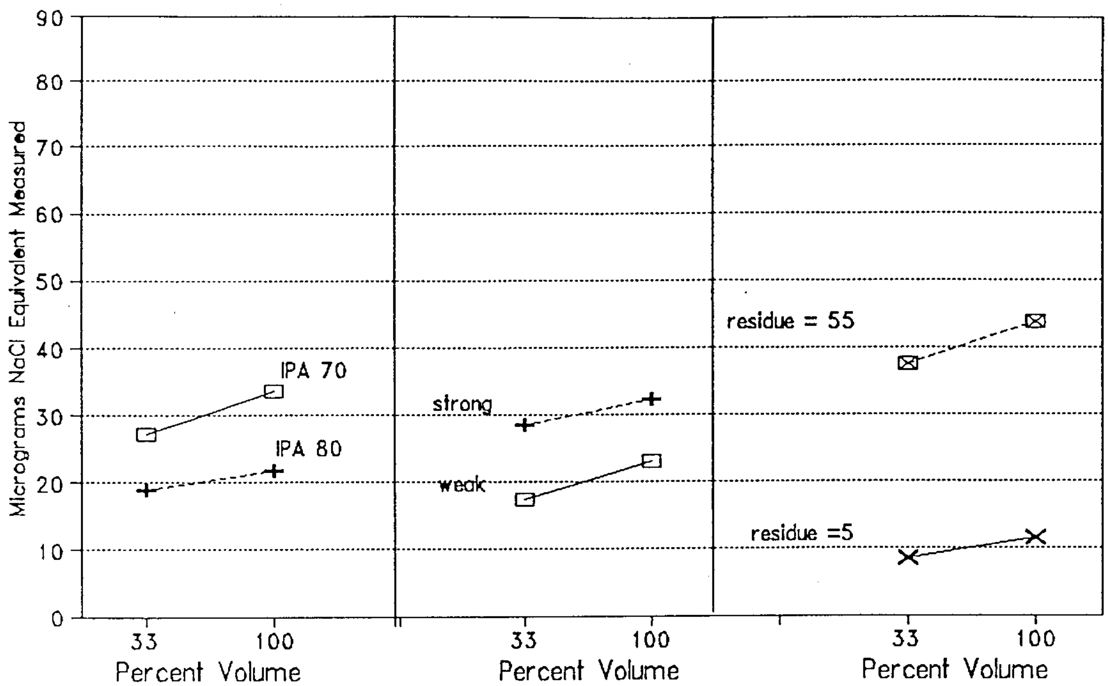
OMEGAMETER 600R
MAIN EFFECTS



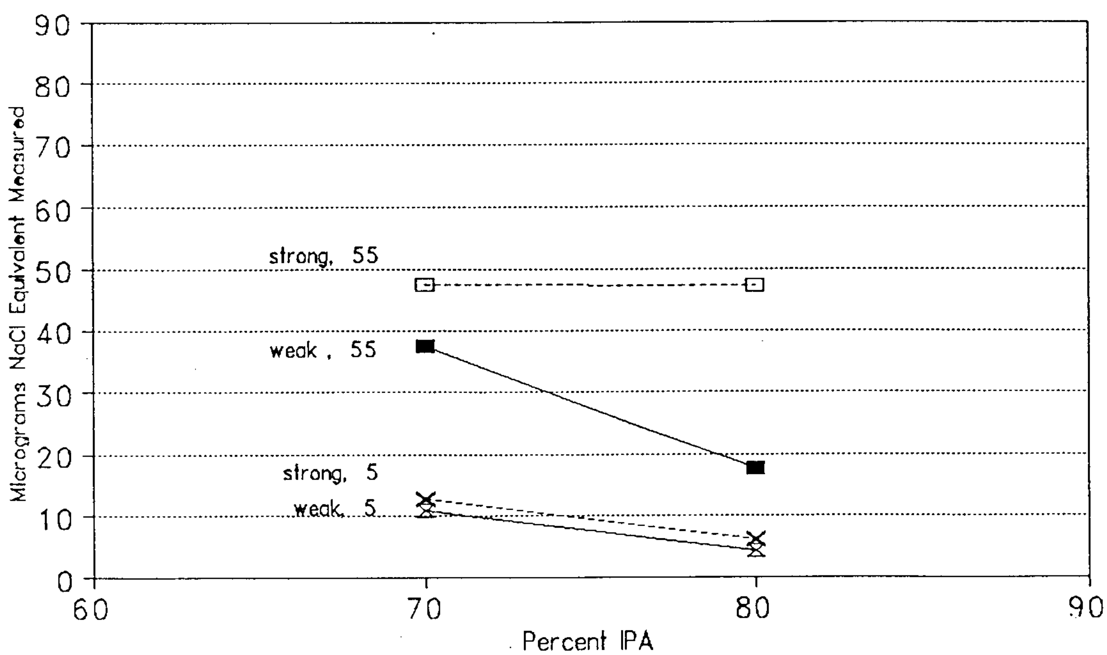
OMEGAMETER 600R
2-WAY INTERACTIONS (page 1)



OMEGAMETER 600R
2-WAY INTERACTIONS (page 2)



OMEGAMETER 600R
3-WAY INTERACTION



OMEGAMETER 600R
IN SOLUTION TEST

Predictor	Coef	Stdev	t-ratio	p	
Constant	26.522	1.788	14.84	0.000	*
R	15.653	1.788	8.76	0.000	*
I	-2.753	1.788	-1.54	0.155	
F	4.684	1.788	2.62	0.026	*
V	1.234	1.788	0.69	0.506	
R*I	-0.222	1.788	-0.12	0.904	
R*F	3.491	1.788	1.95	0.079	
R*V	-1.234	1.788	-0.69	0.506	
I*F	1.484	1.788	0.83	0.426	
I*V	-1.091	1.788	-0.61	0.555	
F*V	0.697	1.788	0.39	0.705	
R*I*F	1.741	1.788	0.97	0.353	
R*I*V	-1.709	1.788	-0.96	0.362	
R*F*V	0.503	1.788	0.28	0.784	
I*F*V	0.697	1.788	0.39	0.705	
R*I*F*V	0.803	1.788	0.45	0.663	
CTR.PT	-4.097	4.499	-0.91	0.384	
CTR*F	-0.409	4.499	-0.09	0.929	

s = 8.257   R-sq = 91.3%   R-sq(adj) = 76.4%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	17	7130.96	419.47	6.15	0.003
Error	10	681.77	68.18		
Total	27	7812.73			

SOURCE	DF	SEQ SS
R	1	5900.07
I	1	122.85
F	1	472.32
V	1	51.52
R*I	1	0.05
R*F	1	242.57
R*V	1	23.13
I*F	1	48.84
I*V	1	25.25
F*V	1	1.28
R*I*F	1	82.35
R*I*V	1	71.03
R*F*V	1	5.27
I*F*V	1	13.87
R*I*F*V	1	13.45
CTR.PT	1	56.54
CTR*F	1	0.56

Unusual Observations

Obs.	R	E	Fit	Stdev.Fit	Residual	St.Resid
9	1.00	17.50	33.30	5.84	-15.80	-2.71R
25	1.00	49.10	33.30	5.84	15.80	2.71R

R denotes an obs. with a large st. resid.

ALPHA METALS

OMEGAMETER 600SMD

Static
Heated
Spray below immersion

OMEGAMETER 600SMD
RANDOMIZED EXPERIMENTAL MATRIX
"IN SOLUTION" TESTS

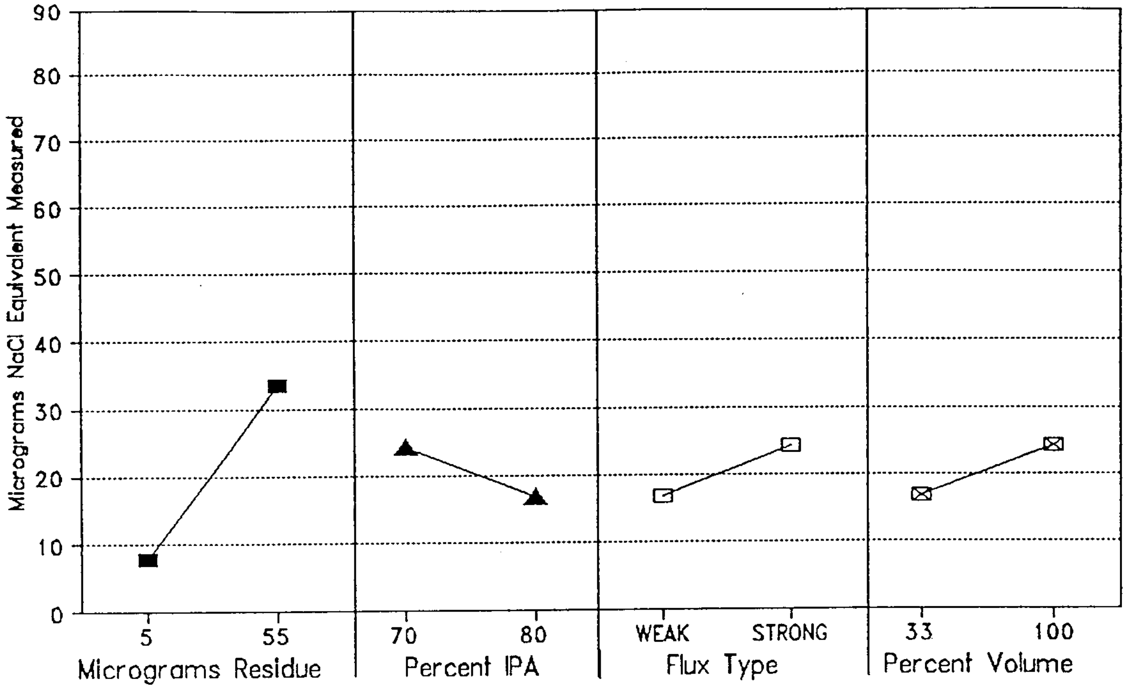
RANDOMIZED RUN SEQUENCE	STANDARD ORDER	A B C D	A AMOUNT OF RESIDUE (μGR/IN²)	B IPA (VOL%)	C TEST CELL VOLUME (% FULL)	D FLUX TYPE	IONIC READING	TEST DURATION	TEST CELL TEMP.
1	9	- - - +	5	70	33	STRONG	19.4	47:50	113°F
2	6	+ - + -	55	70	100	WEAK	41.1	9:10	112°F
3	10	+ - - +	55	70	33	STRONG	36.7	16:00	114°F
4	5	- - + -	5	70	100	WEAK	12.5	24:40	114°F
5	12	+ + + -	55	80	33	STRONG	32.7	11:30	114°F
6	4	+ + - -	55	80	33	WEAK	13.5	8:30	112°F
7	15	- + + +	5	80	100	STRONG	7.4	5:00	112°F
8	7	- + + -	5	80	100	WEAK	5.5	12:20	111°F
9		0 0 0 +	30	75	66	STRONG	27.1	5:30	111°F
10	19	0 0 0 0	30	75	66	NaCl	37.4	7:40	111°F
11		0 0 0 -	30	75	66	WEAK	18.5	4:10	111°F
12	17	0 0 0 0	30	75	66	NaCl	36.0	9:40	111°F
13		0 0 0 +	30	75	66	STRONG	24.7	7:00	110°F
14	18	0 0 0 0	30	75	66	NaCl	33.4	5:00	109°F
15		0 0 0 -	30	75	66	WEAK	19.8	5:00	110°F
16	13	- - + +	5	70	100	STRONG	11.5	37:40	113°F
17	2	+ - - -	55	70	33	WEAK	27.6	7:40	106°F
18	14	+ - + +	55	70	100	STRONG	46.3	7:00	110°F
19	1	- - - -	5	70	33	WEAK	2.0	6:50	109°F
20	11	- + - +	5	80	33	STRONG	4.8	5:00	110°F
21	16	+ + + +	55	80	100	STRONG	41.5	14:20	113°F
22	3	- + - -	5	80	33	WEAK	2.7	5:20	111°F
23	8	+ + + -	55	80	100	WEAK	22.9	5:40	112°F
24	9	- - - +	5	70	33	STRONG	6.7	4:10	105°F
25	6	+ - + -	55	70	100	WEAK	50.4	4:10	108°F
26	10	+ - - +	55	70	33	STRONG	35.1	16:40	110°F
27	5	- - + -	5	70	100	WEAK	11.0	28:30	113°F
28	12	+ + - +	55	80	33	STRONG	32.9	17:10	111°F
29	4	+ + - +	55	80	33	WEAK	16.4	4:10	110°F
30	15	- + + +	5	80	100	STRONG	9.4	18:30	112°F
31	7	- + + -	5	80	100	WEAK	6.0	6:20	112°F

TABLE OF EFFECTS
In Solution Testing

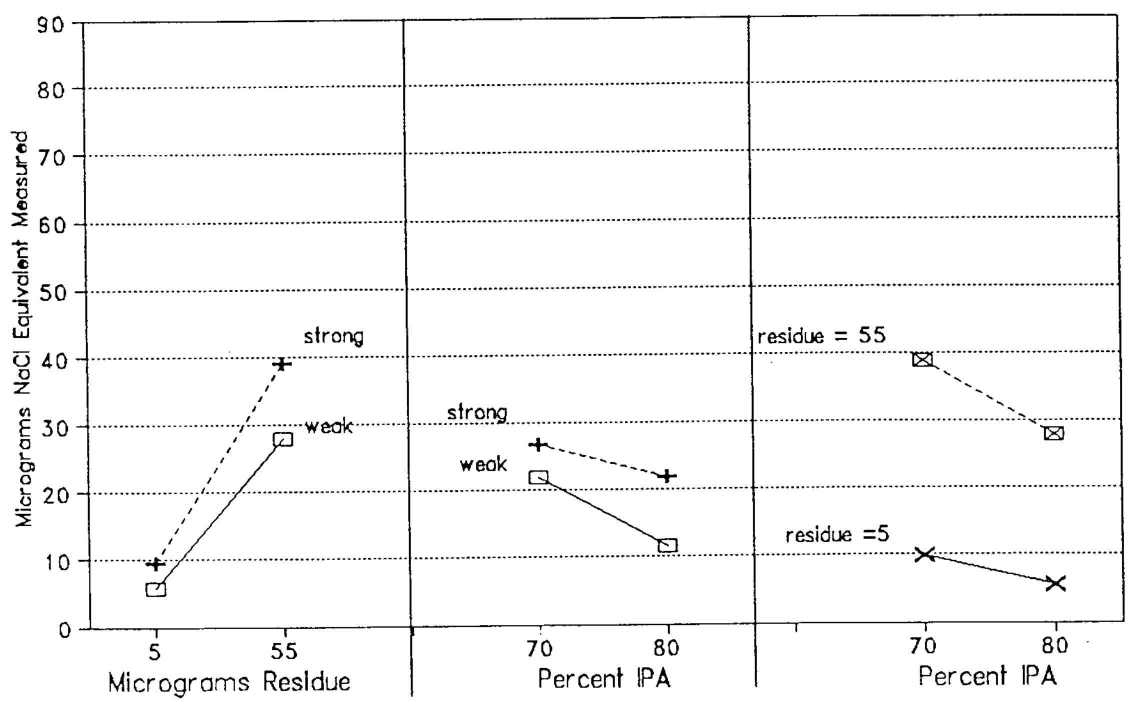
	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN RESPONSE	30.89*	27.20*	26.38*	7.00*	25.33*	20.53*	16.10*	17.98*	13.75*
MAIN EFFECTS									
Residue (R)	51.18*	46.58*	47.26*	11.10*	30.57*	25.91*	28.31*	24.56*	24.11*
IPA (I)	-20.33*	-22.84*	-22.29*	-1.40	-10.0*	-7.60*	-7.85*	-7.19*	-6.69*
Flux (F)	-1.55	-1.49	-9.88*	2.23	10.07*	7.51*	18.46*	19.37*	5.16*
Volume (V)					4.7*	7.45*	-1.01	3.61*	
INTERACTIONS									
R*I	-14.13*	-15.18*	-18.48*	-1.00	-2.35*	-3.29	-6.86*	-3.29*	-4.28*
R*F	0.65	0.70	-8.55*	2.63*	8.07*	3.78*	16.15*	16.47*	4.84*
R*V					1.55*	3.89*	0.72	6.56*	
I*F	11.00*	10.52*	10.28*	1.48	5.75*	2.79	1.63	0.74	2.42*
I*V					1.77*	-1.63	-0.04	-2.88*	
F*V					-0.85	-2.16	-1.60	5.24*	
R*I*F	8.00*	8.06*	8.83*	0.98	5.15*	4.15*	1.05	0.10	1.77
R*I*V					-0.52	-1.39	-1.05	-1.89*	
R*F*V					-1.0	0.38	-1.04	5.35*	
I*F*V					0.87	2.49	0.90	-2.65*	
R*I*F*V					0.12	-0.33	1.04	-2.22*	
CENTER POINT	1.74*	5.42	-0.64	4.48*	2.91	2.00	-0.15	2.22*	1.41

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

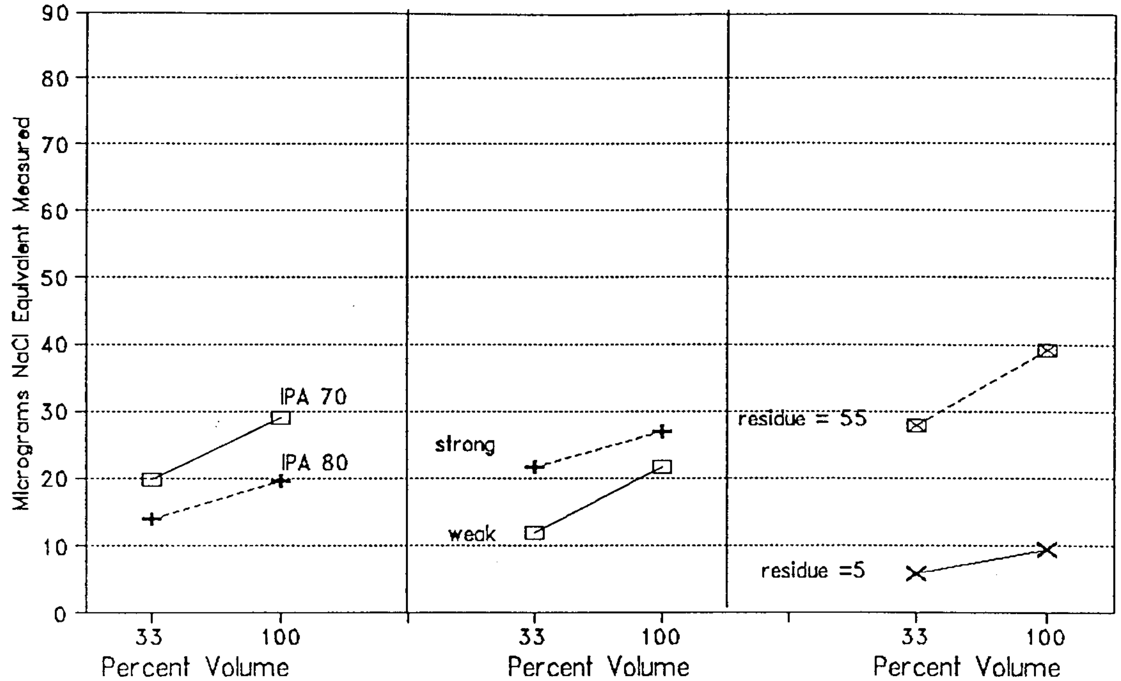
OMEGAMETER 600SMD
MAIN EFFECTS



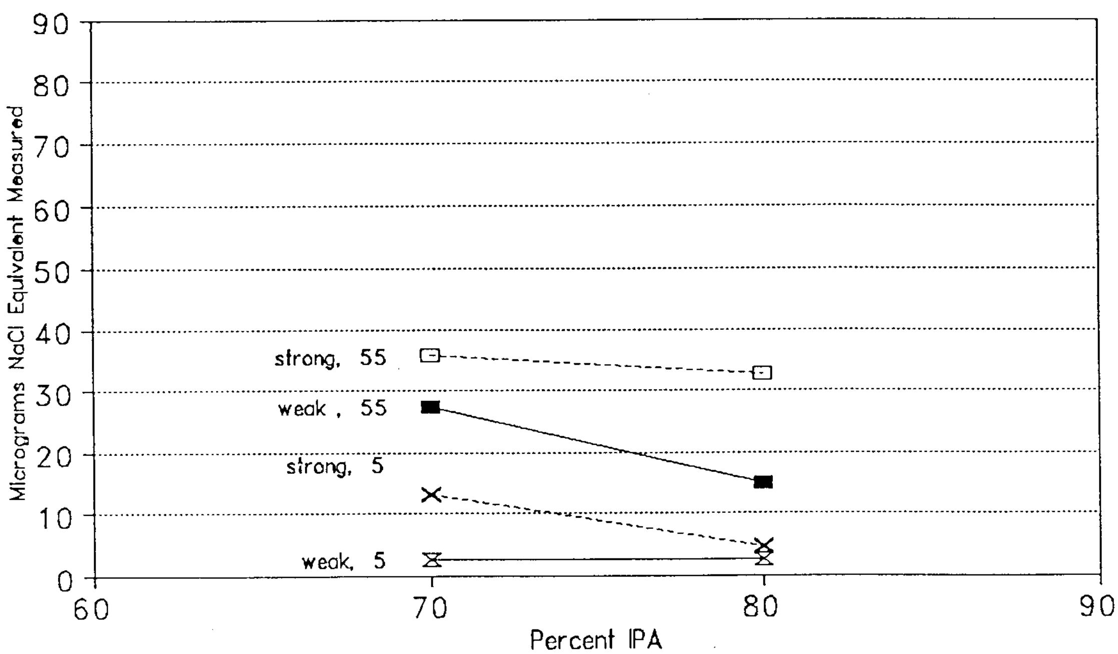
OMEGAMETER 600SMD
2-WAY INTERACTIONS (page 1)



OMEGAMETER 600SMD
2-WAY INTERACTIONS (page 2)



OMEGAMETER 600SMD
3-WAY INTERACTION



OMEGAMETER 600SMD
IN SOLUTION TEST

Predictor	Coef	Stdev	t-ratio	p	
Constant	20.5250	0.7914	25.93	0.000	*
R	12.9563	0.7914	16.37	0.000	*
I	-3.8000	0.7914	-4.80	0.000	*
F	3.7562	0.7914	4.75	0.000	*
V	3.7250	0.7914	4.71	0.000	*
R*I	-1.6438	0.7914	-2.08	0.065	
R*F	1.8875	0.7914	2.38	0.038	*
R*V	1.9438	0.7914	2.46	0.034	*
I*F	1.3938	0.7914	1.76	0.109	
I*V	-0.8125	0.7914	-1.03	0.329	
F*V	-1.0813	0.7914	-1.37	0.202	
R*I*F	2.0750	0.7914	2.62	0.026	*
R*I*V	-0.6938	0.7914	-0.88	0.401	
R*F*V	0.1875	0.7914	0.24	0.818	
I*F*V	1.2437	0.7914	1.57	0.147	
R*I*F*V	-0.1625	0.7914	-0.21	0.841	
CTR.PT	2.000	1.992	1.00	0.339	
CTR*F	-0.381	1.992	-0.19	0.852	

s = 3.655   R-sq = 97.5%   R-sq(adj) = 93.4%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	17	5304.38	312.02	23.35	0.000
Error	10	133.63	13.36		
Total	27	5438.00			

SOURCE	DF	SEQ SS
R	1	3697.68
I	1	463.76
F	1	260.47
V	1	409.54
R*I	1	45.99
R*F	1	48.45
R*V	1	124.54
I*F	1	54.21
I*V	1	13.80
F*V	1	42.46
R*I*F	1	88.85
R*I*V	1	8.95
R*F*V	1	0.67
I*F*V	1	30.40
R*I*F*V	1	0.64
CTR.PT	1	13.47
CTR*F	1	0.49

Unusual Observations

Obs.	R	F.	Fit	Stdev.Fit	Residual	St.Resid
4	-1.00	19.400	13.050	2.585	6.350	2.46R
24	-1.00	6.700	13.050	2.585	-6.350	-2.46R

R denotes an obs. with a large st. resid.

KESTER

IONEX 2000 (series 100)

Static
Unheated
Spray above immersion

IONEX 2000/100
RANDOMIZED EXPERIMENTAL MATRIX
"IN SOLUTION" TESTS

RANDOMIZED RUN SEQUENCE	STANDARD ORDER	A B C D	A AMOUNT OF RESIDUE (μGR/IN²)	B IPA (VOL%)	C TEST CELL VOLUME (% FULL)	D FLUX TYPE	IONIC READING	TEST DURATION	TEST CELL TEMP.
1	9	- - - +	5	70	100	WEAK	0.80	12:00	104°F
2	5	- - + -	5	70	33	STRONG	5.0	12:00	104°F
3	14	+ - + +	55	70	100	STRONG	48.7	12:00	103°F
4	13	- - + +	5	70	100	STRONG	1.2	12:00	103°F
5	2	+ - - -	55	70	33	WEAK	18.4	12:00	104°F
6	6	+ - + -	55	70	33	STRONG	53.5	12:00	104°F
7	1	- - - -	5	70	33	WEAK	2.5	12:00	105°F
8	10	+ - - +	55	70	100	WEAK	22.3	12:00	104°F
9		0 0 + 0	30	75	66	STRONG	23.5	12:00	106°F
10	18	0 0 0 0	30	75	66	NaCl	28.6	12:00	105°F
11		0 0 - 0	30	75	66	WEAK	8.0	12:00	105°F
12	17	0 0 0 0	30	75	66	NaCl	28.5	12:00	105°F
13		0 0 - 0	30	75	66	WEAK	7.5	12:00	105°F
14	19	0 0 0 0	30	75	66	NaCl	28.3	12:00	105°F
15		0 0 + 0	30	75	66	STRONG	24.8	12:00	104°F
16	11	- + - +	5	80	100	WEAK	0.0	12:00	103°F
17	7	- + + -	5	80	33	STRONG	3.6	12:00	104°F
18	8	+ + + -	55	80	33	STRONG	42.6	12:00	104°F
19	12	+ + - +	55	80	100	WEAK	3.9	12:00	103°F
20	15	- + + +	5	80	100	STRONG	2.2	12:00	104°F
21	4	+ + - -	55	80	33	WEAK	4.6	12:00	104°F
22	16	+ + + +	55	80	100	STRONG	40.5	12:00	103°F
23	3	- + - -	5	80	33	WEAK	0.0	12:00	104°F
24	9	- - - +	5	70	100	WEAK	0.0	12:00	106°F
25	5	- - + -	5	70	33	STRONG	4.8	12:00	106°F
26	14	+ - + +	55	70	100	STRONG	54.7	12:00	105°F
27	13	- - + +	5	70	100	STRONG	2.2	12:00	105°F
28	2	+ - - -	55	70	33	WEAK	19.5	12:00	106°F
29	6	+ - + -	55	70	33	STRONG	57.4	12:00	105°F
30	1	- - - -	5	70	33	WEAK	3.0	12:00	105°F
31	10	+ - - +	55	70	100	WEAK	26.4	12:00	105°F

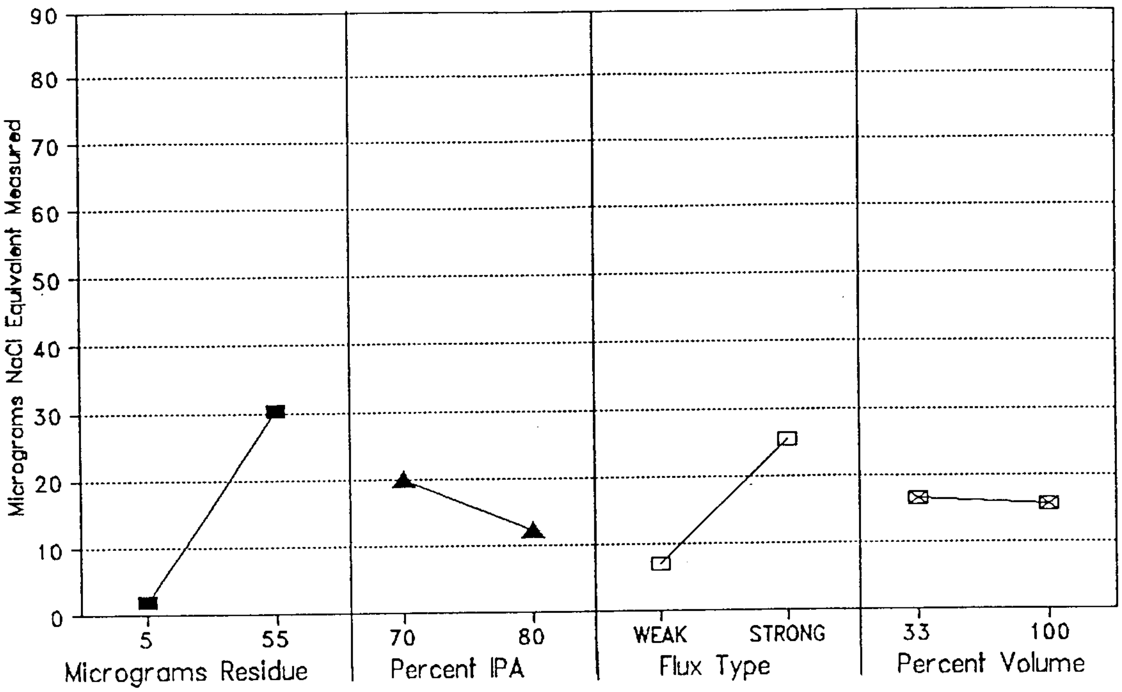
TABLE OF EFFECTS
In Solution Testing

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN RESPONSE	30.89*	27.20*	26.38*	7.00*	25.33*	20.53*	16.10*	17.98*	13.75*
MAIN EFFECTS									
Residue (R)	51.18*	46.58*	47.26*	11.10*	30.57*	25.91*	28.31*	24.56*	24.11*
IPA (I)	-20.33*	-22.84*	-22.29*	-1.40	-10.0*	-7.60*	-7.85*	-7.19*	-6.69*
Flux (F)	-1.55	-1.49	-9.88*	2.23	10.07*	7.51*	18.46*	19.37*	5.16*
Volume (V)					4.7*	7.45*	-1.01	3.61*	
INTERACTIONS									
R*I	-14.13*	-15.18*	-18.48*	-1.00	-2.35*	-3.29	-6.86*	-3.29*	-4.28*
R*F	0.65	0.70	-8.55*	2.63*	8.07*	3.78*	16.15*	16.47*	4.84*
R*V					1.55*	3.89*	0.72	6.56*	
I*F	11.00*	10.52*	10.28*	1.48	5.75*	2.79	1.63	0.74	2.42*
I*V					1.77*	-1.63	-0.04	-2.88*	
F*V					-0.85	-2.16	-1.60	5.24*	
R*I*F	8.00*	8.06*	8.83*	0.98	5.15*	4.15*	1.05	0.10	1.77
R*I*V					-0.52	-1.39	-1.05	-1.89*	
R*F*V					-1.0	0.38	-1.04	5.35*	
I*F*V					0.87	2.49	0.90	-2.65*	
R*I*F*V					0.12	-0.33	1.04	-2.22*	
CENTER POINT	1.74*	5.42	-0.64	4.48*	2.91	2.00	-0.15	2.22*	1.41

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

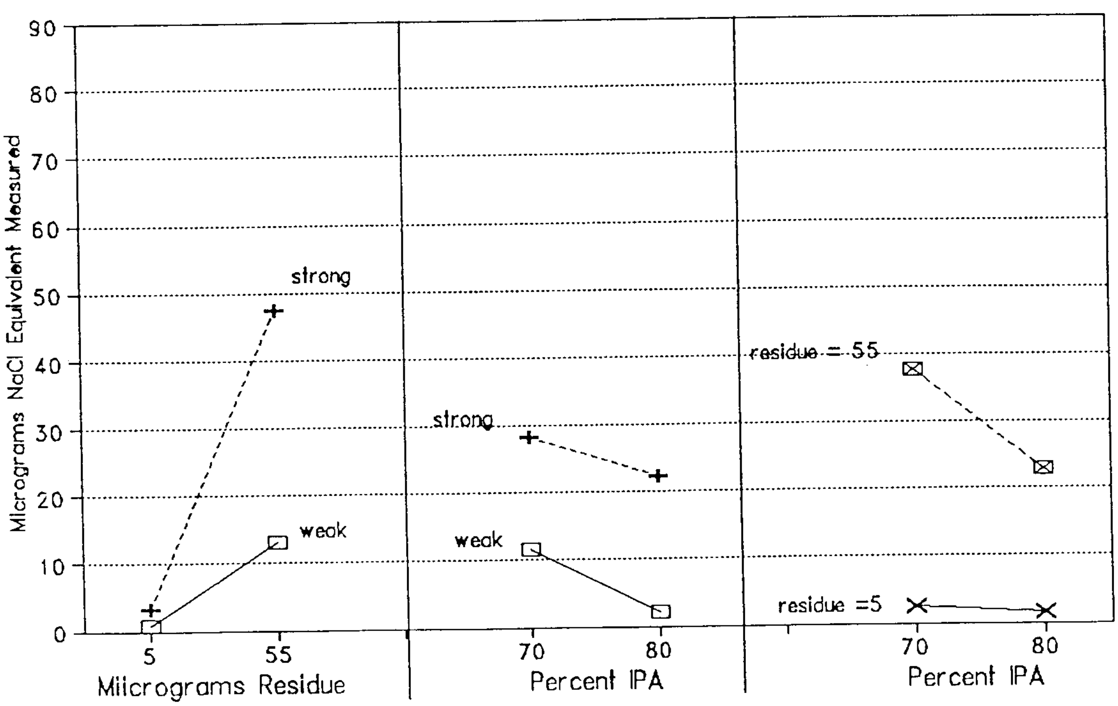
IONEX 2000

MAIN EFFECTS



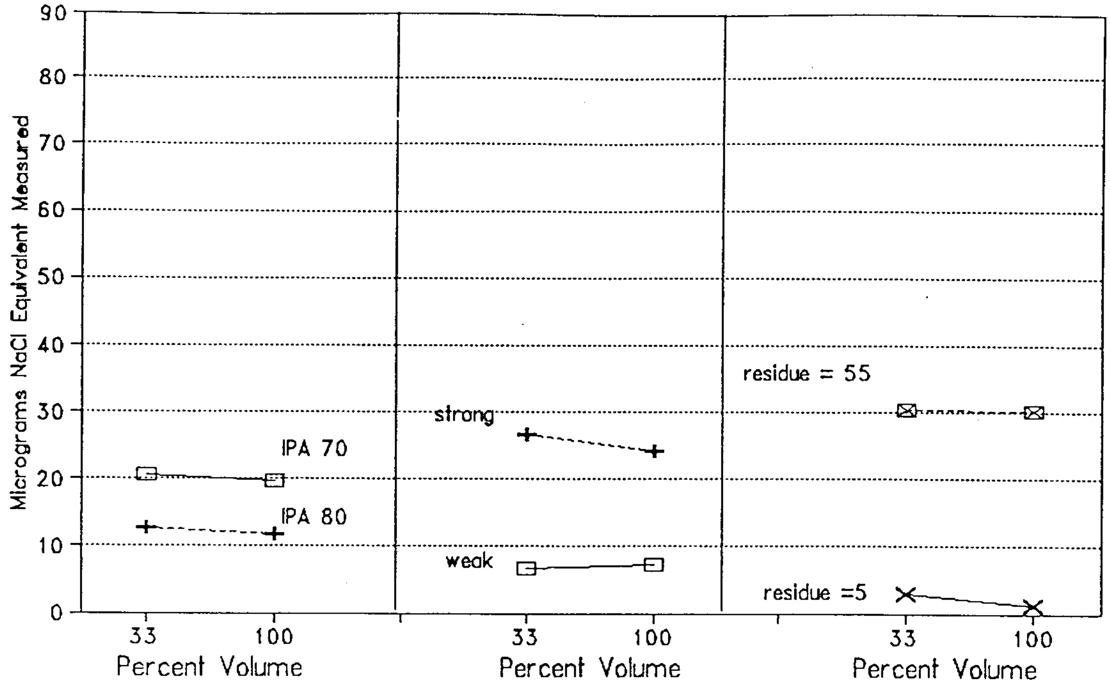
IONEX 2000

2-WAY INTERACTIONS (page 1)



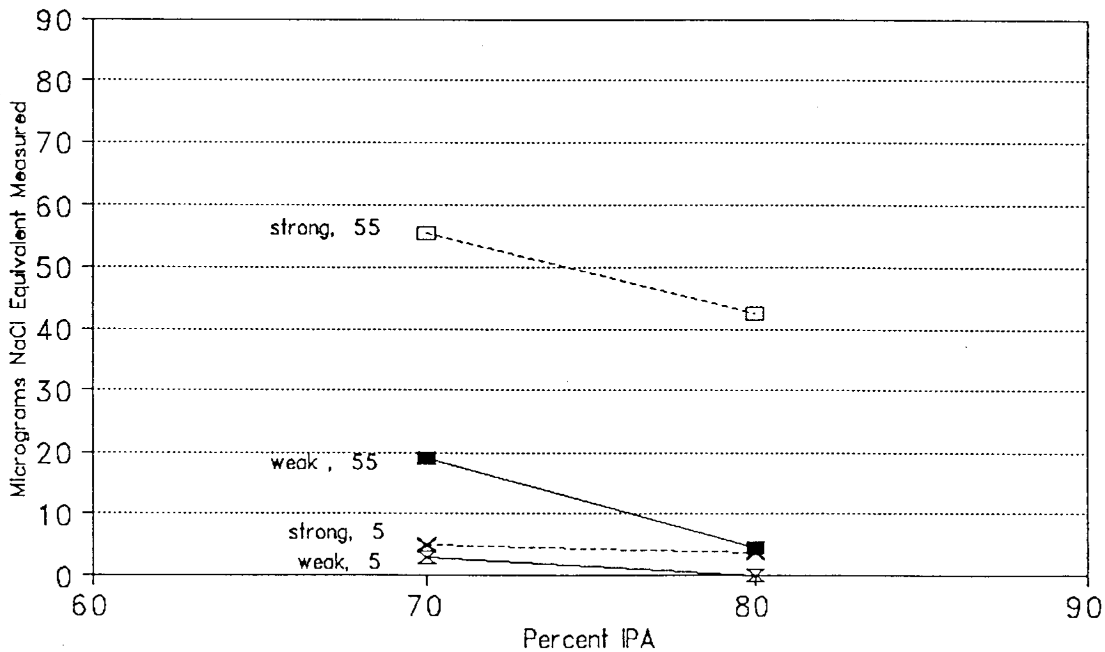
IONEX 2000

2-WAY INTERACTIONS (page 2)



IONEX 2000

3-WAY INTERACTION



IONEX 2000
IN SOLUTION TEST

Predictor	Coef	Stdev	t-ratio	p	
Constant	16.769	1.236	13.57	0.000	*
R	14.731	1.236	11.92	0.000	*
I	-2.475	1.236	-2.00	0.073	
F	8.881	1.236	7.19	0.000	*
V	-1.856	1.236	-1.50	0.164	
R*I	-1.888	1.236	-1.53	0.158	
R*F	7.944	1.236	6.43	0.000	*
R*V	-1.144	1.236	-0.93	0.376	
I*F	0.562	1.236	0.46	0.659	
I*V	-0.787	1.236	-0.64	0.538	
F*V	-0.644	1.236	-0.52	0.614	
R*I*F	0.050	1.236	0.04	0.969	
R*I*V	-1.150	1.236	-0.93	0.374	
R*F*V	-0.081	1.236	-0.07	0.949	
I*F*V	0.900	1.236	0.73	0.483	
R*I*F*V	0.687	1.236	0.56	0.590	
CTR.PT	-0.819	3.110	-0.26	0.798	
CTR*F	-0.681	3.110	-0.22	0.831	

s = 5.708 R-sq = 96.7% R-sq(adj) = 91.2%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	17	9691.50	570.09	17.50	0.000
Error	10	325.76	32.58		
Total	27	10017.26			

SOURCE	DF	SEQ SS
R	1	5618.16
I	1	132.54
F	1	2193.03
V	1	46.69
R*I	1	81.33
R*F	1	1497.84
R*V	1	28.74
I*F	1	8.23
I*V	1	12.77
F*V	1	10.53
R*I*F	1	0.19
R*I*V	1	29.61
R*F*V	1	0.20
I*F*V	1	18.20
R*I*F*V	1	9.61
CTR.PT	1	2.26
CTR*F	1	1.56

Unusual Observations

Obs.	R	G	Fit	Stdev.Fit	Residual	St.Resid
9	1.00	4.60	15.50	4.04	-10.90	-2.70R
25	1.00	26.40	15.50	4.04	10.90	2.70R

R denotes an obs. with a large st. resid.

WESTEK

ICOM 5000

Static
Heated or Unheated
Spray above immersion

ICOM 5000 RGS
RANDOMIZED EXPERIMENTAL MATRIX
"IN SOLUTION" TESTS

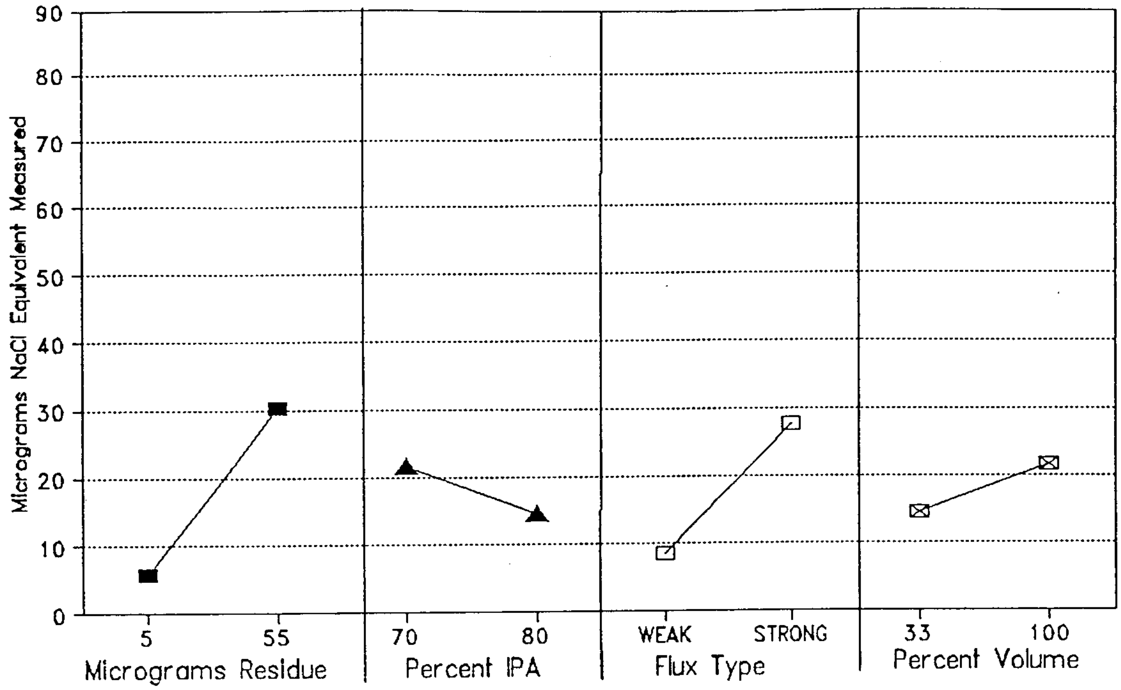
RANDOMIZED RUN SEQUENCE	STANDARD ORDER	A B C D	A AMOUNT OF RESIDUE (µGR/IN²)	B IPA (VOL%)	C TEST CELL VOLUME (ML/SQ IN.)	D FLUX TYPE	IONIC READING	TEST DURATION	TEST CELL TEMP.
1	5	- - + -	5	70	320	WEAK	6.80	15:00	78°F
2	10	+ - - +	55	70	160	STRONG	36.00	15:00	85°F
3	9	- - - +	5	70	160	STRONG	7.80	15:00	91°F
4	6	+ - + -	55	70	320	WEAK	18.79	15:00	94°F
5	7	- + + -	5	80	320	WEAK	2.05	15:00	73°F
6	15	- + + +	5	80	320	STRONG	5.09	15:00	83°F
7	4	+ + - -	55	80	160	WEAK	4.91	15:00	90°F
8	12	+ + - +	55	80	160	STRONG	36.00	15:00	83°F
9		0 0 0 -	30	75	160	WEAK	8.85	15:00	75°F
10	18	0 0 0 0	30	75	160	NaCl	27.37	15:00	84°F
11		0 0 0 +	30	75	160	STRONG	29.29	15:00	91°F
12	19	0 0 0 0	30	75	160	NaCl	34.02	15:00	96°F
13		0 0 0 +	30	75	160	STRONG	34.02	15:00	101°F
14	17	0 0 0 0	30	75	160	NaCl	34.02	15:00	103°F
15		0 0 0 -	30	75	160	WEAK	8.66	15:00	102°F
16	14	+ - + +	55	70	320	STRONG	70.00	15:00	87°F
17	2	+ - - -	55	70	160	WEAK	16.46	15:00	94°F
18	1	- - - -	5	70	160	WEAK	5.85	15:00	98°F
19	13	- - + +	5	70	320	STRONG	9.77	15:00	98°F
20	3	- + - -	5	80	160	WEAK	1.88	15:00	101°F
21	11	- + - +	5	80	160	STRONG	5.96	15:00	92°F
22	8	+ + + -	55	80	320	WEAK	8.32	15:00	97°F
23	16	+ + + +	55	80	320	STRONG	50.73	15:00	72°F
24	5	- - + -	5	70	320	WEAK	7.58	15:00	76°F
25	10	+ - - +	55	70	160	STRONG	36.00	15:00	85°F
26	9	- - - +	5	70	160	STRONG	7.80	15:00	91°F
27	6	+ - + -	55	70	320	WEAK	20.30	15:00	96°F
28	7	- + + -	5	80	320	WEAK	2.14	15:00	81°F
29	11	- + - +	5	80	320	STRONG	5.09	15:00	88°F
30	4	+ + - -	55	80	160	WEAK	5.16	15:00	95°F
31	12	+ + - +	55	80	160	STRONG	36.00	15:00	99°F

TABLE OF EFFECTS
In Solution Testing

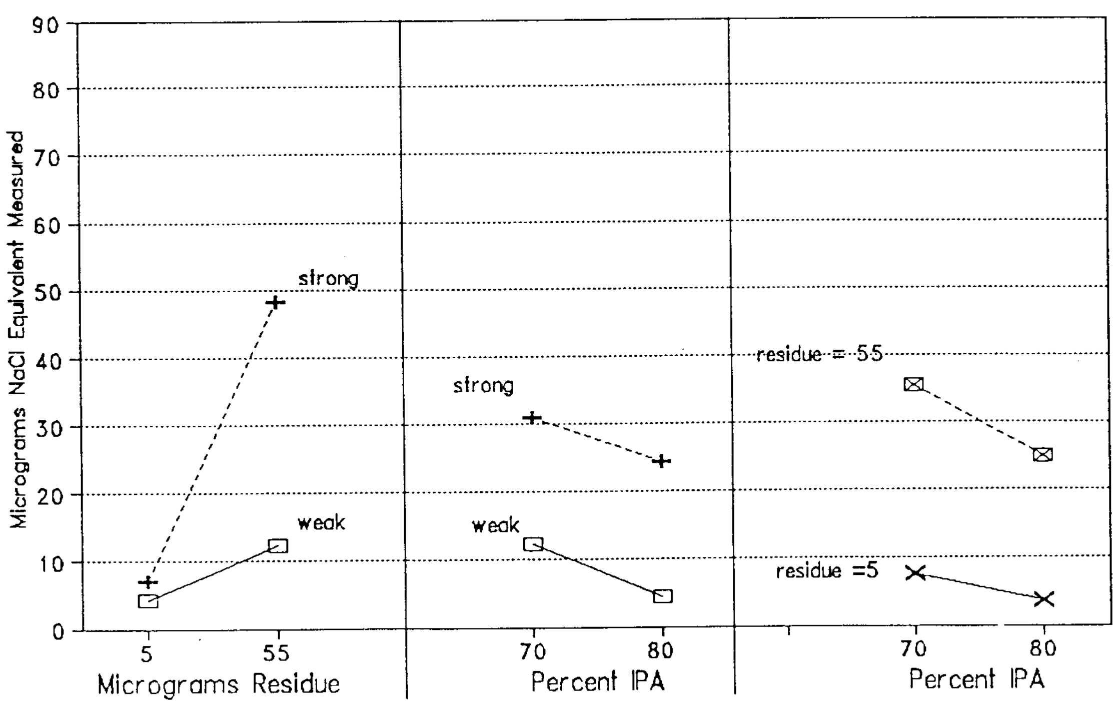
	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN RESPONSE	30.89*	27.20*	26.38*	7.00*	25.33*	20.53*	16.10*	17.98*	13.75*
MAIN EFFECTS									
Residue (R)	51.18*	46.58*	47.26*	11.10*	30.57*	25.91*	28.31*	24.56*	24.11*
IPA (I)	-20.33*	-22.84*	-22.29*	-1.40	-10.0*	-7.60*	-7.85*	-7.19*	-6.69*
Flux (F)	-1.55	-1.49	-9.88*	2.23	10.07*	7.51*	18.46*	19.37*	5.16*
Volume (V)					4.7*	7.45*	-1.01	3.61*	
INTERACTIONS									
R*I	-14.13*	-15.18*	-18.48*	-1.00	-2.35*	-3.29	-6.86*	-3.29*	-4.28*
R*F	0.65	0.70	-8.55*	2.63*	8.07*	3.78*	16.15*	16.47*	4.84*
R*V					1.55*	3.89*	0.72	6.56*	
I*F	11.00*	10.52*	10.28*	1.48	5.75*	2.79	1.63	0.74	2.42*
I*V					1.77*	-1.63	-0.04	-2.88*	
F*V					-0.85	-2.16	-1.60	5.24*	
R*I*F	8.00*	8.06*	8.83*	0.98	5.15*	4.15*	1.05	0.10	1.77
R*I*V					-0.52	-1.39	-1.05	-1.89*	
R*F*V					-1.0	0.38	-1.04	5.35*	
I*F*V					0.87	2.49	0.90	-2.65*	
R*I*F*V					0.12	-0.33	1.04	-2.22*	
CENTER POINT	1.74*	5.42	-0.64	4.48*	2.91	2.00	-0.15	2.22*	1.41

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

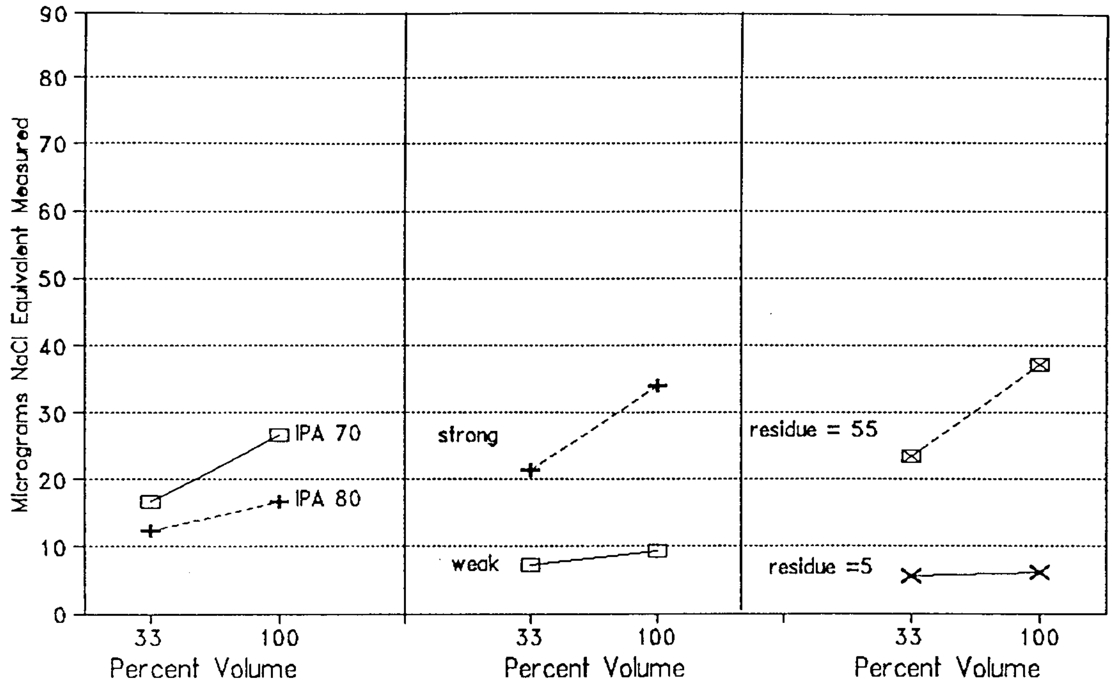
ICOM 5000
MAIN EFFECTS



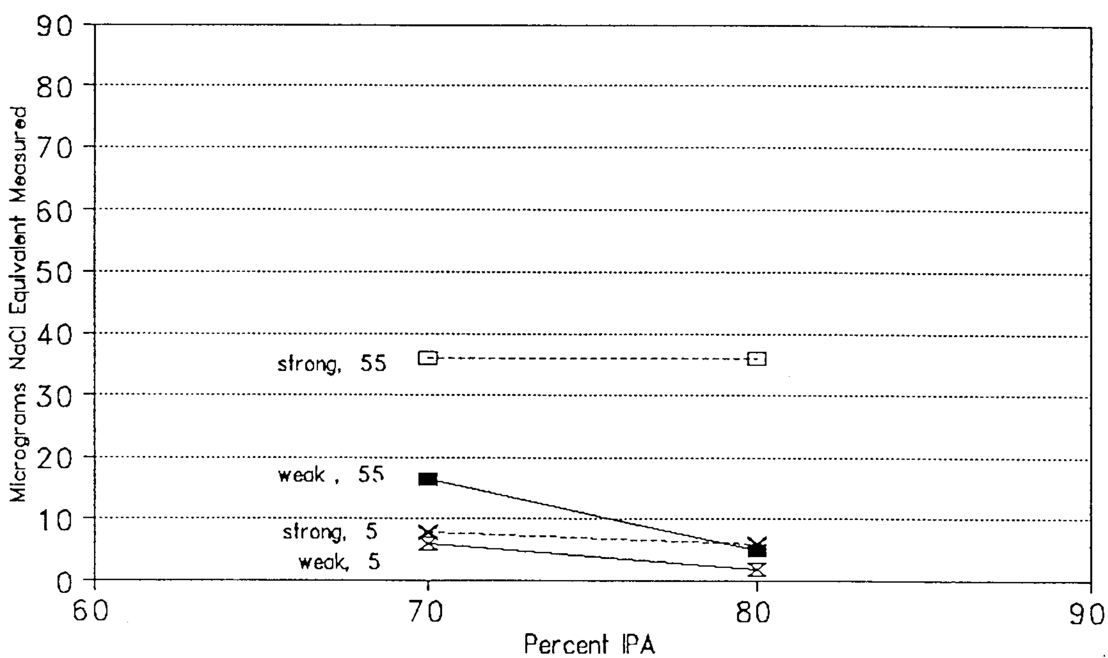
ICOM 5000
2-WAY INTERACTIONS (page 1)



ICOM 5000
2-WAY INTERACTIONS (page 2)



ICOM 5000
3-WAY INTERACTION



ICOM 5000
IN SOLUTION TEST

Predictor	Coef	Stdev	t-ratio	p	
Constant	17.9828	0.2438	73.75	0.000	*
R	12.2784	0.2438	50.36	0.000	*
I	-3.5941	0.2438	-14.74	0.000	*
F	9.6859	0.2438	39.72	0.000	*
V	3.6097	0.2438	14.80	0.000	*
R*I	-1.6459	0.2438	-6.75	0.000	*
R*F	8.2353	0.2438	33.77	0.000	*
R*V	3.2778	0.2438	13.44	0.000	*
I*F	0.3703	0.2438	1.52	0.160	
I*V	-1.4397	0.2438	-5.90	0.000	*
F*V	2.6191	0.2438	10.74	0.000	*
R*I*F	0.0522	0.2438	0.21	0.835	
R*I*V	-0.9441	0.2438	-3.87	0.003	*
R*F*V	2.6759	0.2438	10.97	0.000	*
I*F*V	-1.3241	0.2438	-5.43	0.000	*
R*I*F*V	-1.1097	0.2438	-4.55	0.000	*
CTR.PT	2.2222	0.6136	3.62	0.005	*
CTR*F	1.7641	0.6136	2.87	0.017	*

s = 1.126   R-sq = 99.8%   R-sq(adj) = 99.6%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	17	7943.42	467.26	368.38	0.000
Error	10	12.68	1.27		
Total	27	7956.10			

SOURCE	DF	SEQ SS
R	1	3056.88
I	1	265.47
F	1	2264.40
V	1	339.87
R*I	1	13.27
R*F	1	1284.51
R*V	1	247.53
I*F	1	2.68
I*V	1	47.79
F*V	1	149.70
R*I*F	1	4.18
R*I*V	1	16.57
R*F*V	1	158.26
I*F*V	1	40.96
R*I*F*V	1	24.22
CTR.PT	1	16.63
CTR*F	1	10.48

Unusual Observations

Obs.	R	H	Fit	Stdev.Fit	Residual	St.Resid
19	0.00	29.290	31.655	0.796	-2.365	-2.97R
20	0.00	34.020	31.655	0.796	2.365	2.97R

R denotes an obs. with a large st. resid.

PROTONIQUE

CONTAMINOMETER CM5 (static)

Static
Unheated
No spray

CONTAMINOMETER CM5/STATIC MODE
RANDOMIZED EXPERIMENTAL MATRIX
"IN SOLUTION" TESTS

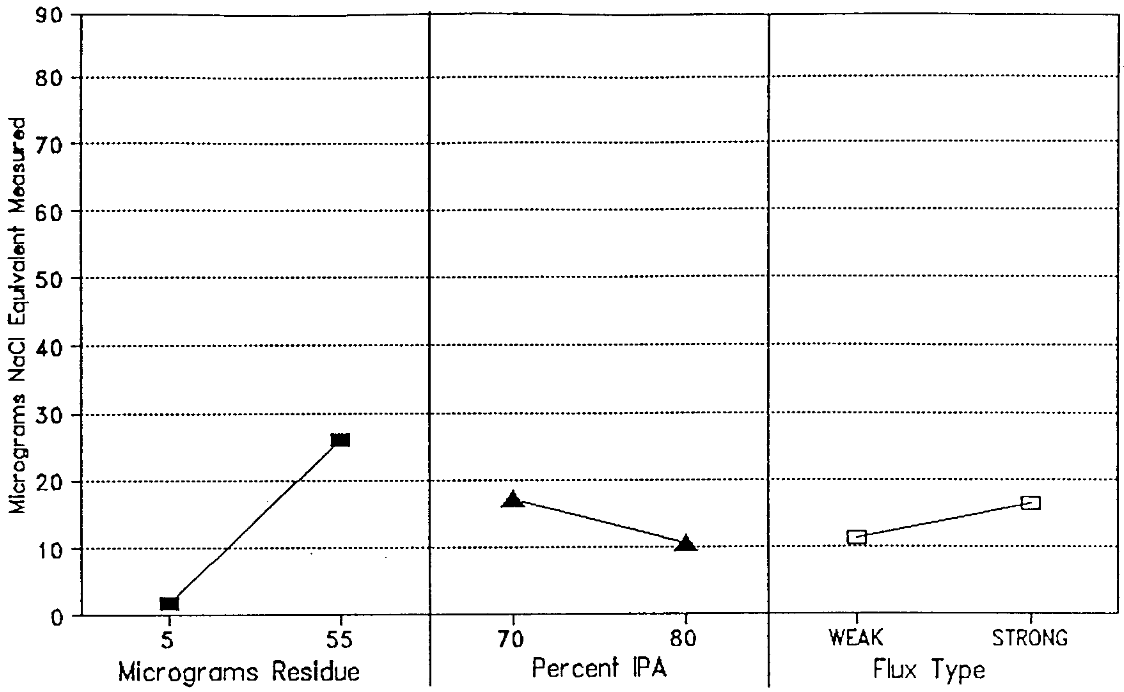
RANDOMIZED RUN SEQUENCE	STANDARD ORDER	A B C	A AMOUNT OF RESIDUE (μGR/IN²)	B IPA (VOL%)	C FLUX TYPE	IONIC READING	TEST DURATION	TEST CELL TEMP.
1	6	+ - +	55	70	STRONG	33.9	3:00	69°F
2	2	+ - -	55	70	WEAK	27.4	3:00	70°F
3	5	- - +	5	70	STRONG	2.6	3:00	71°F
4	1	- - -	5	70	WEAK	2.3	3:00	71°F
5		0 0 +	30	75	STRONG	15.5	3:00	70°F
6	9	0 0 0	30	75	NaCl	16.8	3:00	70°F
7		0 0 -	30	75	WEAK	13.2	3:00	71°F
8	10	0 0 0	30	75	NaCl	17.4	3:00	72°F
9		0 0 +	30	75	STRONG	19.0	3:00	72°F
10	11	0 0 0	30	75	NaCl	17.1	3:00	72°F
11		0 0 -	30	75	WEAK	12.9	3:00	73°F
12	7	- + +	5	80	STRONG	1.0	3:00	71°F
13	8	+ + +	55	80	WEAK	27.4	3:00	71°F
14	4	+ + -	55	80	STRONG	13.2	3:00	72°F
15	3	- + -	5	80	WEAK	0.0	3:00	72°F
16	6	+ - +	55	70	STRONG	34.5	3:00	72°F
17	2	+ - -	55	70	WEAK	29.3	3:00	73°F
18	5	- - +	5	70	WEAK	2.9	3:00	73°F
19	1	- - -	5	70	STRONG	3.9	3:00	73°F

TABLE OF EFFECTS
In Solution Testing

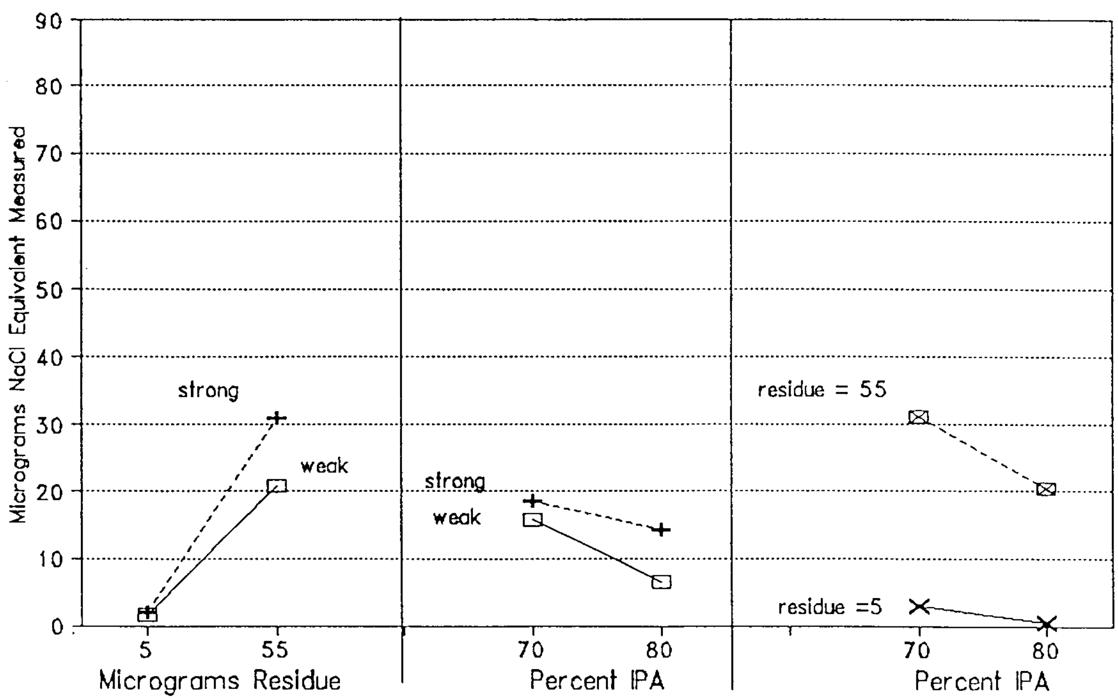
	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN RESPONSE	30.89*	27.20*	26.38*	7.00*	25.33*	20.53*	16.10*	17.98*	13.75*
MAIN EFFECTS									
Residue (R)	51.18*	46.58*	47.26*	11.10*	30.57*	25.91*	28.31*	24.56*	24.11*
IPA (I)	-20.33*	-22.84*	-22.29*	-1.40	-10.0*	-7.60*	-7.85*	-7.19*	-6.69*
Flux (F)	-1.55	-1.49	-9.88*	2.23	10.07*	7.51*	18.46*	19.37*	5.16*
Volume (V)					4.7*	7.45*	-1.01	3.61*	
INTERACTIONS									
R*I	-14.13*	-15.18*	-18.48*	-1.00	-2.35*	-3.29	-6.86*	-3.29*	-4.28*
R*F	0.65	0.70	-8.55*	2.63*	8.07*	3.78*	16.15*	16.47*	4.84*
R*V					1.55*	3.89*	0.72	6.56*	
I*F	11.00*	10.52*	10.28*	1.48	5.75*	2.79	1.63	0.74	2.42*
I*V					1.77*	-1.63	-0.04	-2.88*	
F*V					-0.85	-2.16	-1.60	5.24*	
R*I*F	8.00*	8.06*	8.83*	0.98	5.15*	4.15*	1.05	0.10	1.77
R*I*V					-0.52	-1.39	-1.05	-1.89*	
R*F*V					-1.0	0.38	-1.04	5.35*	
I*F*V					0.87	2.49	0.90	-2.65*	
R*I*F*V					0.12	-0.33	1.04	-2.22*	
CENTER POINT	1.74*	5.42	-0.64	4.48*	2.91	2.00	-0.15	2.22*	1.41

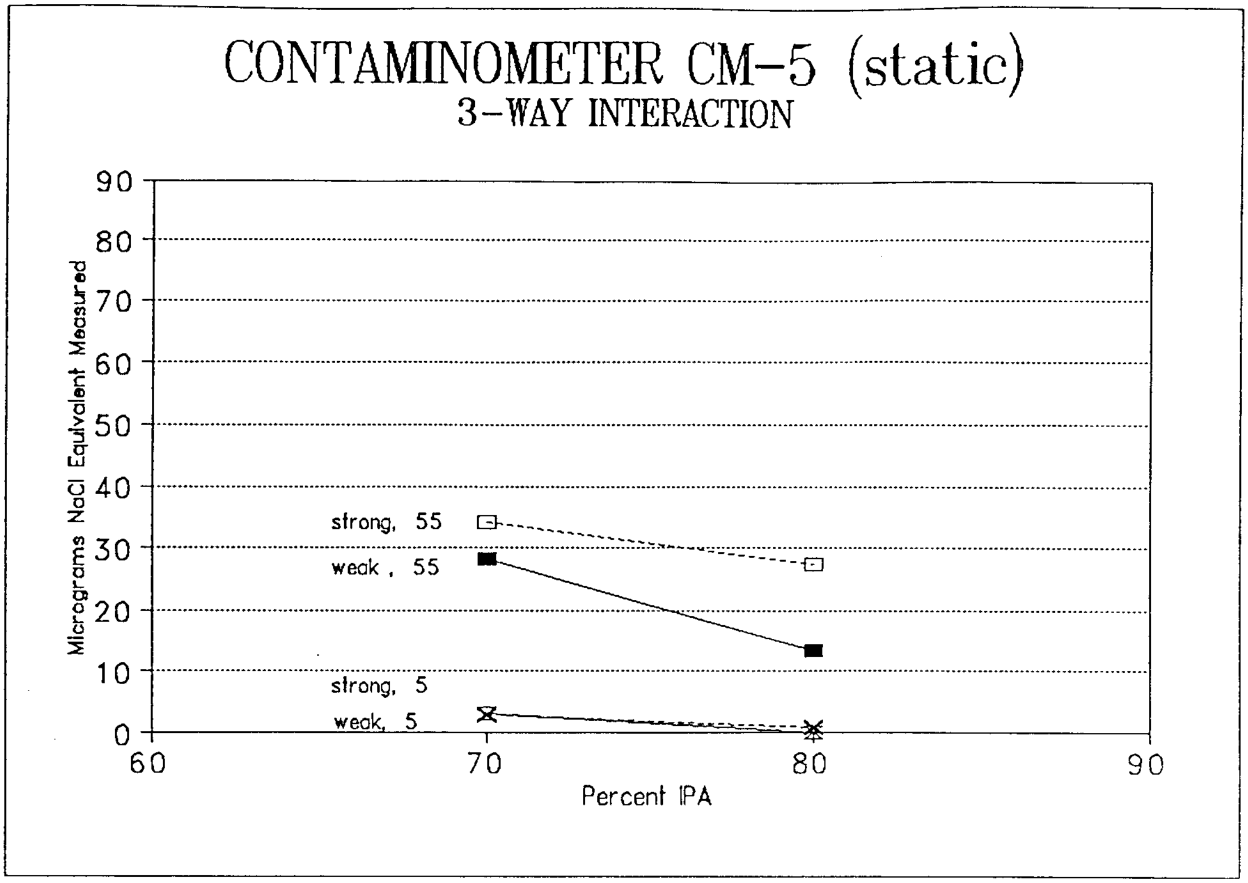
Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s). Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

CONTAMINOMETER CM-5 (static)
MAIN EFFECTS



CONTAMINOMETER CM-5 (static)
2-WAY INTERACTIONS





CONTAMINOMETER CM-5 (static)
3-WAY INTERACTION
Micrograms NaCl Equivalent Measured
Percent IPA
strong, 55
weak , 55
strong, 5
weak, 5
0
10
20
30
40
50
60
70
80
90
60
70
80
90

CONTAMINOMETER CM-5 (static)
IN SOLUTION TEST

Predictor	Coef	Stdev	t-ratio	p	
Constant	13.7463	0.3912	35.14	0.000	*
R	12.0525	0.3912	30.81	0.000	*
I	-3.3462	0.3912	-8.55	0.000	*
F	2.5800	0.3912	6.60	0.001	*
R*I	-2.1375	0.3912	-5.46	0.002	*
R*F	2.4187	0.3912	6.18	0.001	*
I*F	1.2100	0.3912	3.09	0.021	*
R*I*F	0.8863	0.3912	2.27	0.064	
CTR.PT	1.4113	0.7490	1.88	0.109	
CTR*F	-0.4825	0.7490	-0.64	0.543	

s = 1.278 R-sq = 99.6% R-sq(adj) = 98.9%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	9	2276.33	252.93	154.97	0.000
Error	6	9.79	1.63		
Total	15	2286.12			

SOURCE	DF	SEQ SS
R	1	1955.34
I	1	113.91
F	1	74.43
R*I	1	48.73
R*F	1	54.10
I*F	1	14.96
R*I*F	1	8.38
CTR.PT	1	5.79
CTR*F	1	0.68

STATIC VERSUS DYNAMIC

Though extreme care was taken to control all of the operating parameters during testing, the results still show a wide disparity between the systems. In general, however, all of the static systems displayed comparable results as a group, while all of the dynamic systems displayed similar results as a group.

There was a definite disagreement, or separation, between the dynamic family and the static family, particularly when measuring flux residues. Two theories were derived to explain this observation: The first theorized that the dynamic systems were measuring high due to the deionizing columns not removing the ions on the first pass, possibly allowing ions back into the test cell to be counted a second time. Thus, Theory 1 postulates why the results for the dynamic systems were so high. The second theory stated that if solvent resistivity controls the ability of flux constituents to ionize, and since static systems use a fixed volume of solvent that is not regenerated in the test mode, the ionizing ability of the process is limited. In other words, once the resistivity of the solvent is depleted, the solvent is not as aggressive and may not ionize material that was removed from the PWA. Theory 2 proposes that the lower numbers for the static systems were a result of the contamination not being completely ionized and therefore not measured. The dynamic systems, according to Theory 2, are constantly replacing the contaminated, low resistance solvent with clean, aggressive, high resistance solvent.

To check the first theory, two dynamic systems were placed next to each other and some "creative plumbing" was done. The two systems were mated together (see Figure 17) to perform a mutual check. Instead of sending the solvent from the System #1 deionizing columns back into the System #1 test cell, the solvent was diverted into the System #2 test cell so that it could be measured for ionic contamination. If ionic

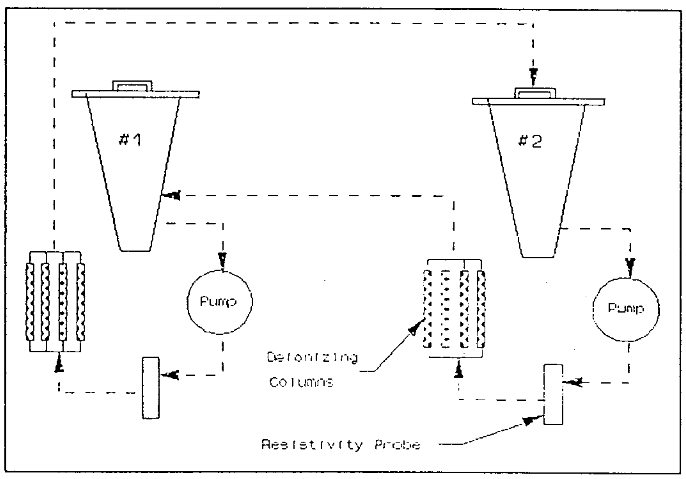


Figure 17 The Dynamic Check

contamination could be introduced into System #1, and some amount was also measured in System #2, then it would be known that ions were indeed escaping the columns and being measured twice.

The two systems were allowed to operate simultaneously for about one hour to allow all the 75% IPA/water to mix and the temperature to stabilize. Four runs were made, introducing weakly ionizable flux to System #1 twice and to System #2 twice. Results showed that less than 0.5 $\mu g/in^2$ was measured in System #1 when contamination was introduced into System #2, and no ions were measured in System #2 when contamination was introduced to System #1. This implies that the contamination was not being measured twice and that the columns in the dynamic systems had adequately removed ions from the solvent during testing.

To test the second theory, two static systems were randomly selected and set up to perform normal tests with 75% IPA/water. The test was set up so that 80, 40, 20, 10 and 5 microliter samples of weakly ionizable flux were added to a set volume of solvent. Theoretically, the ionic results should coincide with the volume of sample being injected. By doubling the volume of contaminant introduced to the test cells, the resulting ionic contamination measured should also double. This testing was also run on two dynamic systems to verify this theory, and also to verify the conclusions drawn in the previous test. The micrograms of ionic contamination versus the microliters of weak flux are given in Table 5 and plotted in Figure 18. There is no way of knowing how much NaCl equivalent is actually contained in 5 microliters of weak flux, but we do know that there is half as much NaCl equivalent in 5 microliters as there is in 10 microliters, and there is half as much NaCl equivalent in 10 microliters as there is in 20 microliters, and so on. Since the results for all four systems were closest and the experimental error smallest at 5 microliters, the average was taken and used as an *"expected"* result. If we assume that 5 microliters of weakly ionizable flux equals 5.87 (+/- 1.5) micrograms of NaCl equivalent, then

TABLE 5
FLUX VOLUME VS IONIC RESULTS

μliters	5	10	20	40	80
Static #1	5.30	8.20	14.90	27.00	49.10
Static #2	6.40	10.20	16.70	28.50	48.20
"Expected"	5.87	11.74	23.48	46.96	93.92
Dynamic #1	4.54	11.88	24.97	49.63	89.34
Dynamic #2	7.25	12.14	24.94	48.12	100.3

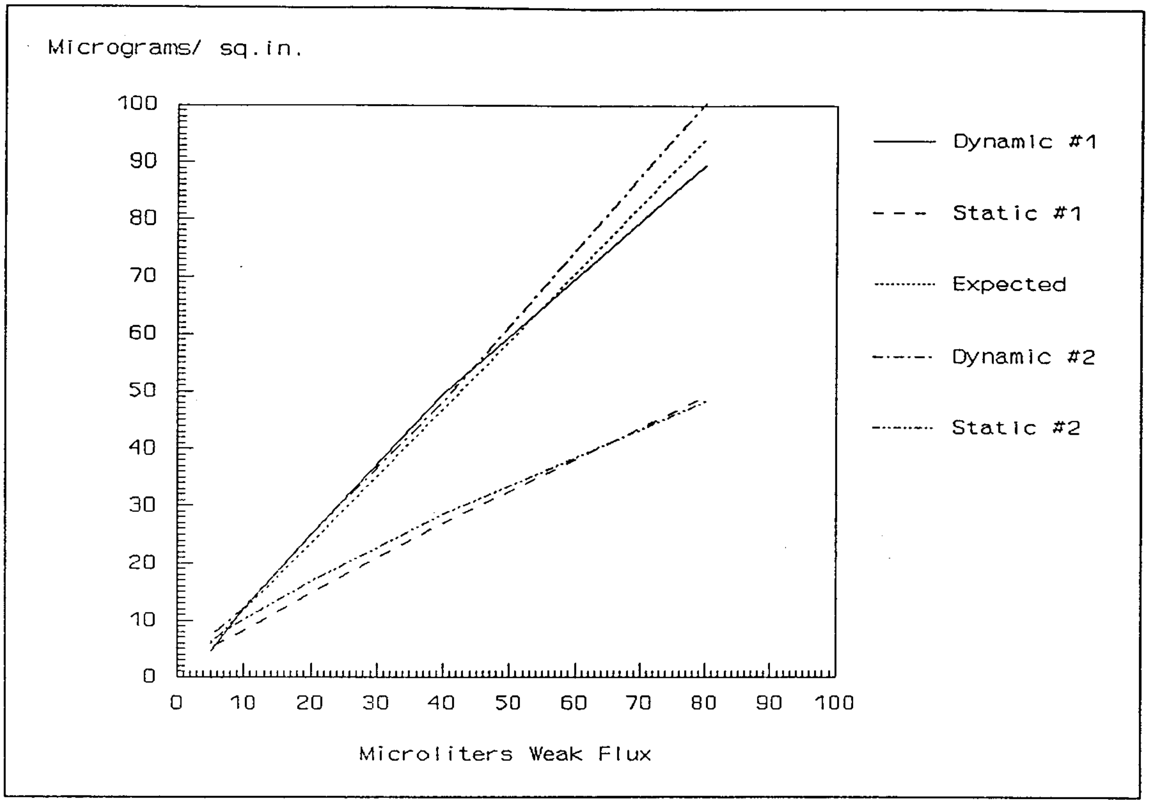


Figure 18 Ionic Results vs Flux Volume

10 microliters of flux *should* equal 11.74 micrograms NaCl equivalent, 20 microliters of flux *should* equal 23.48 micrograms NaCl, etc. If this average is a true representative of 5 microliters, then it could be seen that the data for the dynamic systems was consistent with what was expected. The results for the static systems, however, were not as high as expected. It appears that the ability to ionize contamination may be hampered by the fixed volume associated with the static process.

BOARD AND COVER PLATE TEST RESULTS

TEST COUPON GENERAL TRENDS AND OBSERVATIONS

In the dynamic mode, the Contaminometer CM-5 exhibited behavior outside that of all other dynamic systems and is not included in the discussions or conclusions in this report. After the data was analyzed and made available to Protonique, it was realized that an inappropriate model was sent to the EMPF for this study. The model delivered was engineered for larger (greater than 45 in^2) surface areas and was not sensitive enough for the small surface area that the test program required. Protonique requested that a more concentrated flux be used along with a larger surface area that equated to the same 55, 30 and 5 $\mu g/in^2$. The ICTG, however, decided that the test program could not be modified for one system without compromising the statistical design of the test. Time did not allow Protonique the opportunity to provide a different model more suited to our test needs.

One of the first observations made was with the measurements taken at 30 $\mu g/in^2$ that were supposed to be the center points of the "main effects" graphs. When the raw data and the graphs were examined, the data of the center points were much higher than expected. Unfortunately, this observation was not made until most, if not all, of the laboratory work was complete. An investigation was made comparing the three existing flux dilutions along with three fresh flux dilutions. The Ionograph 500M was randomly selected to conduct the test. The system was run at 80% alcohol (because that was what was in the system at the time) and the standards were run. Results demonstrated that the 5 $\mu g/in^2$, old versus new standards were similar and the 55 $\mu g/in^2$, old versus new were similar. The 30 $\mu g/in^2$ samples, however, were very different. The average measurement for the old flux was 32.45 $\mu g/in^2$, and the new flux dilution was only 12.65 $\mu g/in^2$.

Additional testing was performed using the Ionograph 500M using three different alcohol concentrations and three fresh flux dilutions. Both "in solution" and baked coupon testing were executed, and again the new dilutions were in line with what would be expected, indicating the 30 $\mu g/in^2$ flux used during coupon testing was either contaminated or diluted incorrectly.

In comparing the weakly ionizable flux to the strongly ionizable flux during "in solution" testing, three out of the four dynamic systems showed the variable to be insignificant, while the remaining dynamic and all of the static systems showed that the variable was significant. Though the weakly ionizable and strongly ionizable fluxes appeared to be different from each other, the trends that occurred when altering other variables were similar. As mentioned earlier in this document, however, once the strongly ionizable fluxes were introduced to the test coupons and baked, a wide variance in the data began to appear. Because of the wide variances and the similarities in response to weakly ionizable flux when other variables were altered, it was decided by the ICTG not to perform extensive testing on the strongly ionizable flux.

Since only the weakly ionizable flux was used in this portion of the test, the "in solution" table of effects was recalculated, omitting the strong flux data. The weakly ionizable "in solution" data could then be inserted into the individual system graphs for an easy comparison with the test coupon data. The omission of the strong flux data did not change any of the trends noted earlier.

Weakly ionizable flux was applied to the test boards and processed as per the procedure outlined in this document. The residues were made from the same stock solution used in the "in solution" testing; however, fresh dilutions were made for this portion of the test. The ionic results from all of the systems are plotted on common graphs (ALL SYSTEMS) on the next few pages so that trends can be more easily detected. The top graphs (BOARD TEST w/Blocks) represent measurements that were taken from the test coupon while the standoff cover plate was still in place. The cover plates were then removed and both the cover plate and the test board were tested for additional residue. The "before" and "after" were added together to get a total, which can be seen on the bottom graph (BOARD TEST Total).

Again, the most significant variable that effected the final results was the residue quantity. The change in residue was noticed in the dynamic systems more than the static systems and the separation of the dynamic family versus the static family continued.

The IPA effect was the next most significant, with the same downward trend noted as the alcohol content shifted from 70% to 80%. The dynamic systems were more affected than the static systems and the Ionograph 500M seemed to be particularly effected at 80% IPA. These readings were questioned at the time of testing, but a repeat of the run yielded the same results.

The graphs plotting the standoff effect can be used to compare residue removed from under a 3 mil standoff versus residue removed from under a 9 mil standoff. They also compare residues measured before versus after removal of the cover plate. Surprisingly, the channel depth did not have as big of an effect as anticipated. Examining the graph, we see that the 3 mil lines are close to being parallel to the 9 mil lines, indicating the static systems were equally effective at removing contamination from under both standoffs. If the two lines were perfectly horizontal, this would indicate 100% removal of the residue prior to the cover plate being removed. The slope of the lines, however, indicates that there was some residue being left under both standoff heights.

Standoff height seemed to affect the dynamic systems more than the static systems. Where the 3 mil versus 9 mil lines were nearly parallel for the static systems, the dynamic data sloped differently. The 9 mil lines were more horizontal, meaning most of the residue was removed and measured prior to the plate removal. The 3 mil lines are more sloped, indicating more residue was detected under the 3 mil standoff after the plate was removed. This observance is supported by comparing the residue graphs "board w/blocks" versus "board total". The "total" graph shows that when all residue was measured, all dynamic systems read similar. Examining the "board w/block" graph shows that the Ionograph 500M was most effected. Statistically, the only system that measured the channel depth as being significant was the Ionograph 500M.

The volume effect was perhaps the most unusual observation made in this study. When the volume was increased during the "in solution" testing, the results also tended to increase. But for some reason, when the volume was increased during the board testing, the ionic results tended to drop. This trend was noted on most of the systems, although most significant with the Omegameter 600SMD. At this point, there is no explanation for this observance.

Only the Omegameter 600SMD and the Icom 5000 were capable of testing in either the "heat on" or "heat off" modes. Though statistically temperature was significant only on the Omegameter 600SMD, both systems showed higher results when the heat was on. The data also showed that the heat influenced the 3 mil standoff more than the 9 mil standoff.

TABLE OF EFFECTS
In Solution (Weak Flux Only)

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN RESPONSE	31.66	27.58*	31.32*	5.89*	20.30*	16.10*	6.87*	8.30*	11.17*
MAIN EFFECTS									
Residue (R)	50.53*	47.98*	55.80*	8.48*	22.50*	22.14*	12.16*	8.09*	19.27*
IPA (I)	-31.33*	-32.63*	-32.57*	-2.88	-15.80*	-10.39*	-9.49*	-7.93*	-9.11*
Volume (V)					5.55*	9.61*	0.59	1.98*	
INTERACTIONS									
R*I	-22.13*	-26.34*	-27.31*	-1.98	-7.50*	-7.44*	-7.91*	-3.40*	-6.05*
R*V					2.77*	3.51	1.76x	1.20*	
I*V					-2.65*	-4.11x	-0.94	-0.23	
R*I*V						-1.06	-2.11x	0.33	
CENTER POINT	4.94*	5.89	0.53	6.41*	2.15*	2.38	0.88	0.46	1.89

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

TABLE OF EFFECTS (Board Tests with Blocks)

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	32.59*	18.77*	27.21*	3.81*	15.33*	14.68*	10.73*	12.81*	9.29*
MAIN EFFECTS									
Residue (R)	50.88*	24.01*	37.81*	5.26*	12.28*	16.60*	10.19*	7.21*	11.83*
IPA (I)	-21.88*	-35.43*	-26.69*	-1.41	-20.51*	-11.30*		-4.39*	2.38
Volume (V)					-2.17	-4.63*	-0.93	3.18*	
Channel (C)	5.12	10.27*	0.12	1.11	1.89	0.88	0.05	-1.99	-1.05
Heat (H)						6.94*		2.12	
INTERACTION									
R*I	-17.27*	-22.08*	-20.52*	-1.96	-6.18*	-4.69*	-4.99*	-1.37	0.13
R*V					-3.92x	0.81	0.13	-0.49	
R*C	1.28	7.14	0.16	0.26	0.24	-3.16*	0.13	0.06	0.85
R*H						3.10*		1.86	
I*V					-7.98*	-3.39*	-0.48	1.54	
I*C	1.68	-8.29	-1.70	0.69	1.26	0.64	1.55	-0.89	-3.20
I*H						-0.30		2.88x	
V*C					0.29	1.19	-0.81	1.48	
V*H						1.28	0.13	-1.60	
C*H						-3.73*		-1.82	
R*I*V					-2.18		0.33		
R*I*C	3.83	-5.34	4.44	0.24	-1.14		0.34		0.10
R*V*C					1.92		0.56		
I*V*C					-3.44x		-0.74		
CENTER	53.68*	48.85*	6.48	2.36	16.11*	-0.05	10.00*	1.13	2.45

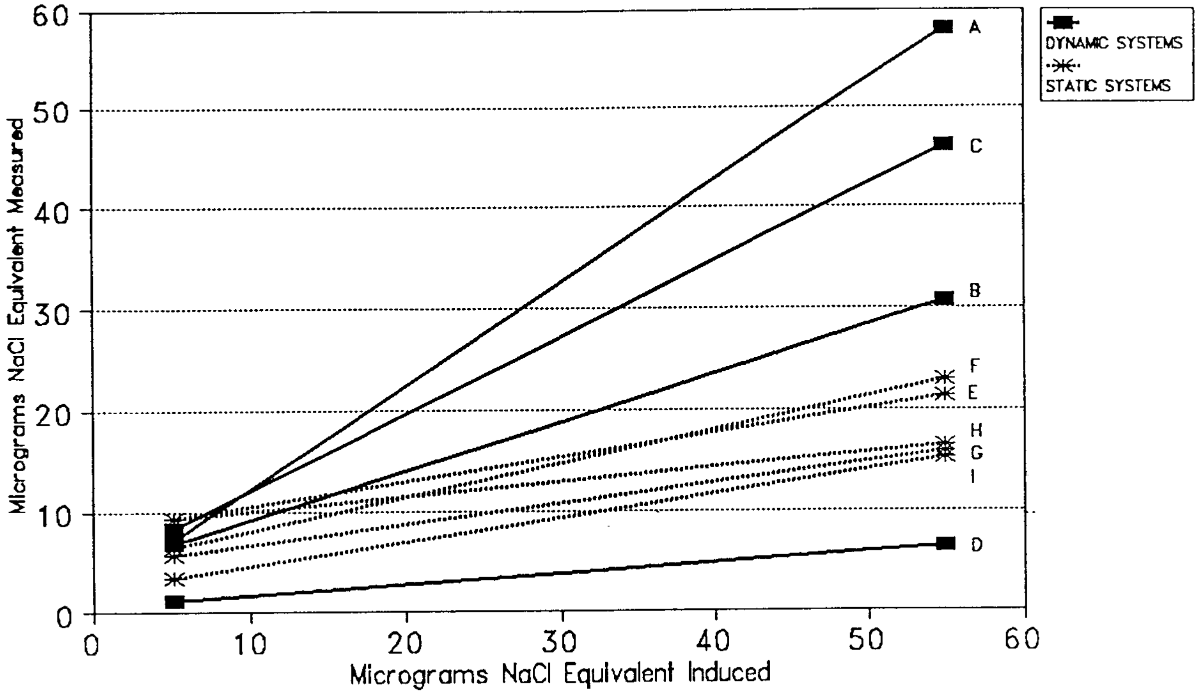
Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

TABLE OF EFFECTS (Board Tests: Total)

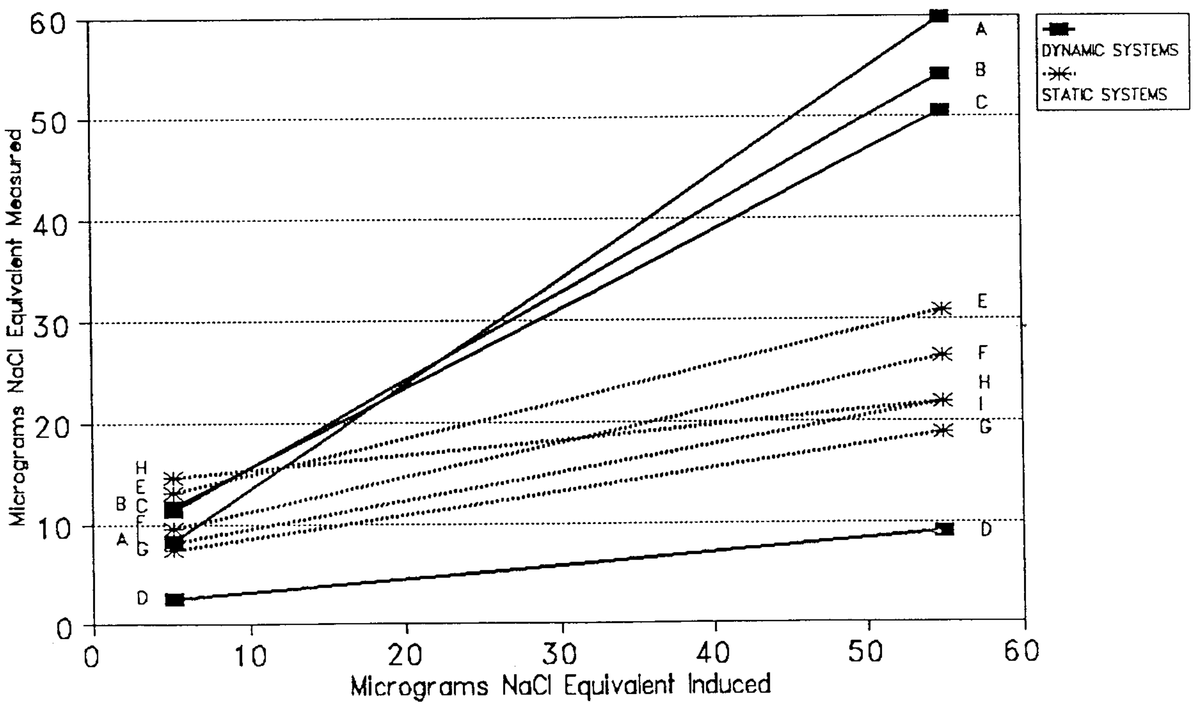
	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	34.01*	32.66*	31.03*	5.68*	22.01*	17.93*	13.14*	18.27*	15.06*
MAIN									
Residue (R)	51.55*	42.86*	38.89*	6.59*	17.82*	17.01*	11.33*	7.33*	13.66*
IPA (I)	-23.88*	-42.32*	-31.83*	-0.61	-27.52*	-14.33*		-4.79*	6.29x
Volume (V)					-1.23	-10.13*	-2.23	3.88	
Channel (C)	2.88	-1.90	-2.79	0.49	-0.37	0.69	0.12	-1.00	-4.49
Heat (H)						6.69*		1.61	
INTERACTION									
R*I	-18.80*	-23.04*	-20.27*	-1.54	-6.37x	-4.13*	-5.68*	-2.46	-3.66
R*V					-2.48	0.07	-0.01	-0.35	
R*C	0.00	-3.50	-0.30	-0.44	-1.09	-3.11x	-0.81	-1.21	4.51
R*H						3.14x		2.72	
I*V					-6.72x	-1.34	0.98	1.78	
I*C	3.38	-6.65	0.06	0.26	-0.03	0.43	1.63	-0.58	-2.31
I*H						0.13		4.85	
V*C					1.56	1.53	-1.54	2.20	
V*H						1.03		-3.12	
C*H						-3.94*		-2.53	
R*I*V					-2.42		1.96		
R*I*C	4.77	-3.11	3.99	-0.31	-2.36		-0.24		6.09x
R*V*C					3.58		0.36		
I*V*C					-4.41		-0.11		
CENTER	53.69*	47.23*	5.84	1.79	9.72x	1.53	8.26*	0.15	1.48

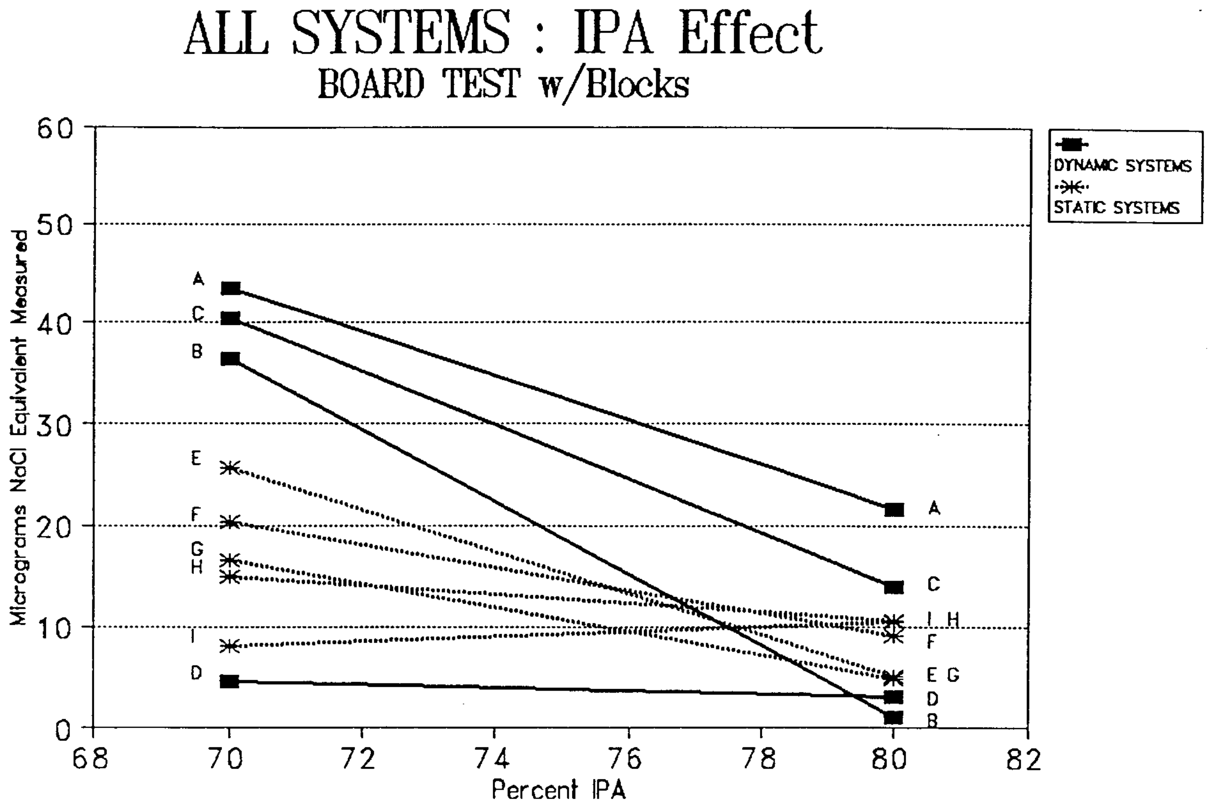
Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

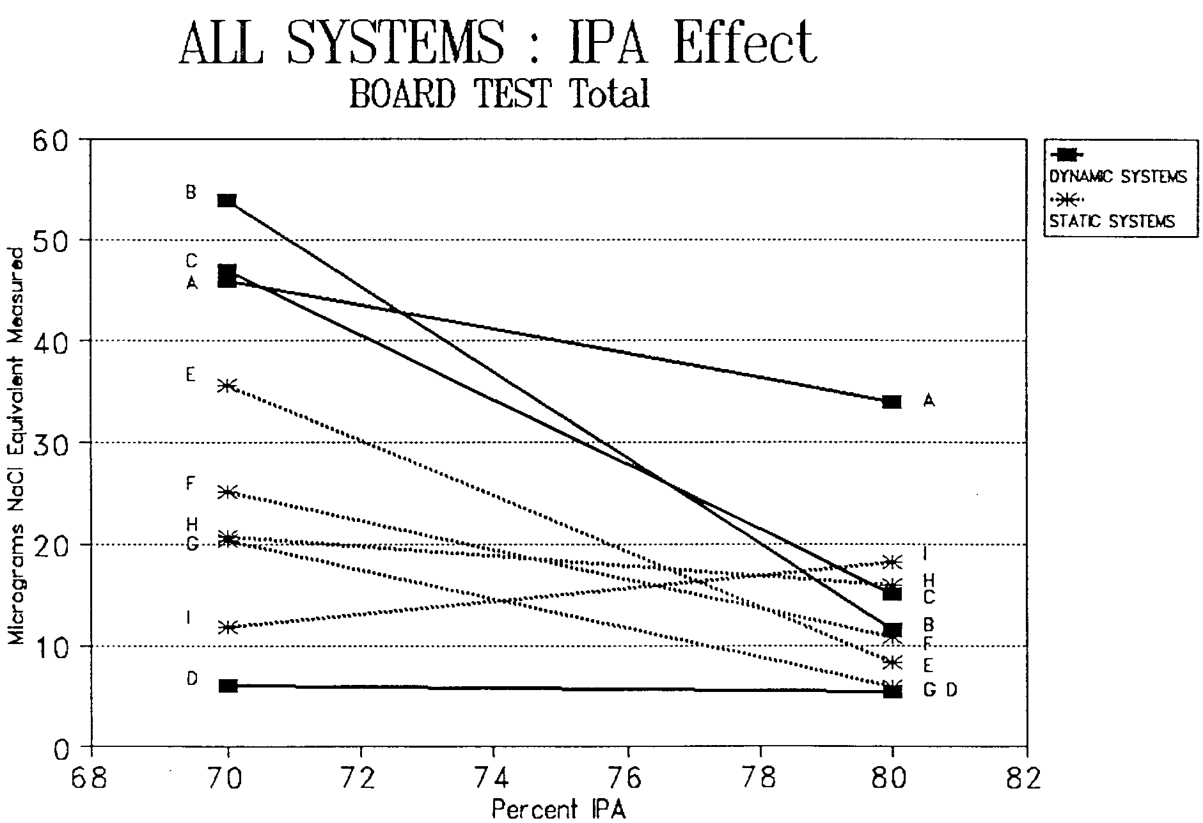
ALL SYSTEMS : Residue Effect
BOARD TEST w/Blocks



ALL SYSTEMS : Residue Effect
BOARD TEST Total

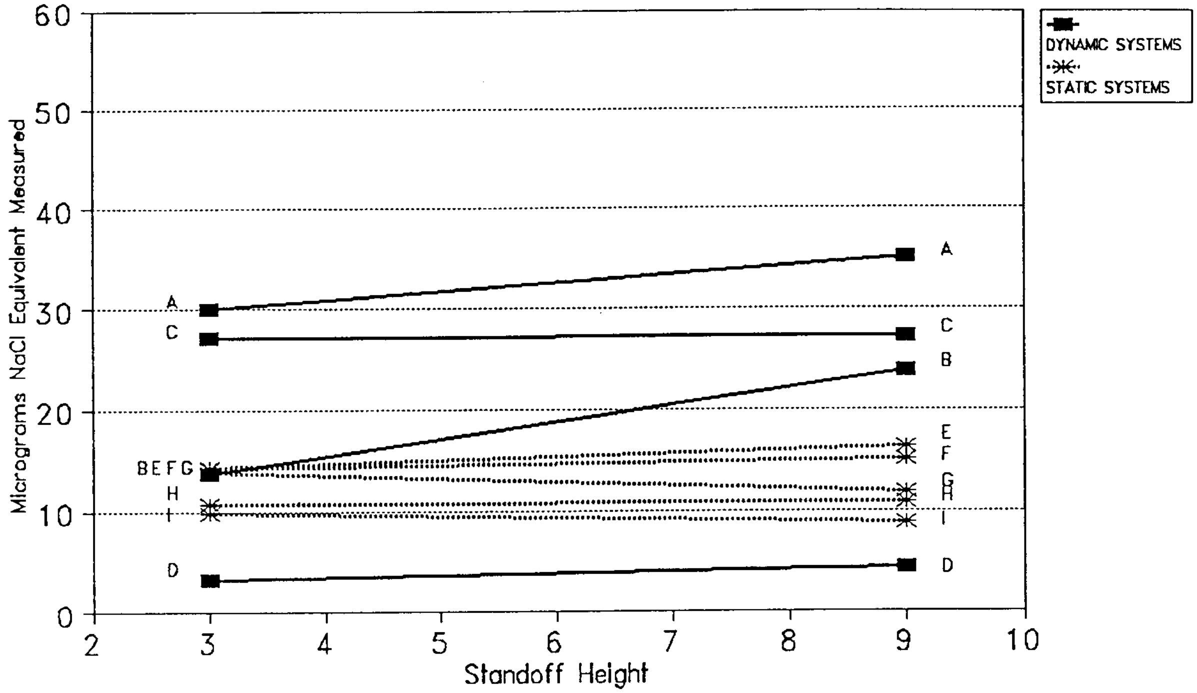



ALL SYSTEMS : IPA Effect
BOARD TEST w/Blocks
Micrograms NaCl Equivalent Measured
Percent IPA
DYNAMIC SYSTEMS
STATIC SYSTEMS
A
C
B
E
F
G
H
I
D
I H
E G
60
50
40
30
20
10
0
68
70
72
74
76
78
80
82


ALL SYSTEMS : IPA Effect
BOARD TEST Total
Micrograms NaCl Equivalent Measured
Percent IPA
DYNAMIC SYSTEMS
STATIC SYSTEMS
B
C
A
E
F
H
G
I
D
G D
60
50
40
30
20
10
0
68
70
72
74
76
78
80
82

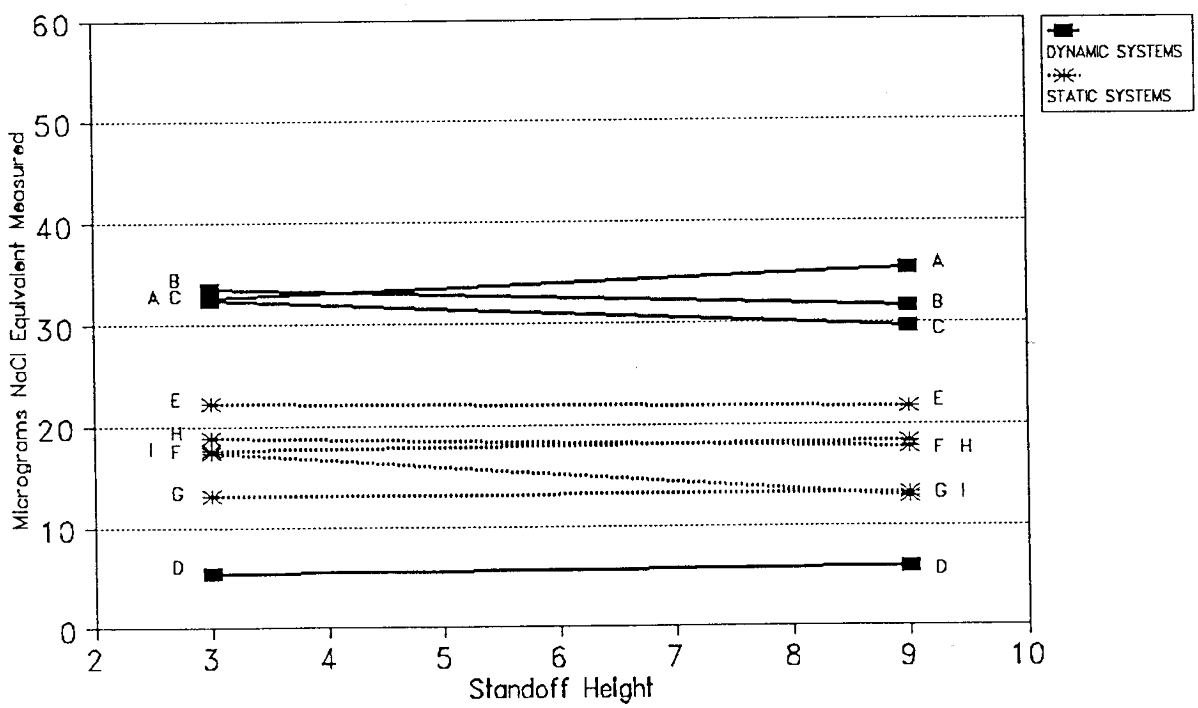
ALL SYSTEMS : Standoff Effect

BOARD TEST w/Blocks



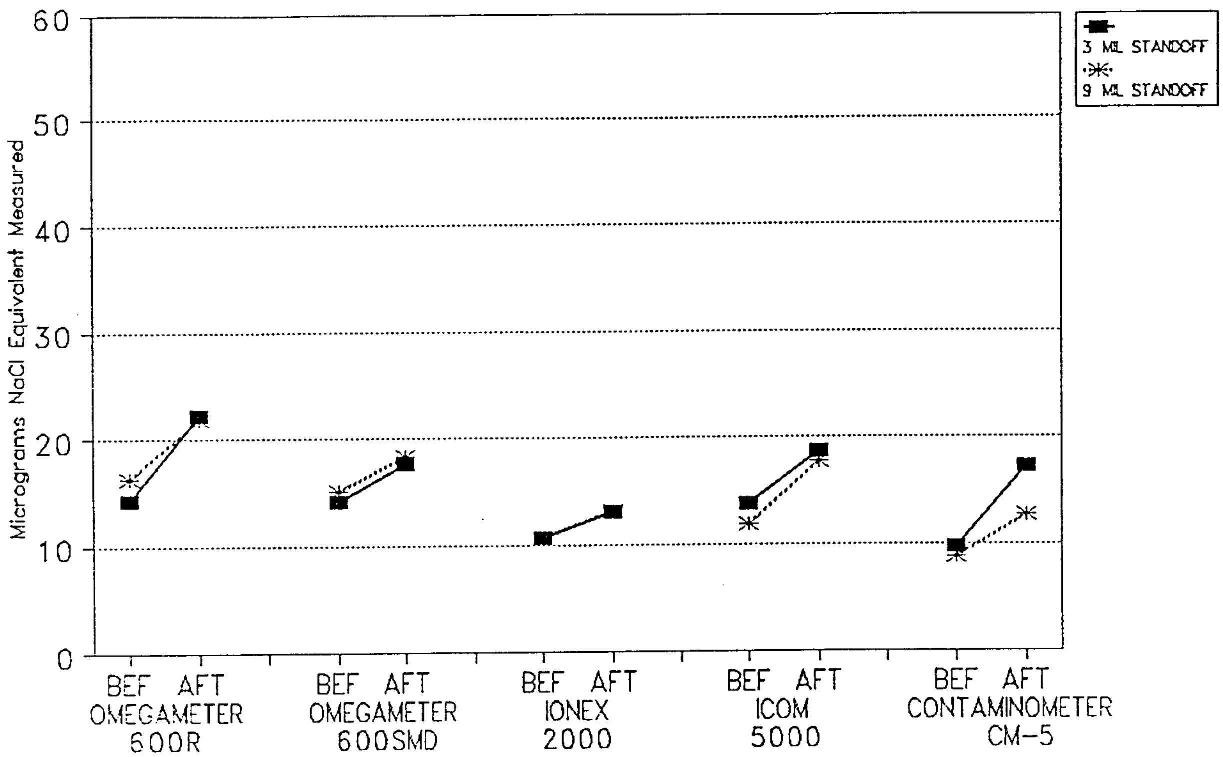
ALL SYSTEMS : Standoff Effect

BOARD TEST Total



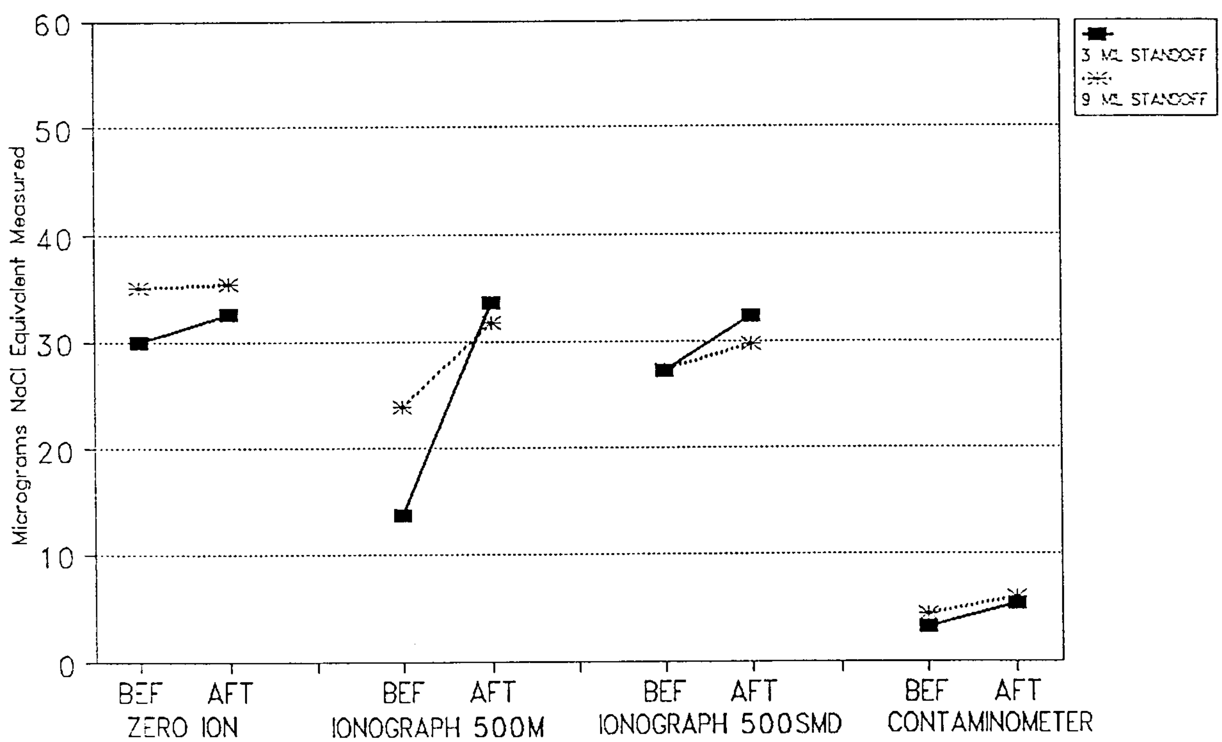
STATIC SYSTEMS: Standoff Effect

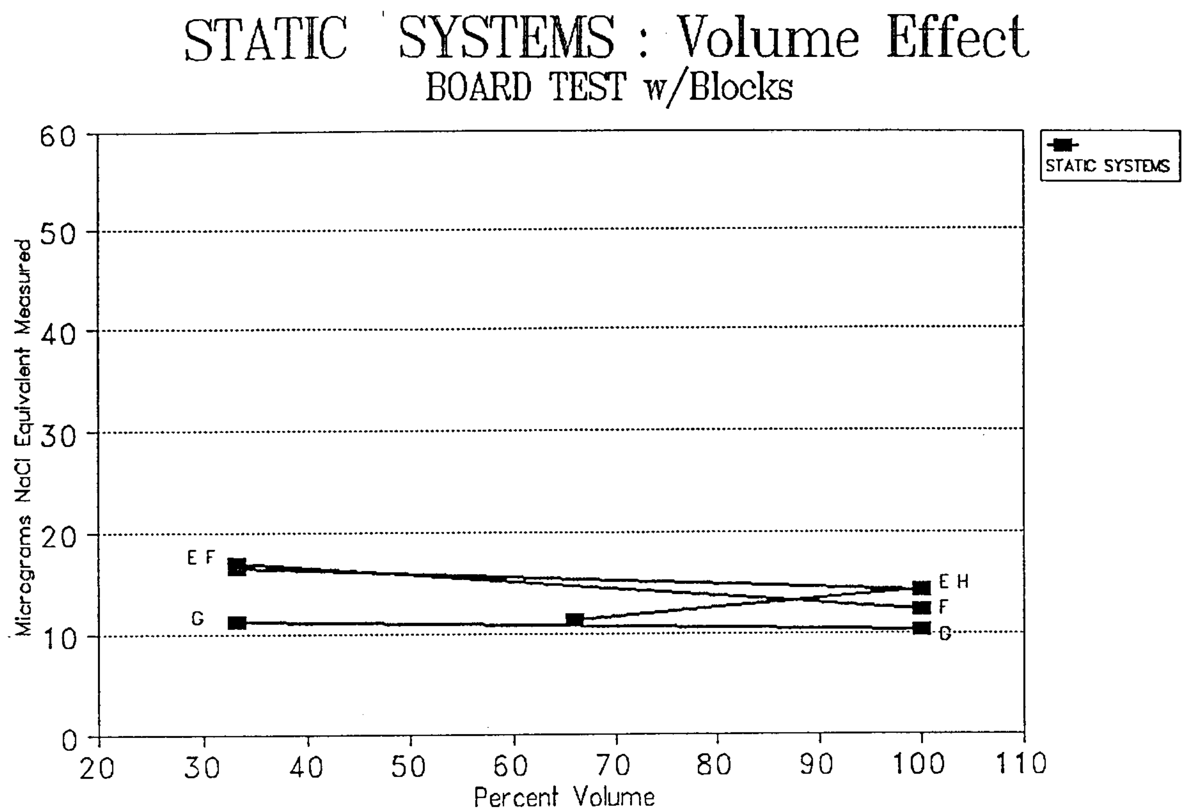
"BEFORE" AND "AFTER" REMOVAL



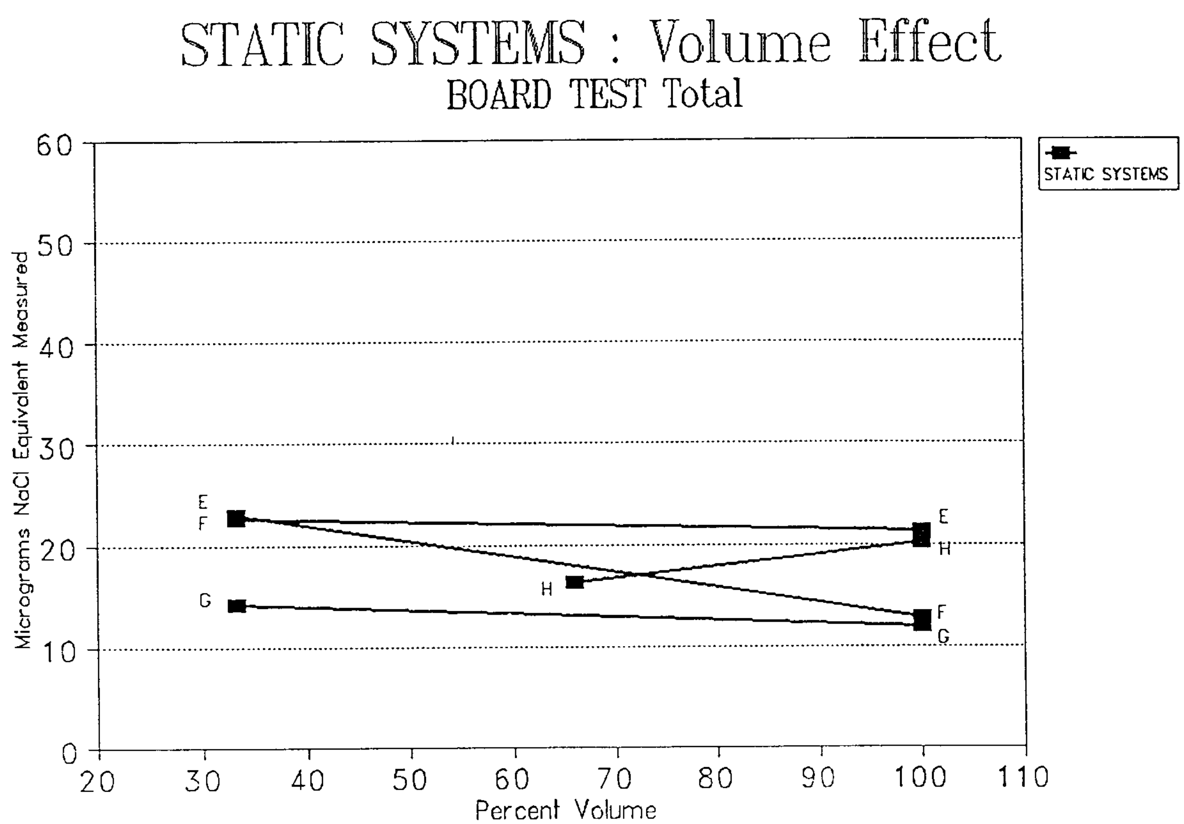
DYNAMIC SYSTEMS Standoff Effect

"BEFORE" AND "AFTER" REMOVAL





STATIC SYSTEMS : Volume Effect
BOARD TEST w/Blocks
STATIC SYSTEMS
Micrograms NaCl Equivalent Measured
Percent Volume
E F
G
E H
F
G



STATIC SYSTEMS : Volume Effect
BOARD TEST Total
STATIC SYSTEMS
Micrograms NaCl Equivalent Measured
Percent Volume
E
F
G
H
E
H
F
G

LONDON CHEMICAL

ZERO ION

Dynamic
Unheated
Spray below immersion

ZERO ION SYSTEM
RANDOMIZED EXPERIMENTAL MATRIX
PWB/WEAK FLUX TESTS

RANDOMIZED RUN SEQUENCE	STANDARD ORDER	A B C	A AMOUNT OF RESIDUE (μGR/IN^2)	B IPA (VOL%)	C CHANNEL DEPTH (MILS)	IONIC READING W/BLOCK	IONIC READING WO/BLOCK	TEST DURATION	TEST CELL TEMP. W/BLK	TEST CELL TEMP. WO/BLK
1	2	+ - -	55	70	3	62.8	13.8	15:00	86°F	88°F
2	6	+ - +	55	70	9	79.5	0.0	15:00	89°F	91°F
3	1	- - -	5	70	3	10.6	3.5	15:00	91°F	93°F
4	5	- - +	5	70	9	14.9	1.8	15:00	92°F	95°F
5	10	0 0 0	30	75	6	83.9	4.3	15:00	86°F	88°F
6	11	0 0 0	30	75	6	89.2	0.0	15:00	90°F	92°F
7	9	0 0 0	30	75	6	85.7	0.0	15:00	93°F	94°F
8	3	- + -	5	80	3	4.0	1.4	15:00	88°F	90°F
9	4	+ + -	55	80	3	32.5	0.0	15:00	90°F	93°F
10	7	- + +	5	80	9	5.7	0.3	15:00	95°F	96°F
11	8	+ + +	55	80	9	44.4	0.0	15:00	96°F	97°F
12	2	+ - -	55	70	3	91.5	0.3	15:00	90°F	91°F
13	6	+ - +	55	70	9	76.6	0.0	15:00	93°F	94°F
14	1	- - -	5	70	3	2.3	0.0	15:00	95°F	96°F
15	5	- - +	5	70	9	10.01	0.0	15:00	97°F	97°F

TABLE OF EFFECTS (Board Tests with Blocks)

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	32.59*	18.77*	27.21*	3.81*	15.33*	14.68*	10.73*	12.81*	9.29*
MAIN									
Residue (R)	50.88*	24.01*	37.81*	5.26*	12.28*	16.60*	10.19*	7.21*	11.83*
IPA (I)	-21.88*	-35.43*	-26.69*	-1.41	-20.51*	-11.30*		-4.39*	2.38
Volume (V)					-2.17	-4.63*	-0.93	3.18*	
Channel (C)	5.12	10.27*	0.12	1.11	1.89	0.88	0.05	-1.99	-1.05
Heat (H)						6.94*		2.12	
INTERACTION									
R*I	-17.27*	-22.08*	-20.52*	-1.96	-6.18*	-4.69*	-4.99*	-1.37	0.13
R*V					-3.92x	0.81	0.13	-0.49	
R*C	1.28	7.14	0.16	0.26	0.24	-3.16*	0.13	0.06	0.85
R*H						3.10*		1.86	
I*V					-7.98*	-3.39*	-0.48	1.54	
I*C	1.68	-8.29	-1.70	0.69	1.26	0.64	1.55	-0.89	-3.20
I*H						-0.30		2.88x	
V*C					0.29	1.19	-0.81	1.48	
V*H						1.28	0.13	-1.60	
C*H						-3.73*		-1.82	
R*I*V					-2.18		0.33		
R*I*C	3.83	-5.34	4.44	0.24	-1.14		0.34		0.10
R*V*C					1.92		0.56		
I*V*C					-3.44x		-0.74		
CENTER	53.68*	48.85*	6.48	2.36	16.11*	-0.05	10.00*	1.13	2.45

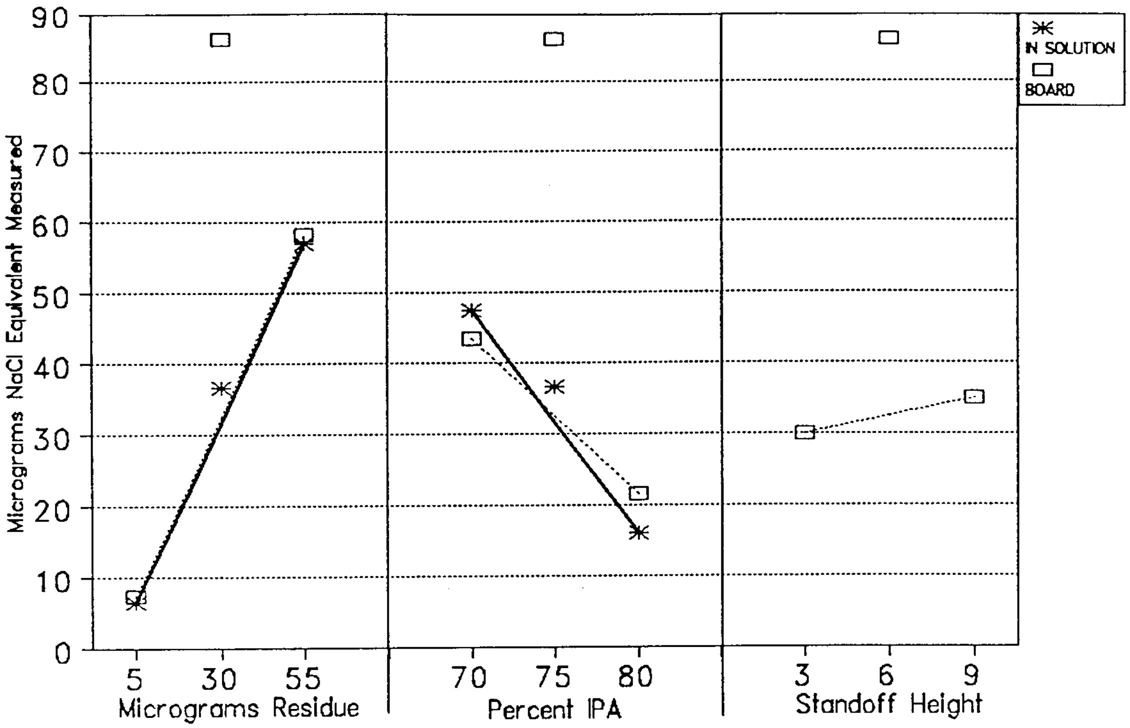
Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

TABLE OF EFFECTS (Board Tests: Total)

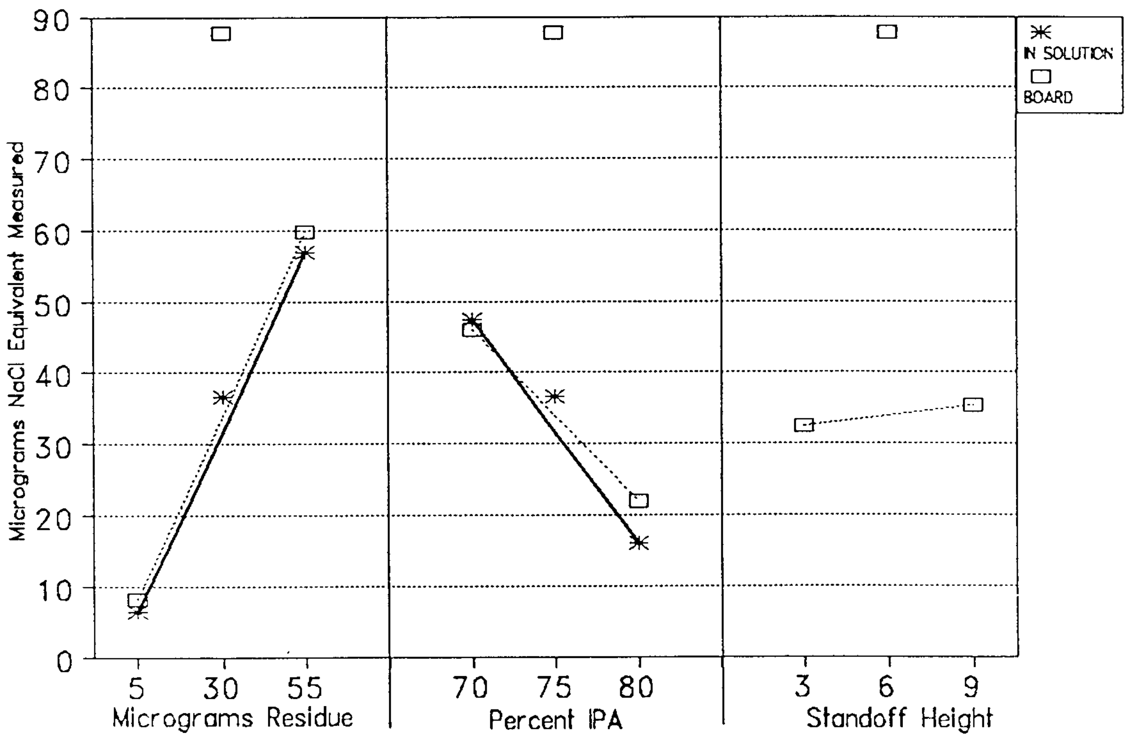
	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	34.01*	32.66*	31.03*	5.68*	22.01*	17.93*	13.14*	18.27*	15.06*
MAIN									
Residue (R)	51.55*	42.86*	38.89*	6.59*	17.82*	17.01*	11.33*	7.33*	13.66*
IPA (I)	-23.88*	-42.32*	-31.83*	-0.61	-27.52*	-14.33*		-4.79*	6.29x
Volume (V)					-1.23	-10.13*	-2.23	3.88	
Channel (C)	2.88	-1.90	-2.79	0.49	-0.37	0.69	0.12	-1.00	-4.49
Heat (H)						6.69*		1.61	
INTERACTION									
R*I	-18.80*	-23.04*	-20.27*	-1.54	-6.37x	-4.13*	-5.68*	-2.46	-3.66
R*V					-2.48	0.07	-0.01	-0.35	
R*C	0.00	-3.50	-0.30	-0.44	-1.09	-3.11x	-0.81	-1.21	4.51
R*H						3.14x		2.72	
I*V					-6.72x	-1.34	0.98	1.78	
I*C	3.38	-6.65	0.06	0.26	-0.03	0.43	1.63	-0.58	-2.31
I*H						0.13		4.85	
V*C					1.56	1.53	-1.54	2.20	
V*H						1.03		-3.12	
C*H						-3.94*		-2.53	
R*I*V					-2.42		1.96		
R*I*C	4.77	-3.11	3.99	-0.31	-2.36		-0.24		6.09x
R*V*C					3.58		0.36		
I*V*C					-4.41		-0.11		
CENTER	53.69*	47.23*	5.84	1.79	9.72x	1.53	8.26*	0.15	1.48

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

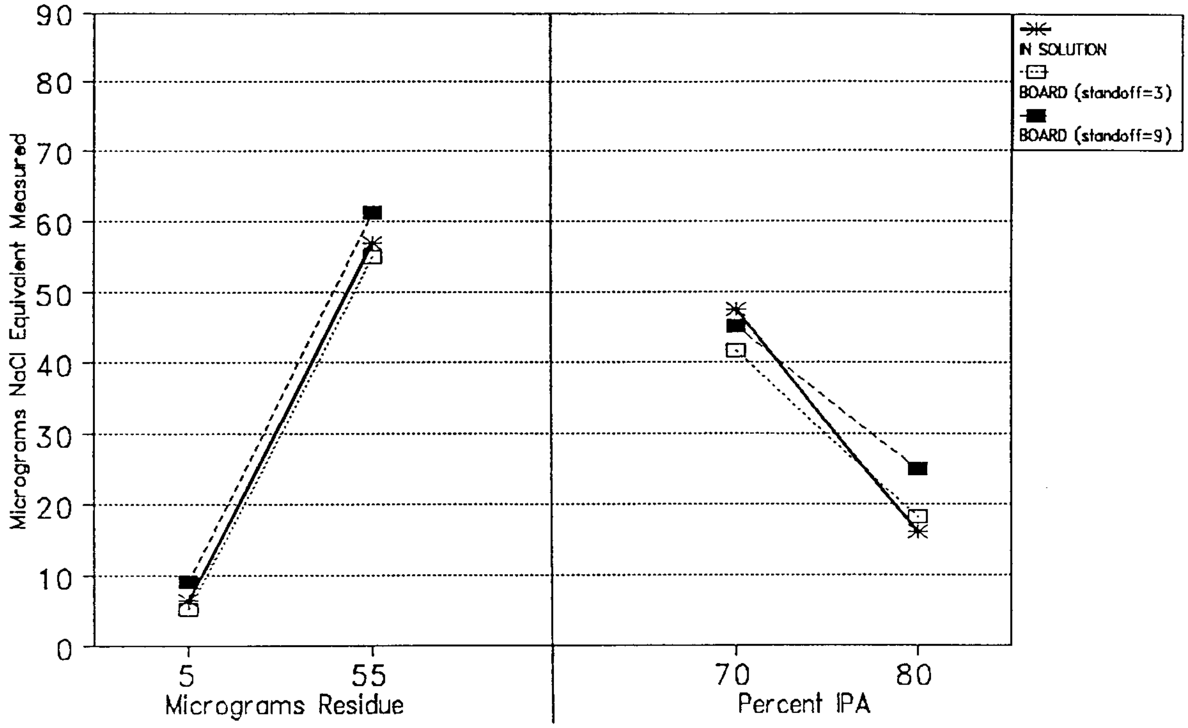
ZERO ION : Board w/Block
MAIN EFFECTS (weak flux only)



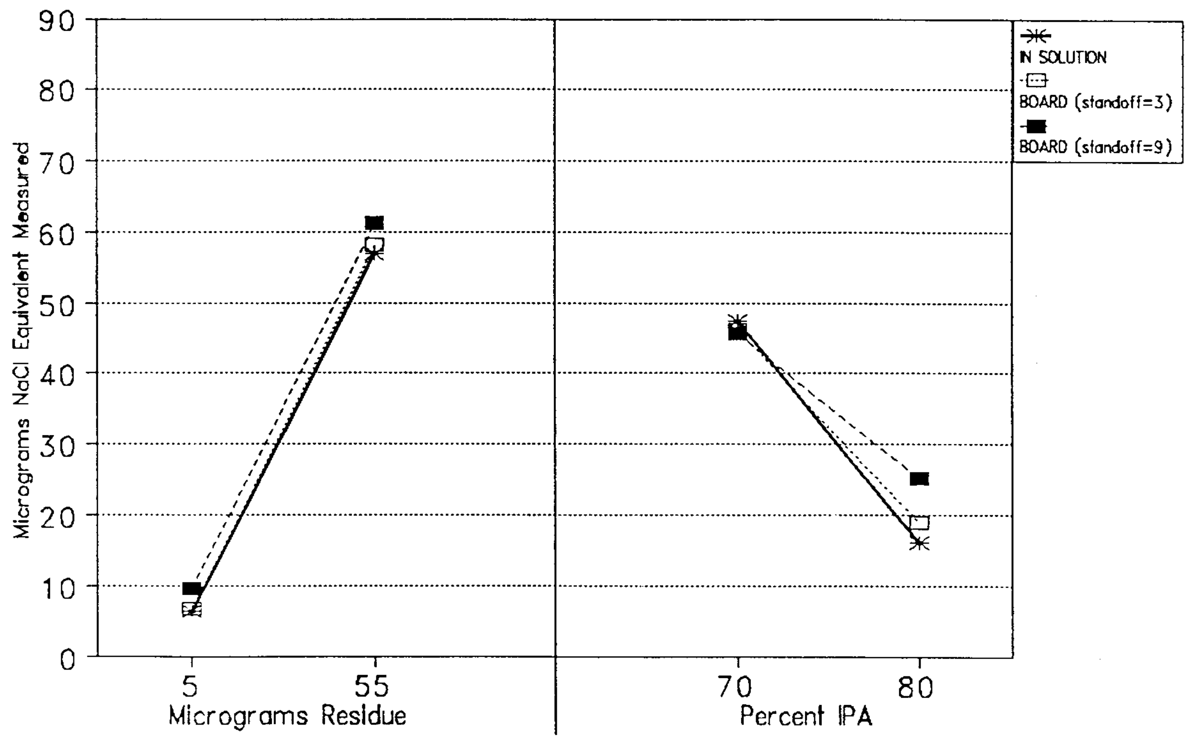
ZERO ION : Board Total
MAIN EFFECTS (weak flux only)

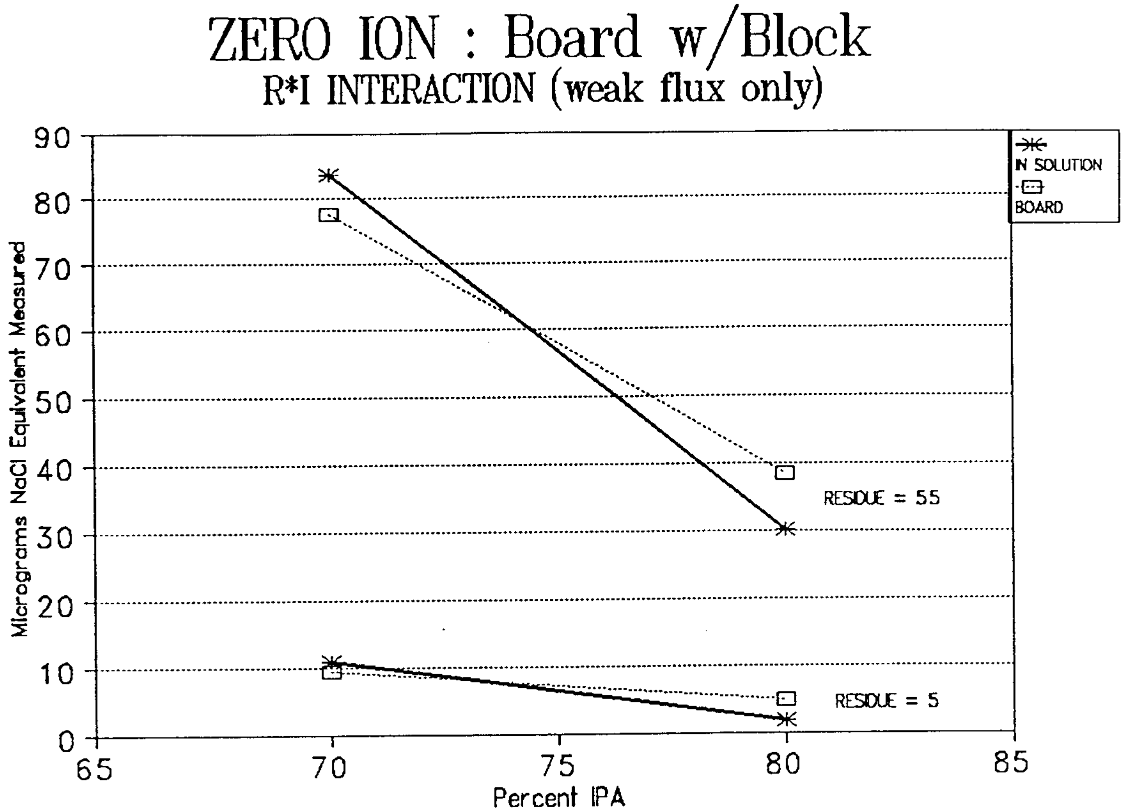


ZERO ION : Board w/Block
2-WAY INTERACTIONS (weak flux only)

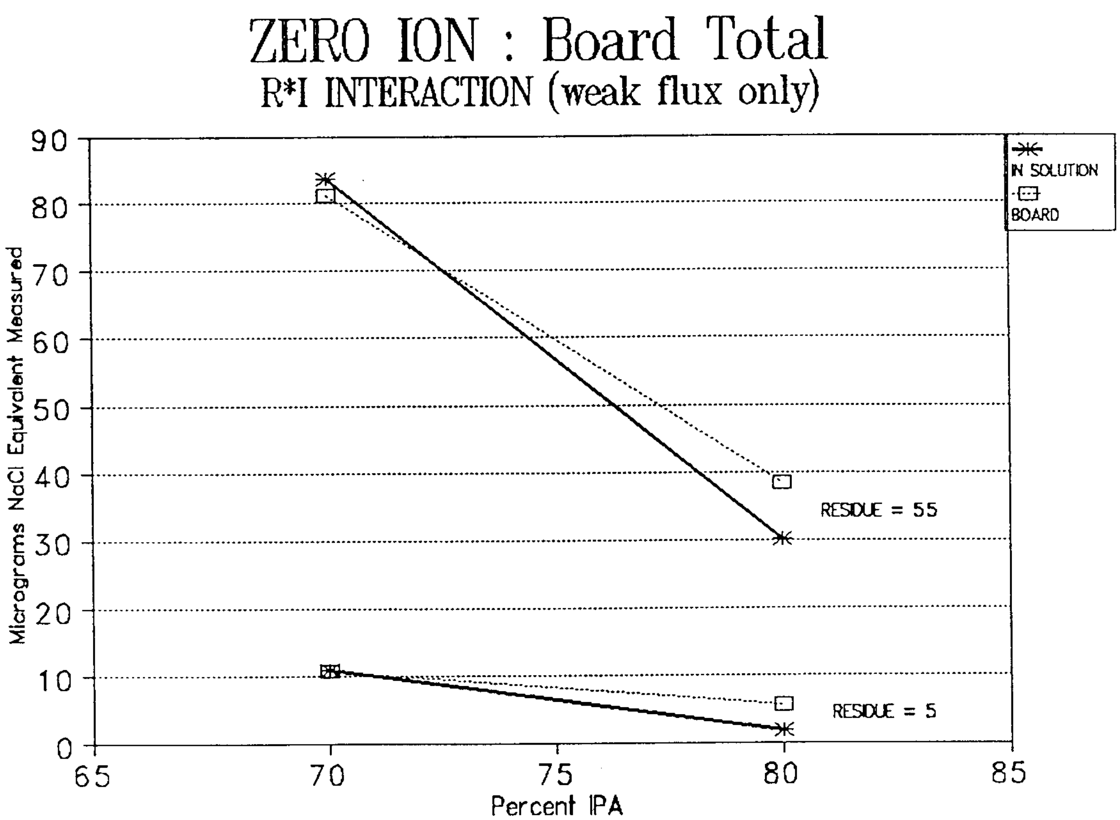


ZERO ION : Board Total
2-WAY INTERACTIONS (weak flux only)

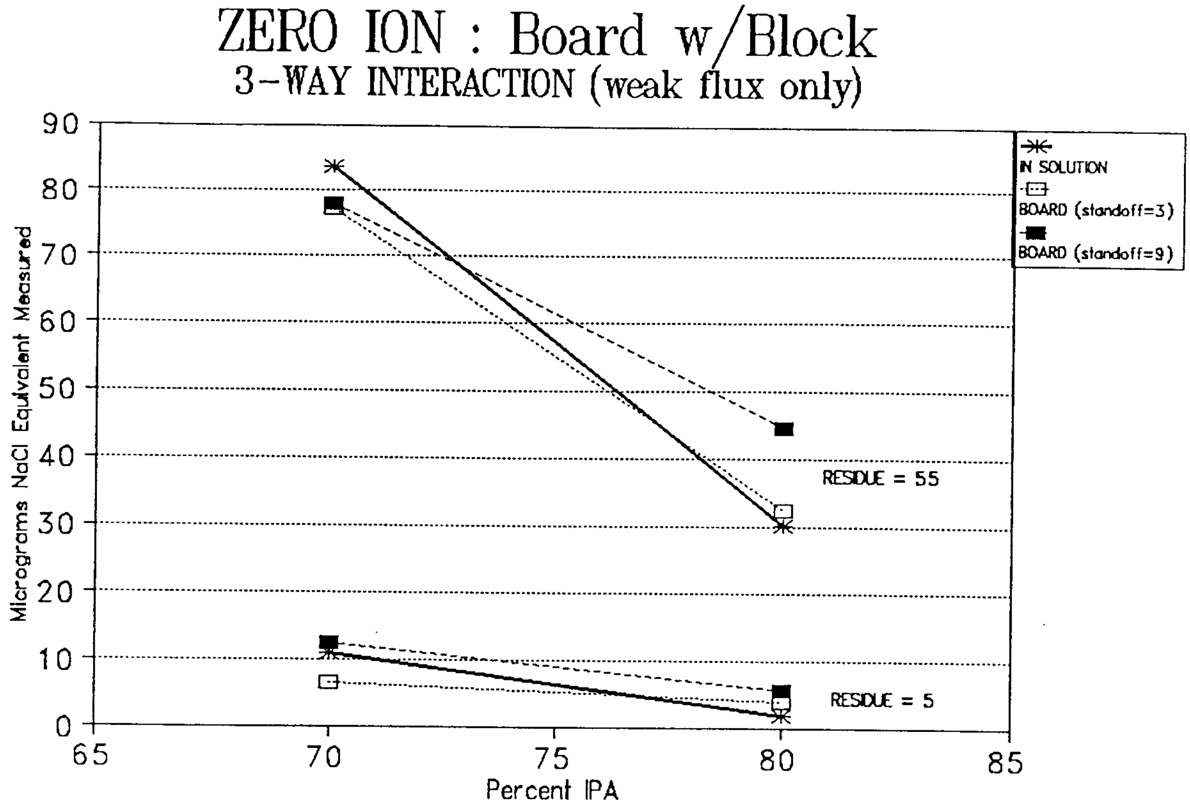


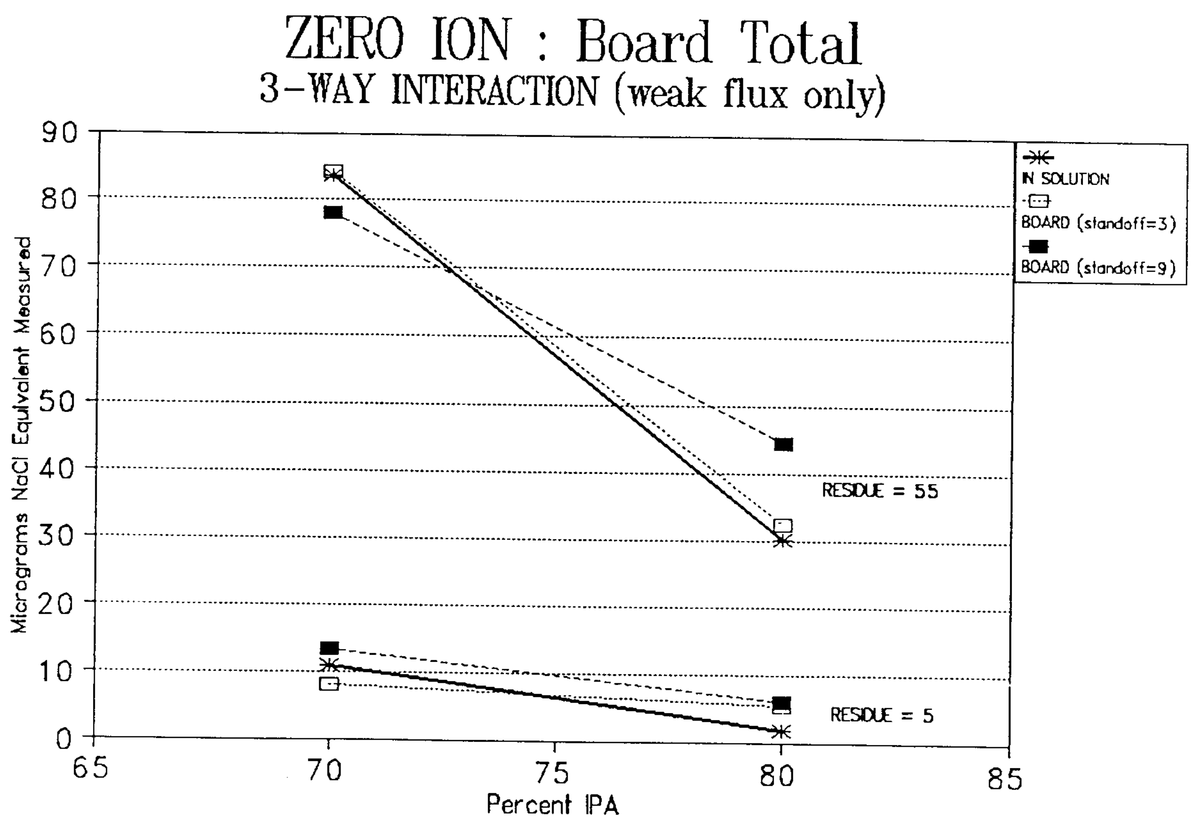


ZERO ION : Board w/Block
R*I INTERACTION (weak flux only)
IN SOLUTION
BOARD
RESIDUE = 55
RESIDUE = 5
Micrograms NaCl Equivalent Measured
Percent IPA
0
10
20
30
40
50
60
70
80
90
65
70
75
80
85



ZERO ION : Board Total
R*I INTERACTION (weak flux only)
IN SOLUTION
BOARD
RESIDUE = 55
RESIDUE = 5
Micrograms NaCl Equivalent Measured
Percent IPA
0
10
20
30
40
50
60
70
80
90
65
70
75
80
85


ZERO ION : Board w/Block
3-WAY INTERACTION (weak flux only)
Micrograms NaCl Equivalent Measured
Percent IPA
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)
RESIDUE = 55
RESIDUE = 5
90
80
70
60
50
40
30
20
10
0
65
70
75
80
85


ZERO ION : Board Total
3-WAY INTERACTION (weak flux only)
Micrograms NaCl Equivalent Measured
Percent IPA
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)
RESIDUE = 55
RESIDUE = 5
90
80
70
60
50
40
30
20
10
0
65
70
75
80
85

ZERO ION
IN SOLUTION TEST (weak flux)

Predictor	Coef	Stdev	t-ratio	p	
Constant	31.663	0.6415	49.36	0.000	*
R	25.2625	0.6415	39.38	0.000	*
I	-15.6625	0.6415	-24.41	0.000	*
R*I	-11.0625	0.6415	-17.24	0.000	*
CTR.PT	4.937	1.228	4.02	0.028	*

s = 1.482 R-sq = 99.9% R-sq(adj) = 99.8%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	4	6989.8	1747.4	796.10	0.000
Error	3	6.6	2.2		
Total	7	6996.3			

SOURCE	DF	SEQ SS
R	1	5028.6
I	1	1273.0
R*I	1	652.7
CTR.PT	1	35.5

ZERO ION
BOARD TEST w/BLOCK

Predictor	Coef	Stdev	t-ratio	p	
Constant	32.588	2.730	11.94	0.000	*
R	25.438	2.730	9.32	0.000	*
I	-10.938	2.730	-4.01	0.007	*
C	2.562	2.730	0.94	0.384	
R*I	-8.637	2.730	-3.16	0.019	*
R*C	0.638	2.730	0.23	0.823	
I*C	0.838	2.730	0.31	0.769	
R*I*C	1.913	2.730	0.70	0.510	
CTR.PT	53.679	5.827	9.21	0.000	*

s = 8.917 R-sq = 97.4% R-sq(adj) = 93.9%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	17810.9	2226.4	28.00	0.000
Error	6	477.0	79.5		
Total	14	18287.9			

SOURCE	DF	SEQ SS
R	1	9622.0
I	1	537.2
C	1	62.6
R*I	1	795.8
R*C	1	0.0
I*C	1	7.5
R*I*C	1	39.0
CTR.PT	1	6746.8

Unusual Observations

Obs.	R	ZERO.B	Fit	Stdev.Fit	Residual	St.Resid
1	1.00	62.80	77.15	6.30	-14.35	-2.28R
10	1.00	91.50	77.15	6.30	14.35	2.28R

R denotes an obs. with a large st. resid.

ZERO ION
BOARD TEST TOTAL

Predictor	Coef	Stdev	t-ratio	p	
Constant	34.013	1.847	18.42	0.000	*
R	25.775	1.847	13.96	0.000	*
I	-11.938	1.847	-6.46	0.001	*
C	1.438	1.847	0.78	0.466	
R*I	-9.400	1.847	-5.09	0.002	*
R*C	-0.000	1.847	-0.00	1.000	
I*C	1.688	1.847	0.91	0.396	
R*I*C	2.825	1.847	1.53	0.177	
CTR.PT	53.687	3.942	13.62	0.000	*

s = 6.032   R-sq = 98.8%   R-sq(adj) = 97.3%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	18556.4	2319.5	63.76	0.000
Error	6	218.3	36.4		
Total	14	18774.7			

SOURCE	DF	SEQ SS
R	1	10028.3
I	1	701.3
C	1	9.2
R*I	1	942.5
R*C	1	10.6
I*C	1	30.4
R*I*C	1	85.1
CTR.PT	1	6748.9

ALPHA METALS

IONOGRAPH 500M

Dynamic
Unheated
Spray below immersion

IONOGRAPH 500M
RANDOMIZED EXPERIMENTAL MATRIX
PWB/WEAK FLUX TESTS

RANDOMIZED RUN SEQUENCE	STANDARD ORDER	A B C	A AMOUNT OF RESIDUE (μGR/IN²)	B IPA (VOL%)	C CHANNEL DEPTH (MILS)	IONIC READING W/BLOCK	IONIC READING WO/BLOCK	TEST DURATION	TEST CELL TEMP.
1	2	+ - -	55	70	3	40.20	39.40	15:00	29.5°C
2	6	+ - +	55	70	9	73.54	10.37	15:00	30.5°C
3	1	- - -	5	70	3	15.12	9.31	15:00	28.8°C
4	5	- - +	5	70	9	16.96	8.25	15:00	34.0°C
5	9	0 0 0	30	75	6	70.43	8.82	15:00	29.6°C
6	10	0 0 0	30	75	6	74.48	16.31	15:00	30.9°C
7	11	0 0 0	30	75	6	57.94	11.68	15:00	33.2°C
8	8	+ + +	55	80	9	3.91	9.91	6:00	33.7°C
9	3	- + -	5	80	3	0.0	2.55	7:00	29.6°C
10	4	+ + -	55	80	3	0.13	28.85	6:00	29.6°C
11	7	- + +	5	80	9	0.18	0.44	5:00	31.7°C
12	2	+ - -	55	70	3	47.83	41.74	15:00	28.6°C
13	6	+ - +	55	70	9	76.57	17.42	15:00	32.8°C
14	1	- - -	5	70	3	5.69	6.47	7:00	32.9°C
15	5	- - +	5	70	9	15.99	5.67	15:00	33.2°C

TABLE OF EFFECTS (Board Tests with Blocks)

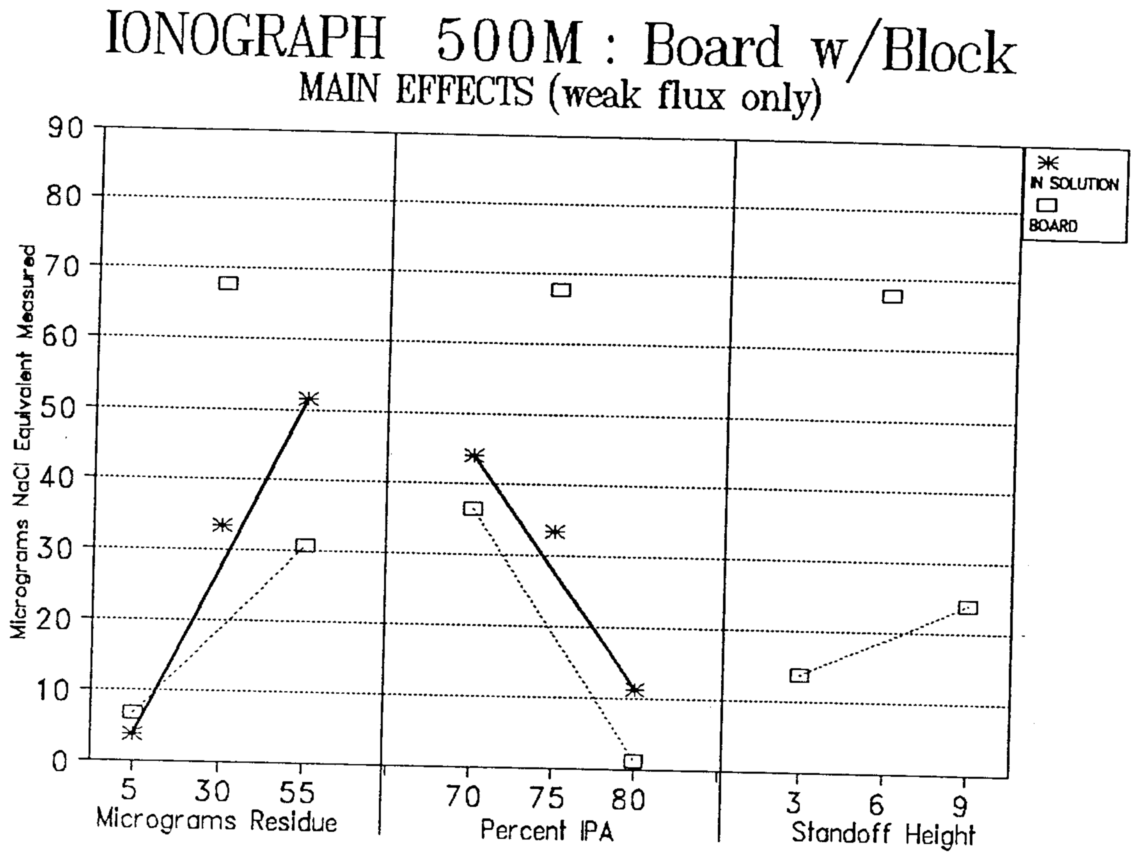
	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Ionograph 500M	Ionograph 500SMD	CM-5 dynamic	Omegameter 600R	Omegameter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	32.59*	18.77*	27.21*	3.81*	15.33*	14.68*	10.73*	12.81*	9.29*
MAIN									
Residue (R)	50.88*	24.01*	37.81*	5.26*	12.28*	16.60*	10.19*	7.21*	11.83*
IPA (I)	-21.88*	-35.43*	-26.69*	-1.41	-20.51*	-11.30*		-4.39*	2.38
Volume (V)					-2.17	-4.63*	-0.93	3.18*	
Channel (C)	5.12	10.27*	0.12	1.11	1.89	0.88	0.05	-1.99	-1.05
Heat (H)						6.94*		2.12	
INTERACTION									
R*I	-17.27*	-22.08*	-20.52*	-1.96	-6.18*	-4.69*	-4.99*	-1.37	0.13
R*V					-3.92x	0.81	0.13	-0.49	
R*C	1.28	7.14	0.16	0.26	0.24	-3.16*	0.13	0.06	0.85
R*H						3.10*		1.86	
I*V					-7.98*	-3.39*	-0.48	1.54	
I*C	1.68	-8.29	-1.70	0.69	1.26	0.64	1.55	-0.89	-3.20
I*H						-0.30		2.88x	
V*C					0.29	1.19	-0.81	1.48	
V*H						1.28	0.13	-1.60	
C*H						-3.73*		-1.82	
R*I*V					-2.18		0.33		
R*I*C	3.83	-5.34	4.44	0.24	-1.14		0.34		0.10
R*V*C					1.92		0.56		
I*V*C					-3.44x		-0.74		
CENTER	53.68*	48.85*	6.48	2.36	16.11*	-0.05	10.00*	1.13	2.45

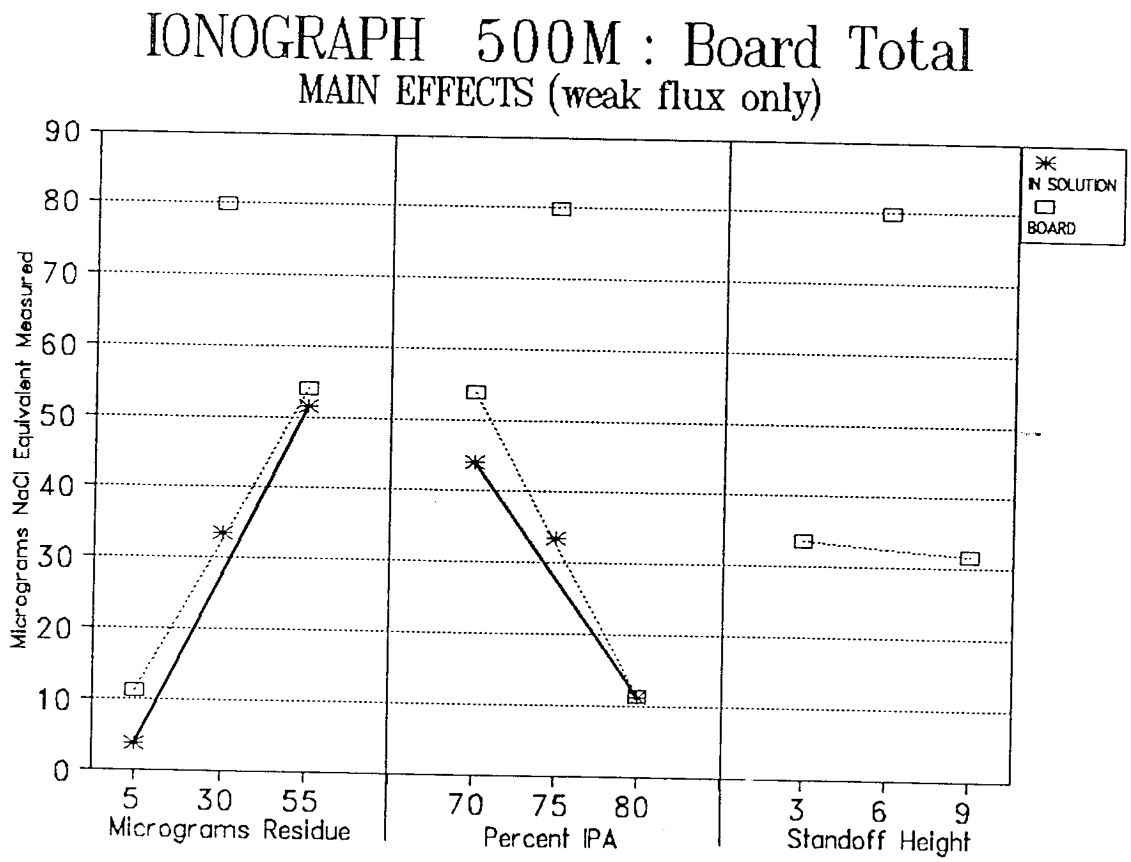
Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

TABLE OF EFFECTS (Board Tests: Total)

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	34.01*	32.66*	31.03*	5.68*	22.01*	17.93*	13.14*	18.27*	15.06*
MAIN									
Residue (R)	51.55*	42.86*	38.89*	6.59*	17.82*	17.01*	11.33*	7.33*	13.66*
IPA (I)	-23.88*	-42.32*	-31.83*	-0.61	-27.52*	-14.33*		-4.79*	6.29x
Volume (V)					-1.23	-10.13*	-2.23	3.88	
Channel (C)	2.88	-1.90	-2.79	0.49	-0.37	0.69	0.12	-1.00	-4.49
Heat (H)						6.69*		1.61	
INTERACTION									
R*I	-18.80*	-23.04*	-20.27*	-1.54	-6.37x	-4.13*	-5.68*	-2.46	-3.66
R*V					-2.48	0.07	-0.01	-0.35	
R*C	0.00	-3.50	-0.30	-0.44	-1.09	-3.11x	-0.81	-1.21	4.51
R*H						3.14x		2.72	
I*V					-6.72x	-1.34	0.98	1.78	
I*C	3.38	-6.65	0.06	0.26	-0.03	0.43	1.63	-0.58	-2.31
I*H						0.13		4.85	
V*C					1.56	1.53	-1.54	2.20	
V*H						1.03		-3.12	
C*H						-3.94*		-2.53	
R*I*V					-2.42		1.96		
R*I*C	4.77	-3.11	3.99	-0.31	-2.36		-0.24		6.09x
R*V*C					3.58		0.36		
I*V*C					-4.41		-0.11		
CENTER	53.69*	47.23*	5.84	1.79	9.72x	1.53	8.26*	0.15	1.48

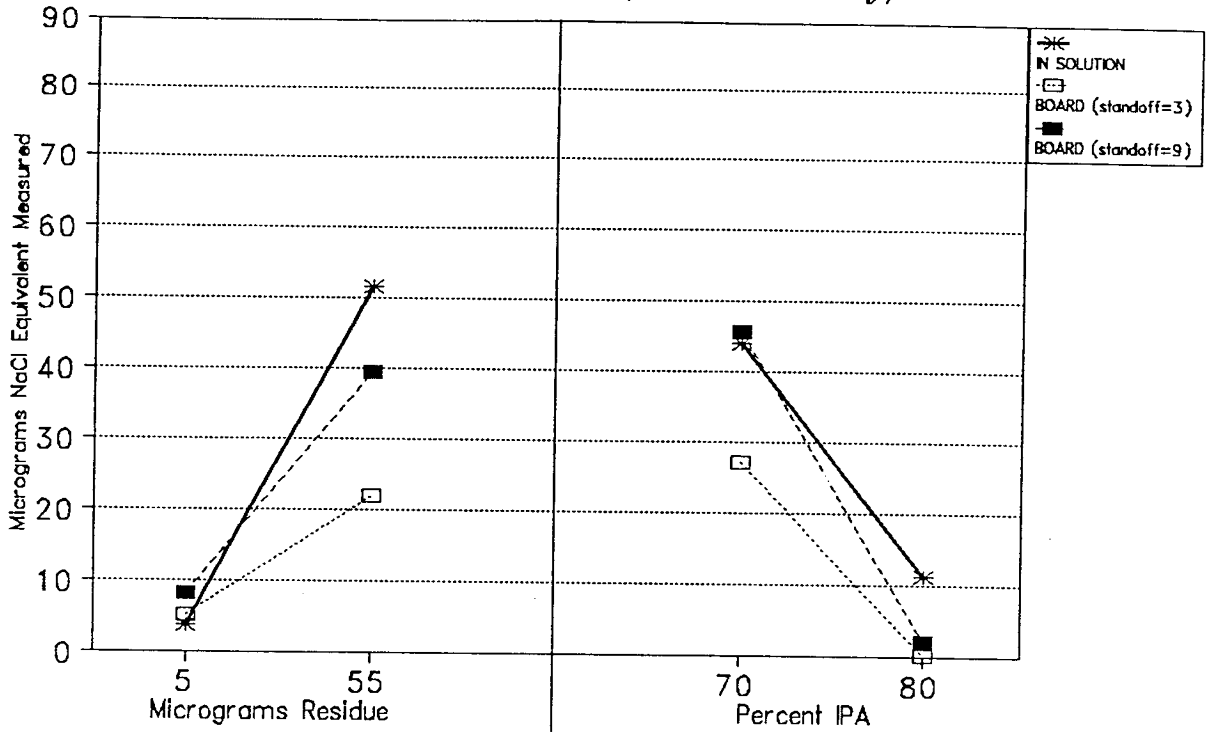
Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.


IONOGRAPH 500M : Board w/Block
MAIN EFFECTS (weak flux only)
Micrograms NaCl Equivalent Measured
0
10
20
30
40
50
60
70
80
90
5
30
55
Micrograms Residue
70
75
80
Percent IPA
3
6
9
Standoff Height
IN SOLUTION
BOARD


IONOGRAPH 500M : Board Total
MAIN EFFECTS (weak flux only)
Micrograms NaCl Equivalent Measured
0
10
20
30
40
50
60
70
80
90
5
30
55
Micrograms Residue
70
75
80
Percent IPA
3
6
9
Standoff Height
IN SOLUTION
BOARD

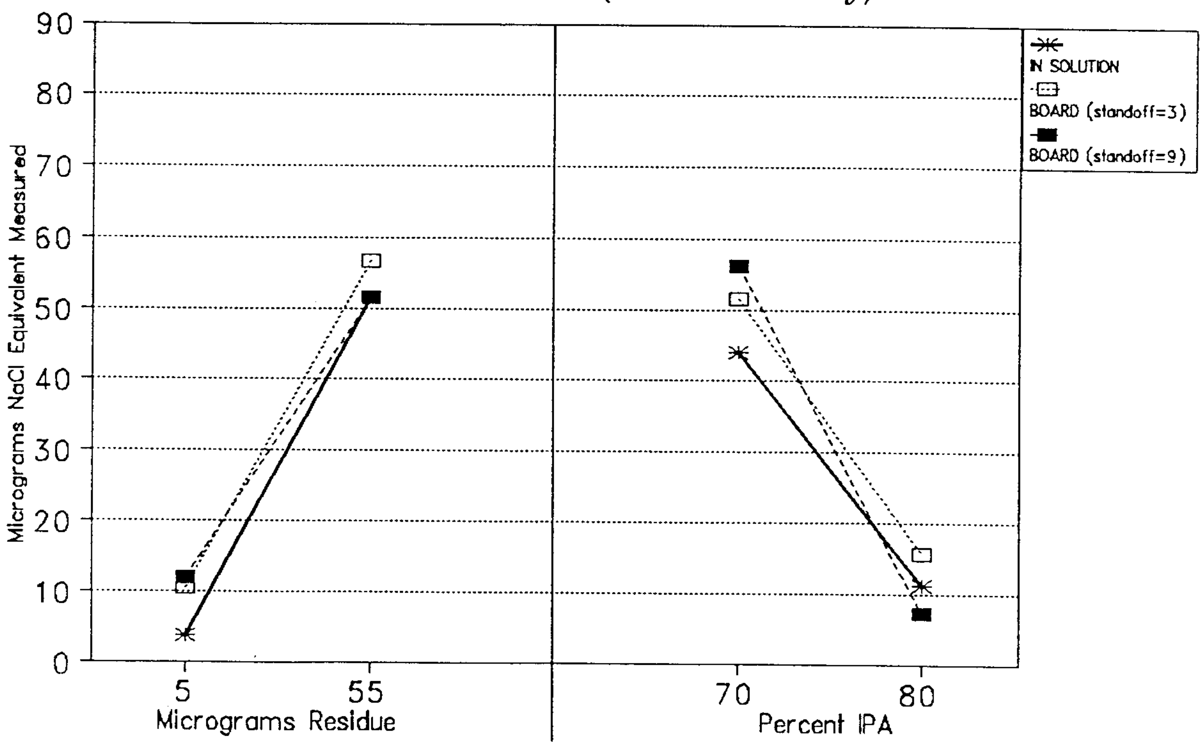
IONOGRAPH 500M : Board w/Block

2-WAY INTERACTIONS (weak flux only)



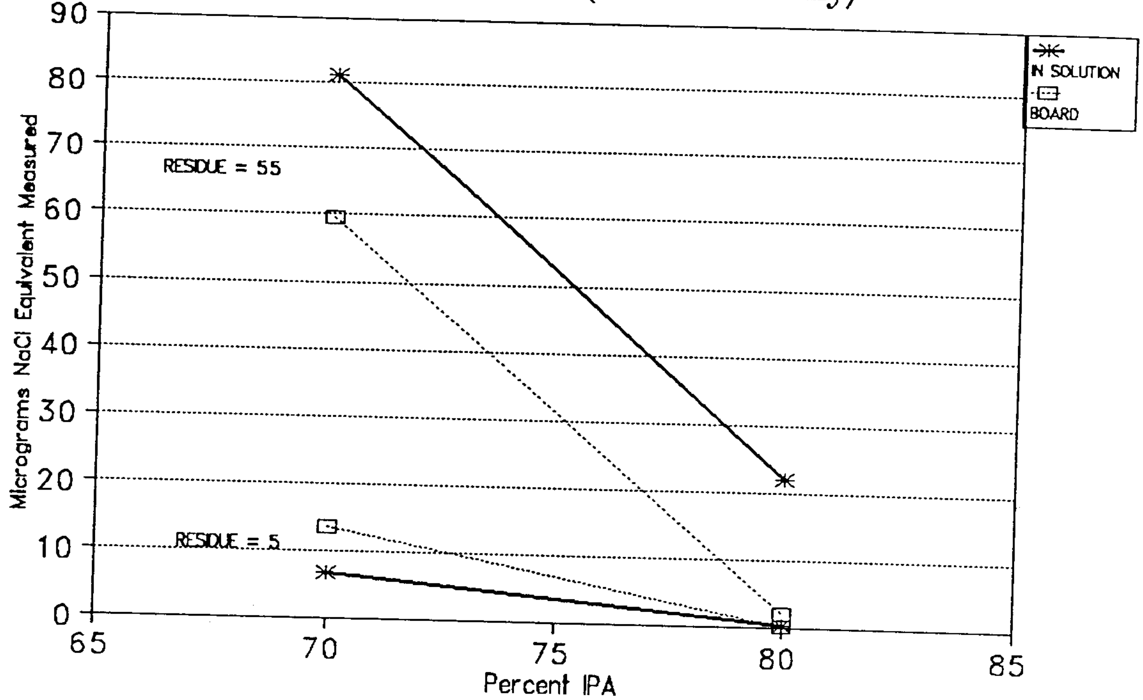
IONOGRAPH 500M : Board Total

2-WAY INTERACTIONS (weak flux only)



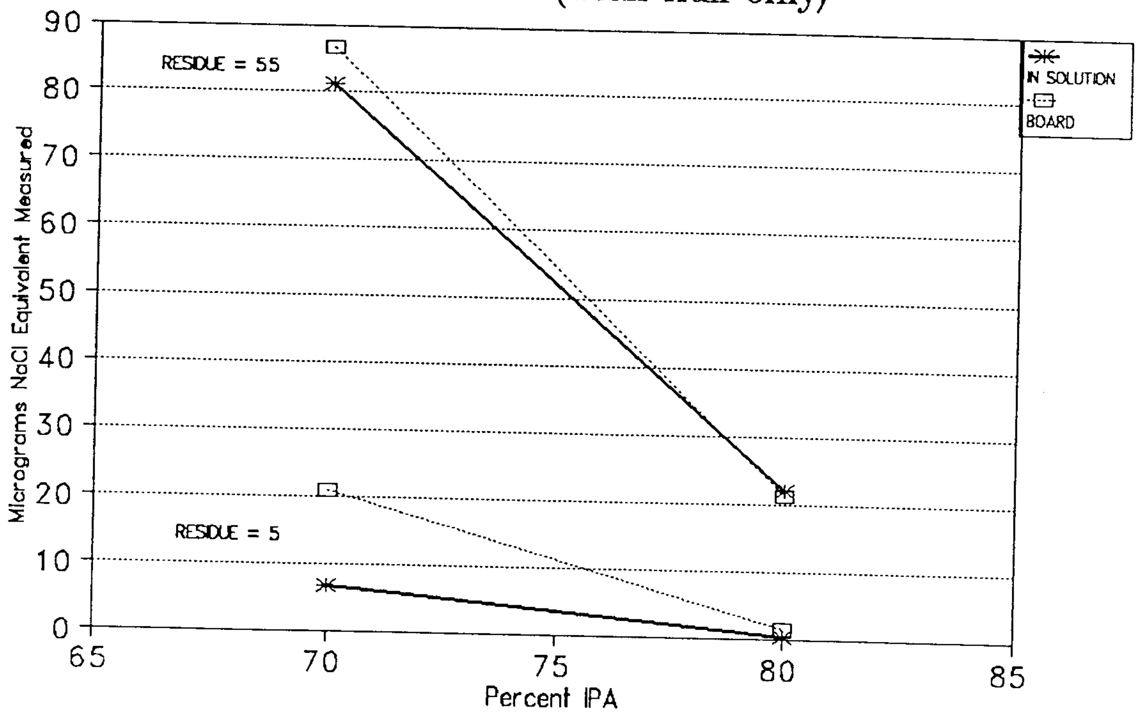
IONOGRAPH 500M : Board w/Block

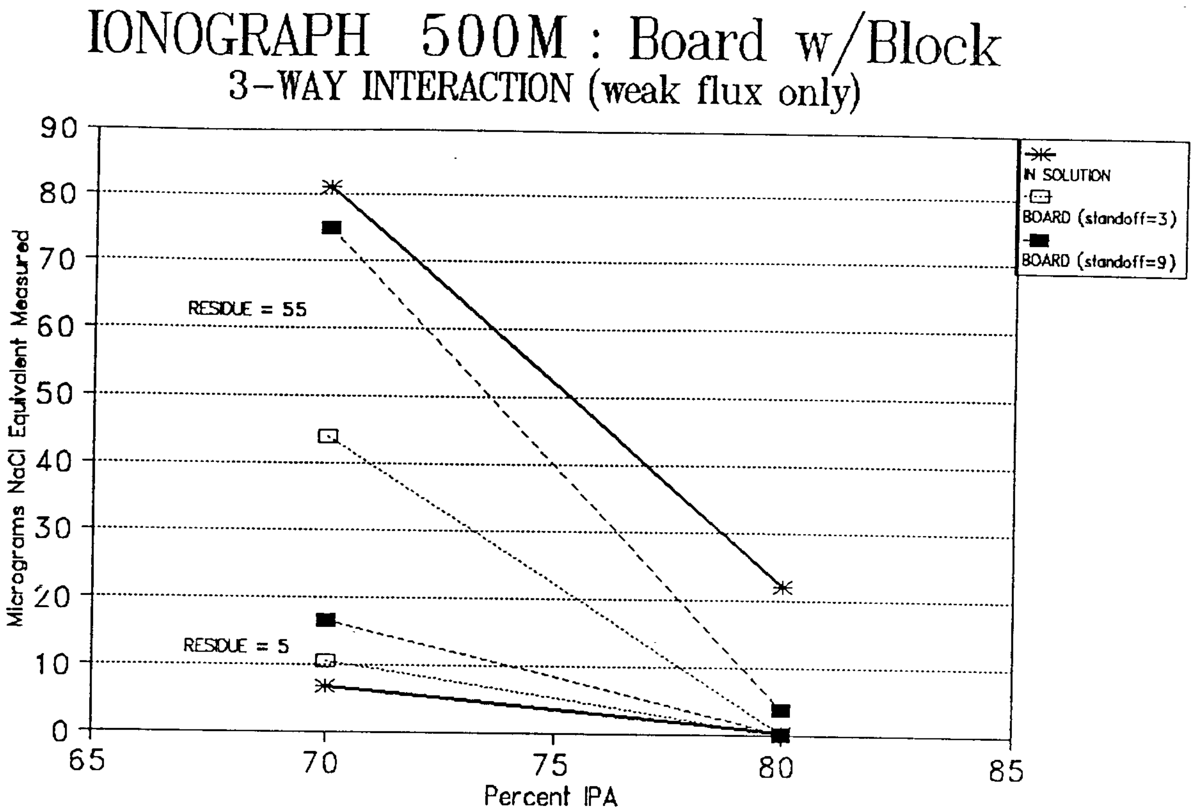
R*I INTERACTION (weak flux only)

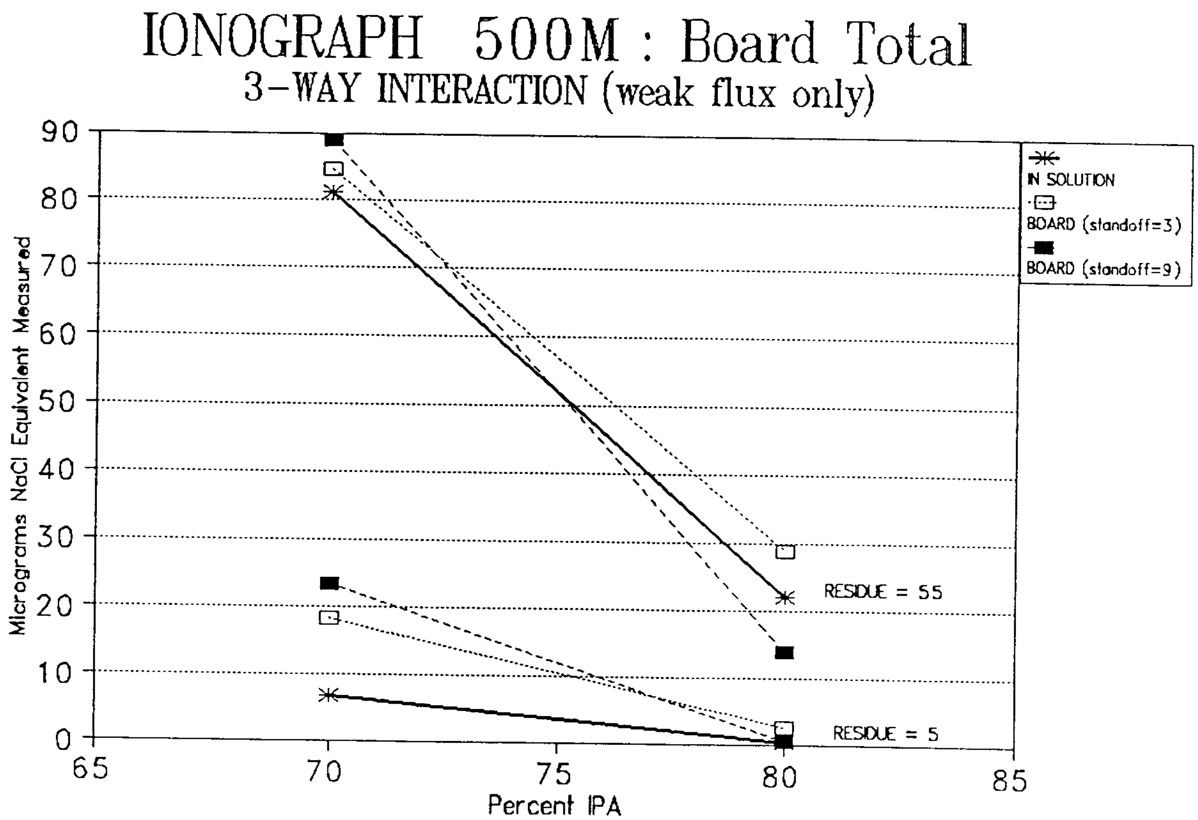


IONOGRAPH 500M : Board Total

R*I INTERACTION (weak flux only)




IONOGRAPH 500M : Board w/Block
3-WAY INTERACTION (weak flux only)
Micrograms NaCl Equivalent Measured
90
80
70
60
50
40
30
20
10
0
65
70
75
80
85
Percent IPA
RESIDUE = 55
RESIDUE = 5
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)


IONOGRAPH 500M : Board Total
3-WAY INTERACTION (weak flux only)
Micrograms NaCl Equivalent Measured
90
80
70
60
50
40
30
20
10
0
65
70
75
80
85
Percent IPA
RESIDUE = 55
RESIDUE = 5
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)

IONOGRAPH 500M
IN SOLUTION TEST (weak flux)

Predictor	Coef	Stdev	t-ratio	p	
Constant	27.584	2.305	11.97	0.001	*
R	23.989	2.305	10.41	0.002	*
I	-16.314	2.305	-7.08	0.006	*
R*I	-13.169	2.305	-5.71	0.011	*
CTR.PT	5.886	4.414	1.33	0.275	

s = 5.323   R-sq = 98.8%   R-sq(adj) = 97.3%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	4	7176.6	1794.1	63.32	0.003
Error	3	85.0	28.3		
Total	7	7261.6			

SOURCE	DF	SEQ SS
R	1	4832.0
I	1	1369.3
R*I	1	924.9
CTR.PT	1	50.4

IONOGRAPH 500M
BOARD TEST w/BLOCK

Predictor	Coef	Stdev	t-ratio	p	
Constant	18.772	1.885	9.96	0.000	*
R	12.006	1.885	6.37	0.001	*
I	-17.716	1.885	-9.40	0.000	*
C	5.134	1.885	2.72	0.034	*
R*I	-11.041	1.885	-5.86	0.001	*
R*C	3.571	1.885	1.90	0.107	
I*C	-4.144	1.885	-2.20	0.070	
R*I*C	-2.671	1.885	-1.42	0.206	
CTR.PT	48.845	4.022	12.14	0.000	*

s = 6.155   R-sq = 98.3%   R-sq(adj) = 96.0%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	13033.8	1629.2	43.01	0.000
Error	6	227.3	37.9		
Total	14	13261.1			

SOURCE	DF	SEQ SS
R	1	2952.9
I	1	2186.7
C	1	509.3
R*I	1	1300.4
R*C	1	238.9
I*C	1	183.2
R*I*C	1	76.1
CTR.PT	1	5586.4

IONOGRAPH 500M
BOARD TEST TOTAL

Predictor	Coef	Stdev	t-ratio	p	
Constant	32.655	2.521	12.95	0.000	*
R	21.429	2.521	8.50	0.000	*
I	-21.162	2.521	-8.39	0.000	*
C	-0.948	2.521	-0.38	0.720	
R*I	-11.522	2.521	-4.57	0.004	*
R*C	-1.751	2.521	-0.69	0.513	
I*C	-3.324	2.521	-1.32	0.235	
R*I*C	-1.557	2.521	-0.62	0.560	
CTR.PT	47.232	5.381	8.78	0.000	*

s = 8.234   R-sq = 97.8%   R-sq(adj) = 94.8%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	17892.3	2236.5	32.99	0.000
Error	6	406.8	67.8		
Total	14	18299.1			

SOURCE	DF	SEQ SS
R	1	7662.9
I	1	3427.6
C	1	0.3
R*I	1	1416.0
R*C	1	18.2
I*C	1	117.9
R*I*C	1	25.9
CTR.PT	1	5223.5

ALPHA METALS

IONOGRAPH 500SMD

Dynamic
Heated
Spray below immersion

IONOGRAPH 500 SMD
RANDOMIZED EXPERIMENTAL MATRIX
PWB/WEAK FLUX TESTS

RANDOMIZED RUN SEQUENCE	STANDARD ORDER	A B C	A AMOUNT OF RESIDUE (μGR/IN^2)	B IPA (VOL%)	C CHANNEL DEPTH (MILS)	IONIC READING W/BLOCK	IONIC READING WO/BLOCK	TEST DURATION	TEST CELL TEMP.
1	1	- - -	5	70	3	8.86	4.95	15:00	44.7°C 44.6°C
2	2	+ - -	55	70	3	57.90	9.90	15:00	44.9°C 44.2°C
3	5	- - +	5	70	9	13.86	4.48	15:00	44.9°C 44.2°C
4	6	+ - +	55	70	9	54.04	6.03	15:00	44.8°C 44.4°C
5	10	0 0 0	30	75	6	34.92	3.74	15:00	44.2°C 44.0°C
6	11	0 0 0	30	75	6	30.07	3.28	15:00	44.8°C 44.4°C
7	9	0 0 0	30	75	6	36.07	2.54	15:00	44.9°C 44.7°C
8	4	+ + -	55	80	3	20.99	2.96	12:00 6:00	44.4°C 44.0°C
9	7	- + +	5	80	9	2.13	0.47	5:00 5:00	44.9°C 44.7°C
10	3	- + -	5	80	3	8.31	0.70	7:00 5:00	44.2°C 44.8°C
11	8	+ + +	55	80	9	24.01	0.90	7:00 10:00	44.4°C 44.4°C
12	1	- - -	5	70	3	7.83	11.66	7:00 15:00	44.1°C 44.6°C
13	2	+ - -	55	70	3	83.99	8.41	15:00 15:00	44.2°C 44.4°C
14	5	- - +	5	70	9	15.01	2.83	15:00 6:00	44.4°C 44.1°C
15	6	+ - +	55	70	9	82.95	2.91	15:00 9:00	44.7°C 44.9°C

TABLE OF EFFECTS (Board Tests with Blocks)

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	32.59*	18.77*	27.21*	3.81*	15.33*	14.68*	10.73*	12.81*	9.29*
MAIN									
Residue (R)	50.88*	24.01*	37.81*	5.26*	12.28*	16.60*	10.19*	7.21*	11.83*
IPA (I)	-21.88*	-35.43*	-26.69*	-1.41	-20.51*	-11.30*		-4.39*	2.38
Volume (V)					-2.17	-4.63*	-0.93	3.18*	
Channel (C)	5.12	10.27*	0.12	1.11	1.89	0.88	0.05	-1.99	-1.05
Heat (H)						6.94*		2.12	
INTERACTION									
R*I	-17.27*	-22.08*	-20.52*	-1.96	-6.18*	-4.69*	-4.99*	-1.37	0.13
R*V					-3.92x	0.81	0.13	-0.49	
R*C	1.28	7.14	0.16	0.26	0.24	-3.16*	0.13	0.06	0.85
R*H						3.10*		1.86	
I*V					-7.98*	-3.39*	-0.48	1.54	
I*C	1.68	-8.29	-1.70	0.69	1.26	0.64	1.55	-0.89	-3.20
I*H						-0.30		2.88x	
V*C					0.29	1.19	-0.81	1.48	
V*H						1.28	0.13	-1.60	
C*H						-3.73*		-1.82	
R*I*V					-2.18		0.33		
R*I*C	3.83	-5.34	4.44	0.24	-1.14		0.34		0.10
R*V*C					1.92		0.56		
I*V*C					-3.44x		-0.74		
CENTER	53.68*	48.85*	6.48	2.36	16.11*	-0.05	10.00*	1.13	2.45

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
*** indicates a factor is statistically significant with > 95% confidence, based on experimental error.**
x indicates a factor is statistically significant with 90 - 95% confidence.

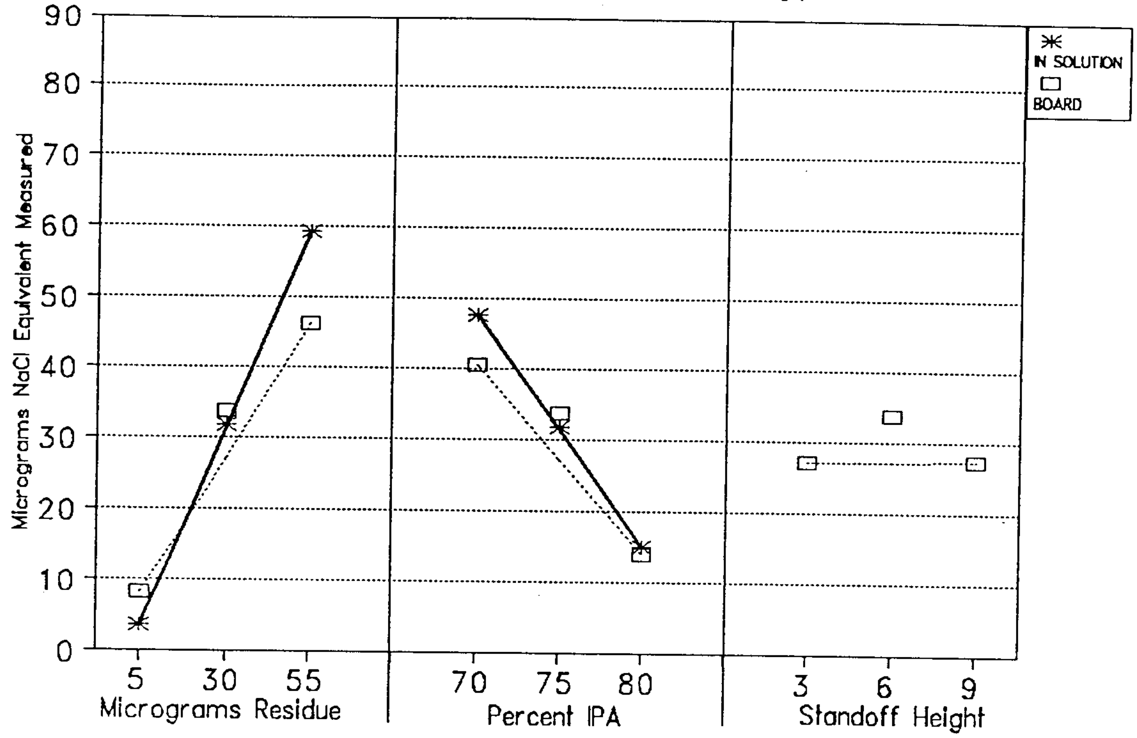
TABLE OF EFFECTS (Board Tests: Total)

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	34.01*	32.66*	31.03*	5.68*	22.01*	17.93*	13.14*	18.27*	15.06*
MAIN									
Residue (R)	51.55*	42.86*	38.89*	6.59*	17.82*	17.01*	11.33*	7.33*	13.66*
IPA (I)	-23.88*	-42.32*	-31.83*	-0.61	-27.52*	-14.33*		-4.79*	6.29x
Volume (V)					-1.23	-10.13*	-2.23	3.88	
Channel (C)	2.88	-1.90	-2.79	0.49	-0.37	0.69	0.12	-1.00	-4.49
Heat (H)						6.69*		1.61	
INTERACTION									
R*I	-18.80*	-23.04*	-20.27*	-1.54	-6.37x	-4.13*	-5.68*	-2.46	-3.66
R*V					-2.48	0.07	-0.01	-0.35	
R*C	0.00	-3.50	-0.30	-0.44	-1.09	-3.11x	-0.81	-1.21	4.51
R*H						3.14x		2.72	
I*V					-6.72x	-1.34	0.98	1.78	
I*C	3.38	-6.65	0.06	0.26	-0.03	0.43	1.63	-0.58	-2.31
I*H						0.13		4.85	
V*C					1.56	1.53	-1.54	2.20	
V*H						1.03		-3.12	
C*H						-3.94*		-2.53	
R*I*V					-2.42		1.96		
R*I*C	4.77	-3.11	3.99	-0.31	-2.36		-0.24		6.09x
R*V*C					3.58		0.36		
I*V*C					-4.41		-0.11		
CENTER	53.69*	47.23*	5.84	1.79	9.72x	1.53	8.26*	0.15	1.48

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

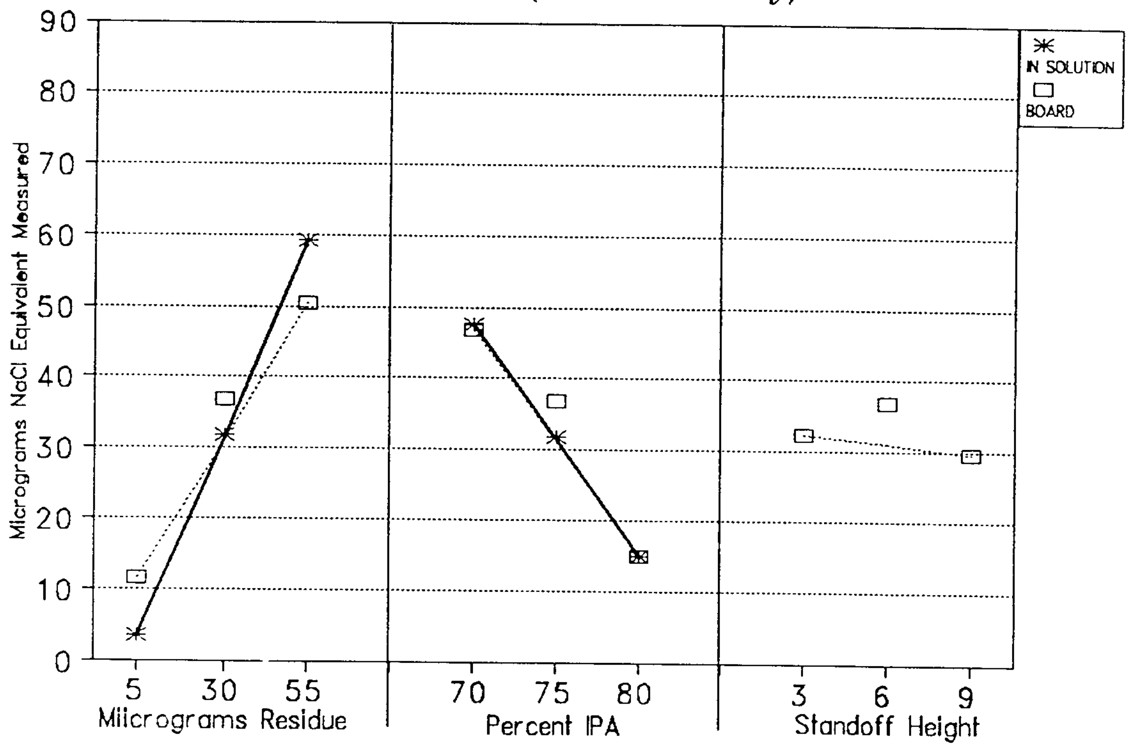
IONOGRAPH 500SMD : Board w/Block

MAIN EFFECTS (weak flux only)



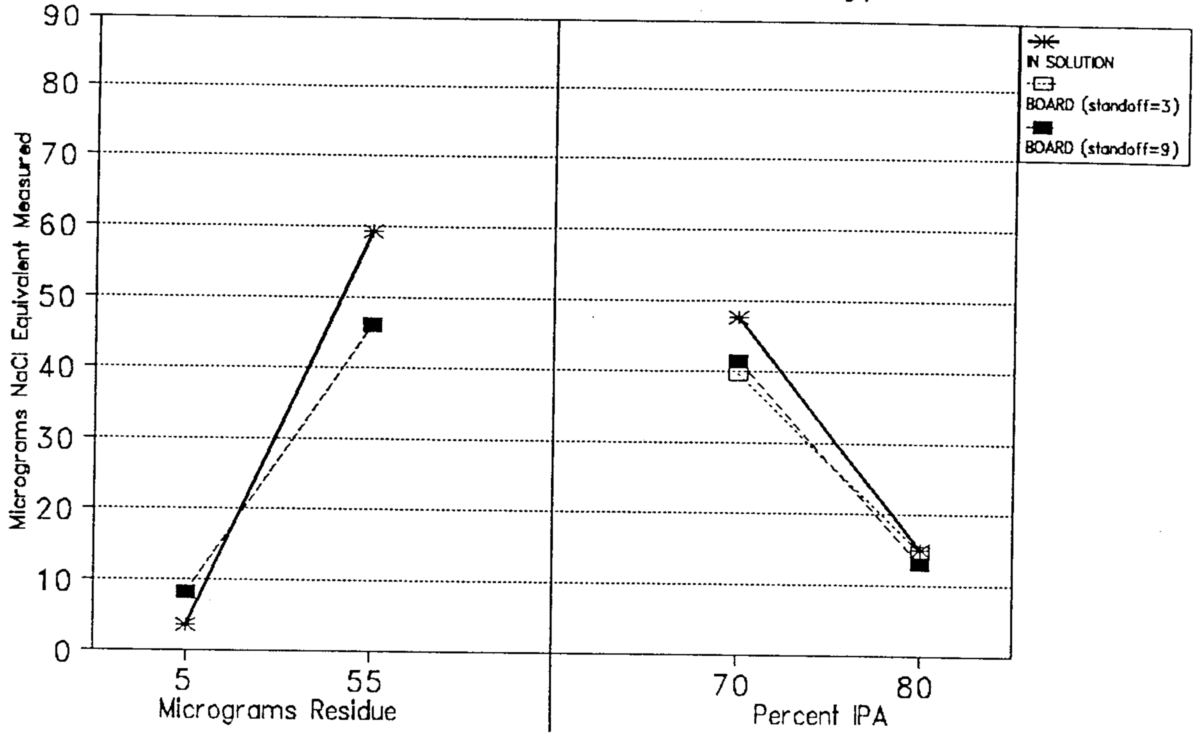
IONOGRAPH 500SMD : Board Total

MAIN EFFECTS (weak flux only)



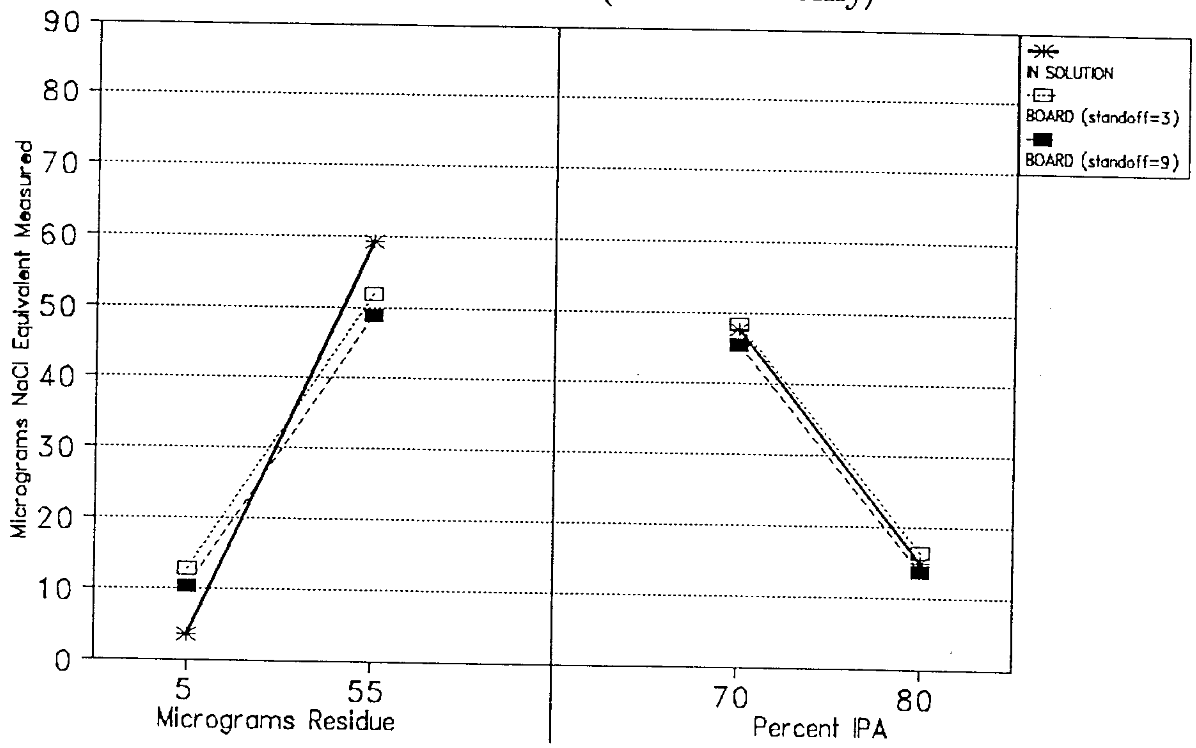
IONOGRAPH 500SMD : Board w/Block

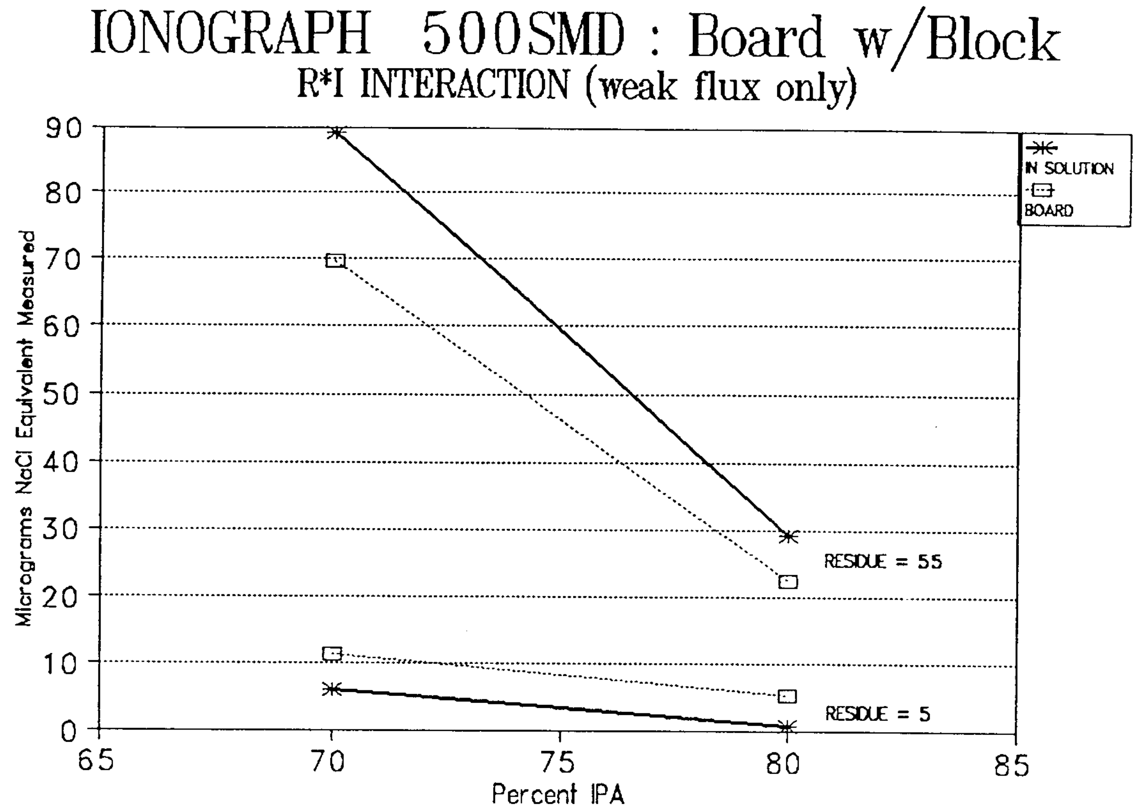
2-WAY INTERACTIONS (weak flux only)

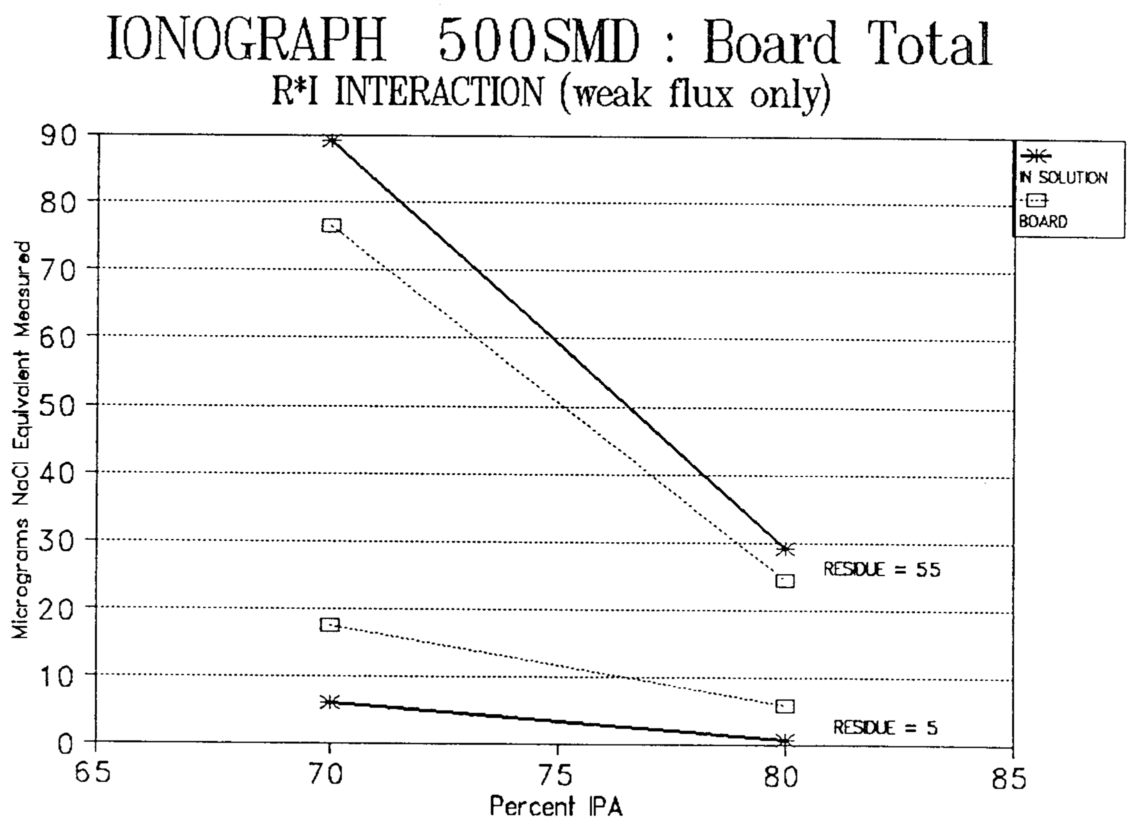


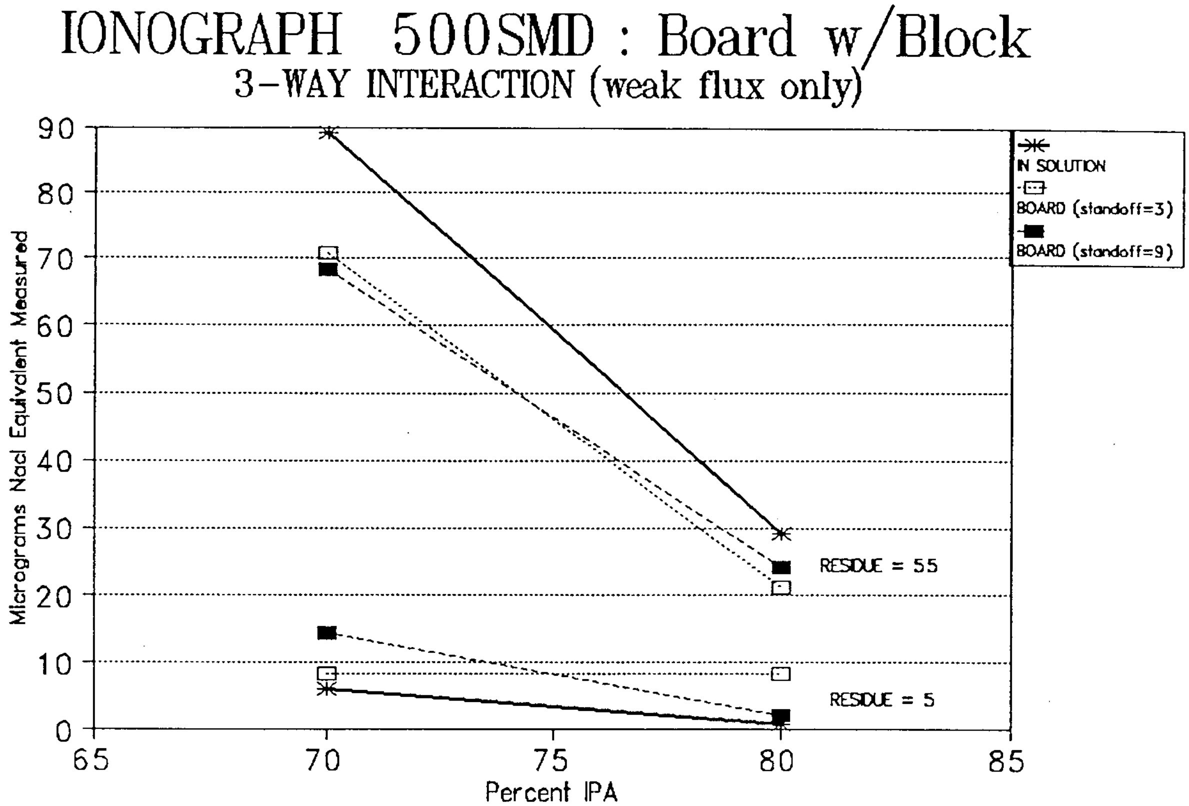
IONOGRAPH 500SMD : Board Total

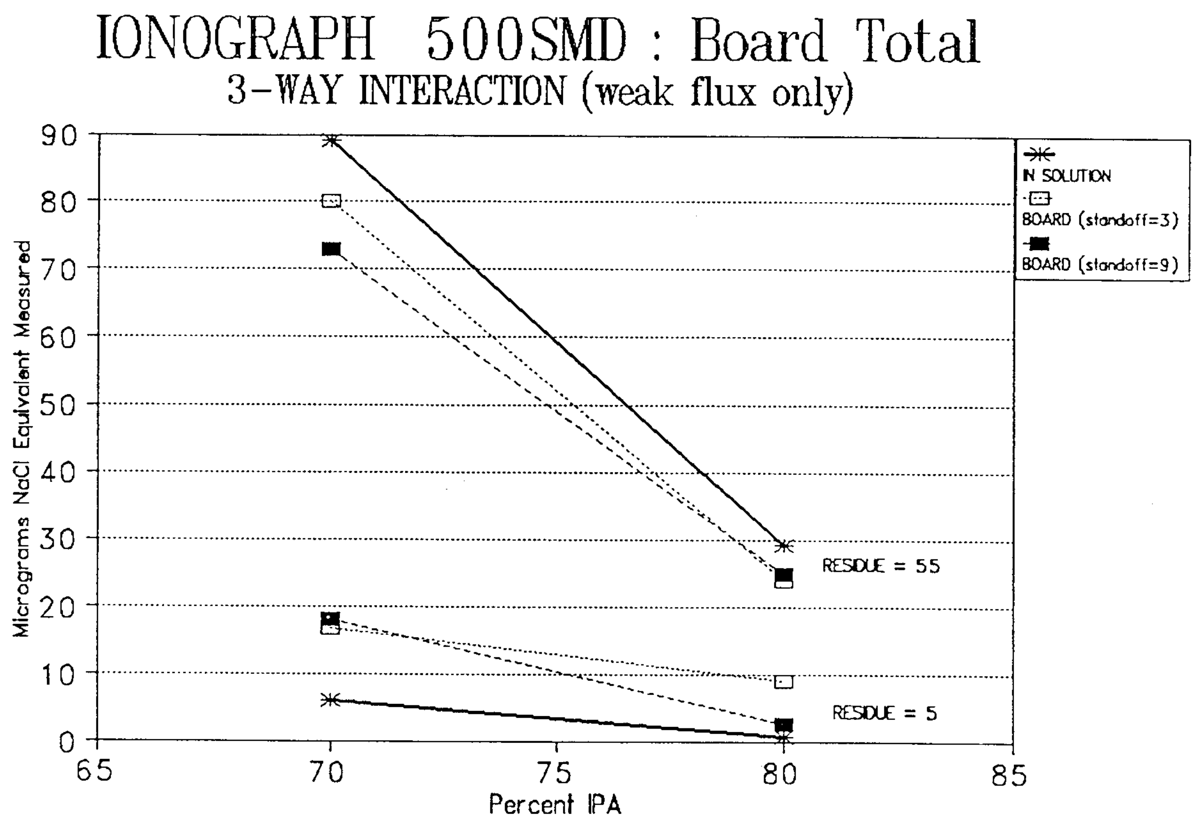
2-WAY INTERACTIONS (weak flux only)




IONOGRAPH 500SMD : Board w/Block
R*I INTERACTION (weak flux only)
Micrograms NaCl Equivalent Measured
Percent IPA
IN SOLUTION
BOARD
RESIDUE = 55
RESIDUE = 5


IONOGRAPH 500SMD : Board Total
R*I INTERACTION (weak flux only)
Micrograms NaCl Equivalent Measured
Percent IPA
IN SOLUTION
BOARD
RESIDUE = 55
RESIDUE = 5


IONOGRAPH 500SMD : Board w/Block
3-WAY INTERACTION (weak flux only)
Micrograms Nacl Equivalent Measured
Percent IPA
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)
RESIDUE = 55
RESIDUE = 5


IONOGRAPH 500SMD : Board Total
3-WAY INTERACTION (weak flux only)
Micrograms NaCl Equivalent Measured
Percent IPA
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)
RESIDUE = 55
RESIDUE = 5

IONOGRAPH 500SMD
IN SOLUTION TEST (weak flux)

Predictor	Coef	Stdev	t-ratio	p	
Constant	31.319	0.8484	36.92	0.000	*
R	27.9013	0.8484	32.89	0.000	*
I	-16.2838	0.8484	-19.19	0.000	*
R*I	-13.6562	0.8484	-16.10	0.001	*
CTR.PT	0.531	1.625	0.33	0.765	

s = 1.959 R-sq = 99.9% R-sq(adj) = 99.7%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	4	8764.1	2191.0	570.73	0.000
Error	3	11.5	3.8		
Total	7	8775.6			

SOURCE	DF	SEQ SS
R	1	6319.3
I	1	1449.7
R*I	1	994.6
CTR.PT	1	0.4

IONOGRAPH 500SMD
BOARD TEST w/BLOCK

Predictor	Coef	Stdev	t-ratio	p	
Constant	27.208	3.490	7.80	0.000	*
R	18.903	3.490	5.42	0.002	*
I	-13.347	3.490	-3.82	0.009	*
C	0.060	3.490	0.02	0.987	
R*I	-10.262	3.490	-2.94	0.026	*
R*C	0.082	3.490	0.02	0.982	
I*C	-0.850	3.490	-0.24	0.816	
R*I*C	2.218	3.490	0.64	0.549	
CTR.PT	6.479	7.450	0.87	0.418	

s = 11.40 R-sq = 92.1% R-sq(adj) = 81.5%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	9080.3	1135.0	8.73	0.008
Error	6	779.7	130.0		
Total	14	9860.1			

SOURCE	DF	SEQ SS
R	1	5980.0
I	1	1811.9
C	1	1.4
R*I	1	1123.4
R*C	1	5.2
I*C	1	7.7
R*I*C	1	52.5
CTR.PT	1	98.3

IONOGRAPH 500SMD
BOARD TEST w/BLOCK

Predictor	Coef	Stdev	t-ratio	p	
Constant	27.208	3.490	7.80	0.000	*
R	18.903	3.490	5.42	0.002	*
I	-13.347	3.490	-3.82	0.009	*
C	0.060	3.490	0.02	0.987	
R*I	-10.262	3.490	-2.94	0.026	*
R*C	0.082	3.490	0.02	0.982	
I*C	-0.850	3.490	-0.24	0.816	
R*I*C	2.218	3.490	0.64	0.549	
CTR.PT	6.479	7.450	0.87	0.418	

s = 11.40 R-sq = 92.1% R-sq(adj) = 81.5%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	9080.3	1135.0	8.73	0.008
Error	6	779.7	130.0		
Total	14	9860.1			

SOURCE	DF	SEQ SS
R	1	5980.0
I	1	1811.9
C	1	1.4
R*I	1	1123.4
R*C	1	5.2
I*C	1	7.7
R*I*C	1	52.5
CTR.PT	1	98.3

IONOGRAPH 500SMD
BOARD TEST TOTAL

Predictor	Coef	Stdev	t-ratio	p	
Constant	31.034	3.236	9.59	0.000	*
R	19.447	3.236	6.01	0.001	*
I	-15.917	3.236	-4.92	0.003	*
C	-1.393	3.236	-0.43	0.682	
R*I	-10.134	3.236	-3.13	0.020	*
R*C	-0.151	3.236	-0.05	0.964	
I*C	0.031	3.236	0.01	0.993	
R*I*C	1.993	3.236	0.62	0.561	
CTR.PT	5.839	6.906	0.85	0.430	

s = 10.57 R-sq = 93.8% R-sq(adj) = 85.5%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	10124.3	1265.5	11.33	0.004
Error	6	670.0	111.7		
Total	14	10794.4			

SOURCE	DF	SEQ SS
R	1	6251.8
I	1	2623.2
C	1	23.6
R*I	1	1095.5
R*C	1	8.0
I*C	1	0.0
R*I*C	1	42.4
CTR.PT	1	79.8

PROTONIQUE

CONTAMINOMETER CM5 (dynamic)

Dynamic
Unheated
No Spray

CONTAMINOMETER CM5/DYNAMIC MODE
RANDOMIZED EXPERIMENTAL MATRIX
PWB/WEAK FLUX TESTS

RANDOMIZED RUN SEQUENCE	STANDARD ORDER	A B C	A AMOUNT OF RESIDUE (μGR/IN²)	B IPA (VOL%)	C CHANNEL DEPTH (MILS)	IONIC READING W/BLOCK	IONIC READING WO/BLOCK	TEST DURATION W/BLK	TEST DURATION WO/BLK	TEST CELL TEMP. W/BLK	TEST CELL TEMP. WO/BLK
1	2	+ - -	55	70	3	2.5	3.5	1:36	1:36	76°F	76°F
2	6	+ - +	55	70	9	7.9	2.3	3:16	1:36	75°F	75°F
3	1	- - -	5	70	3	0.7	0.7	1:36	1:36	75°F	75°F
4	5	- - +	5	70	9	0.8	0.4	1:36	1:36	75°F	75°F
5	9	0 0 0	30	75	6	7.0	0.8	3:16	1:36	75°F	75°F
6	10	0 0 0	30	75	6	6.4	1.1	4:56	1:36	75°F	75°F
7	11	0 0 0	30	75	6	5.1	2.0	3:16	1:36	75°F	75°F
8	7	- + +	5	80	9	2.1	1.5	1:36	1:36	74°F	74°F
9	3	- + -	5	80	3	0.8	1.3	1:36	1:36	75°F	75°F
10	4	+ + -	55	80	3	3.6	4.3	3:16	3:16	76°F	76°F
11	8	+ + +	55	80	9	5.9	2.0	3:16	1:36	76°F	76°F
12	2	+ - -	55	70	3	13.3	0.7	8:16	1:36	76°F	76°F
13	6	+ - +	55	70	9	8.8	1.2	3:16	1:36	76°F	76°F
14	1	- - -	5	70	3	0.7	1.4	1:36	1:36	76°F	76°F
15	5	- - +	5	70	9	1.4	1.6	1:36	1:36	76°F	76°F

TABLE OF EFFECTS (Board Tests with Blocks)

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	32.59*	18.77*	27.21*	3.81*	15.33*	14.68*	10.73*	12.81*	9.29*
MAIN									
Residue (R)	50.88*	24.01*	37.81*	5.26*	12.28*	16.60*	10.19*	7.21*	11.83*
IPA (I)	-21.88*	-35.43*	-26.69*	-1.41	-20.51*	-11.30*		-4.39*	2.38
Volume (V)					-2.17	-4.63*	-0.93	3.18*	
Channel (C)	5.12	10.27*	0.12	1.11	1.89	0.88	0.05	-1.99	-1.05
Heat (H)						6.94*		2.12	
INTERACTION									
R*I	-17.27*	-22.08*	-20.52*	-1.96	-6.18*	-4.69*	-4.99*	-1.37	0.13
R*V					-3.92x	0.81	0.13	-0.49	
R*C	1.28	7.14	0.16	0.26	0.24	-3.16*	0.13	0.06	0.85
R*H						3.10*		1.86	
I*V					-7.98*	-3.39*	-0.48	1.54	
I*C	1.68	-8.29	-1.70	0.69	1.26	0.64	1.55	-0.89	-3.20
I*H						-0.30		2.88x	
V*C					0.29	1.19	-0.81	1.48	
V*H						1.28	0.13	-1.60	
C*H						-3.73*		-1.82	
R*I*V					-2.18		0.33		
R*I*C	3.83	-5.34	4.44	0.24	-1.14		0.34		0.10
R*V*C					1.92		0.56		
I*V*C					-3.44x		-0.74		
CENTER	53.68*	48.85*	6.48	2.36	16.11*	-0.05	10.00*	1.13	2.45

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

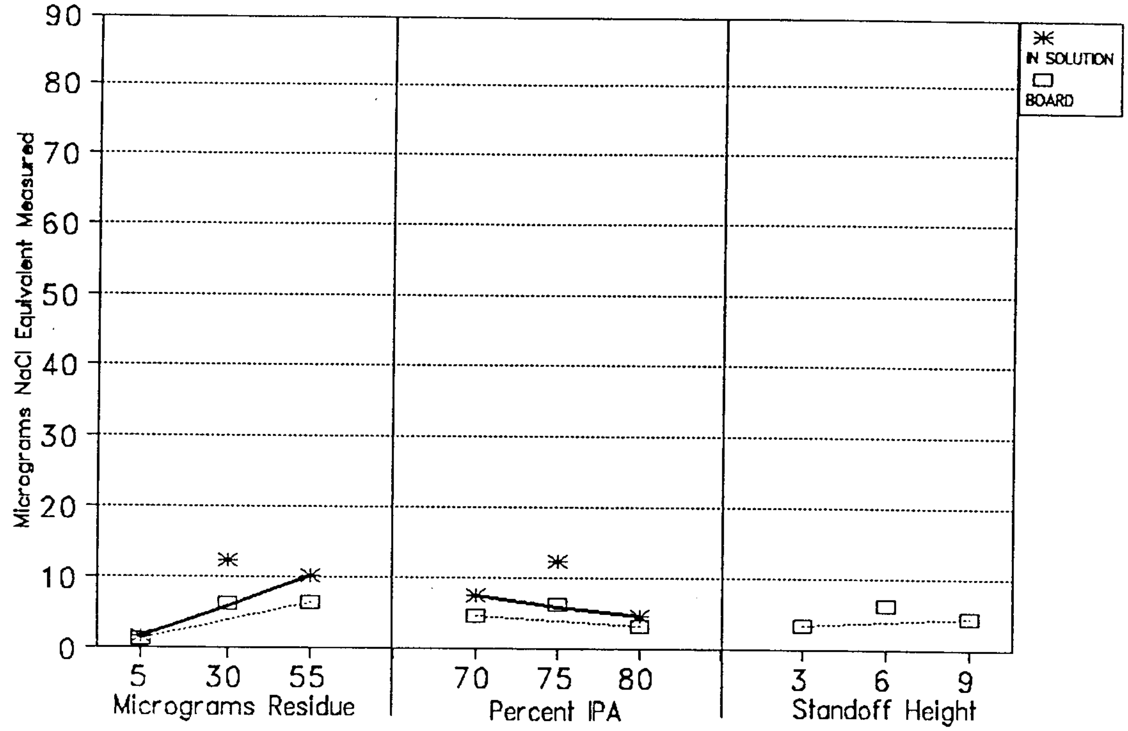
TABLE OF EFFECTS (Board Tests: Total)

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	34.01*	32.66*	31.03*	5.68*	22.01*	17.93*	13.14*	18.27*	15.06*
MAIN									
Residue (R)	51.55*	42.86*	38.89*	6.59*	17.82*	17.01*	11.33*	7.33*	13.66*
IPA (I)	-23.88*	-42.32*	-31.83*	-0.61	-27.52*	-14.33*		-4.79*	6.29x
Volume (V)					-1.23	-10.13*	-2.23	3.88	
Channel (C)	2.88	-1.90	-2.79	0.49	-0.37	0.69	0.12	-1.00	-4.49
Heat (H)						6.69*		1.61	
INTERACTION									
R*I	-18.80*	-23.04*	-20.27*	-1.54	-6.37x	-4.13*	-5.68*	-2.46	-3.66
R*V					-2.48	0.07	-0.01	-0.35	
R*C	0.00	-3.50	-0.30	-0.44	-1.09	-3.11x	-0.81	-1.21	4.51
R*H						3.14x		2.72	
I*V					-6.72x	-1.34	0.98	1.78	
I*C	3.38	-6.65	0.06	0.26	-0.03	0.43	1.63	-0.58	-2.31
I*H						0.13		4.85	
V*C					1.56	1.53	-1.54	2.20	
V*H						1.03		-3.12	
C*H						-3.94*		-2.53	
R*I*V					-2.42		1.96		
R*I*C	4.77	-3.11	3.99	-0.31	-2.36		-0.24		6.09x
R*V*C					3.58		0.36		
I*V*C					-4.41		-0.11		
CENTER	53.69*	47.23*	5.84	1.79	9.72x	1.53	8.26*	0.15	1.48

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
*** indicates a factor is statistically significant with > 95% confidence, based on experimental error.**
x indicates a factor is statistically significant with 90 - 95% confidence.

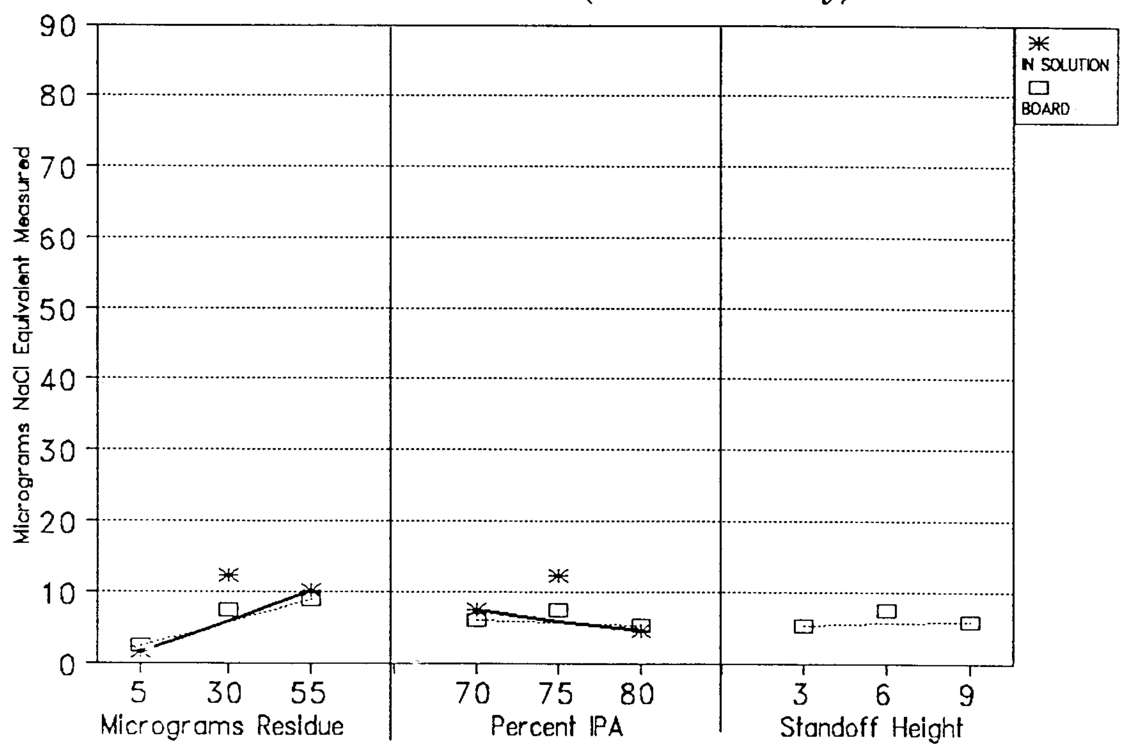
CONTAMINOMETER (dynamic): Board w/Block

MAIN EFFECTS (weak flux only)

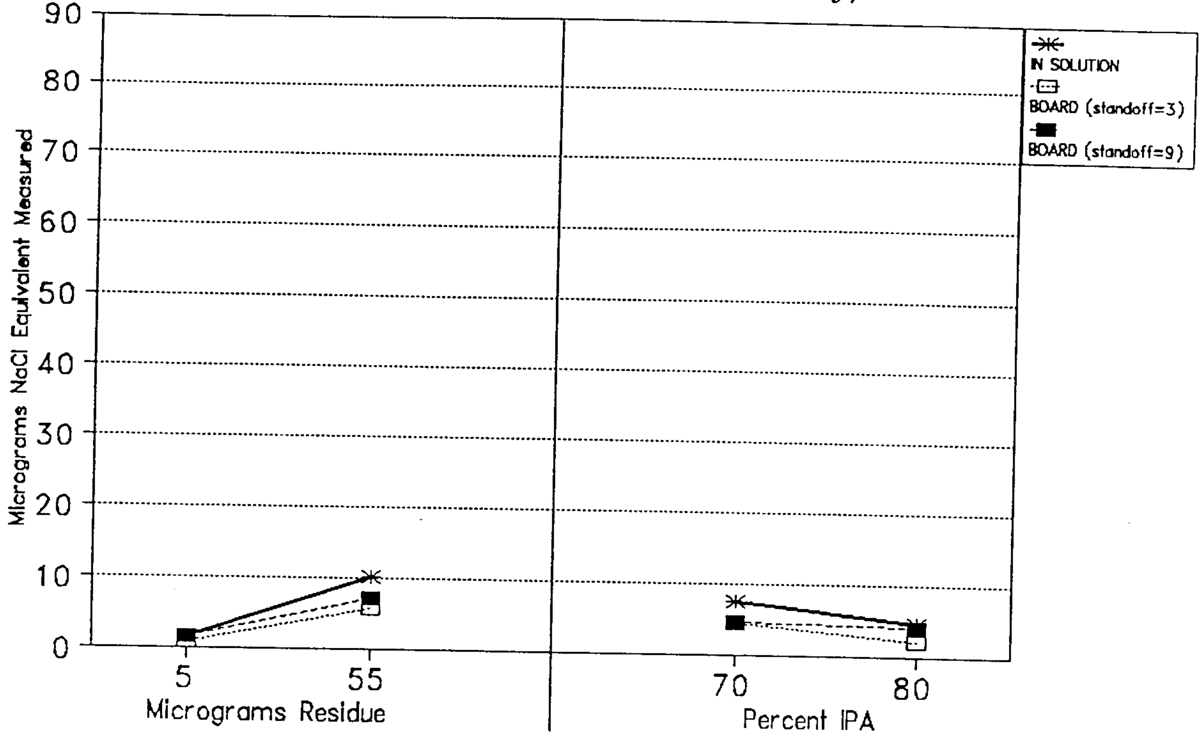


CONTAMINOMETER (dynamic) ; Board Total

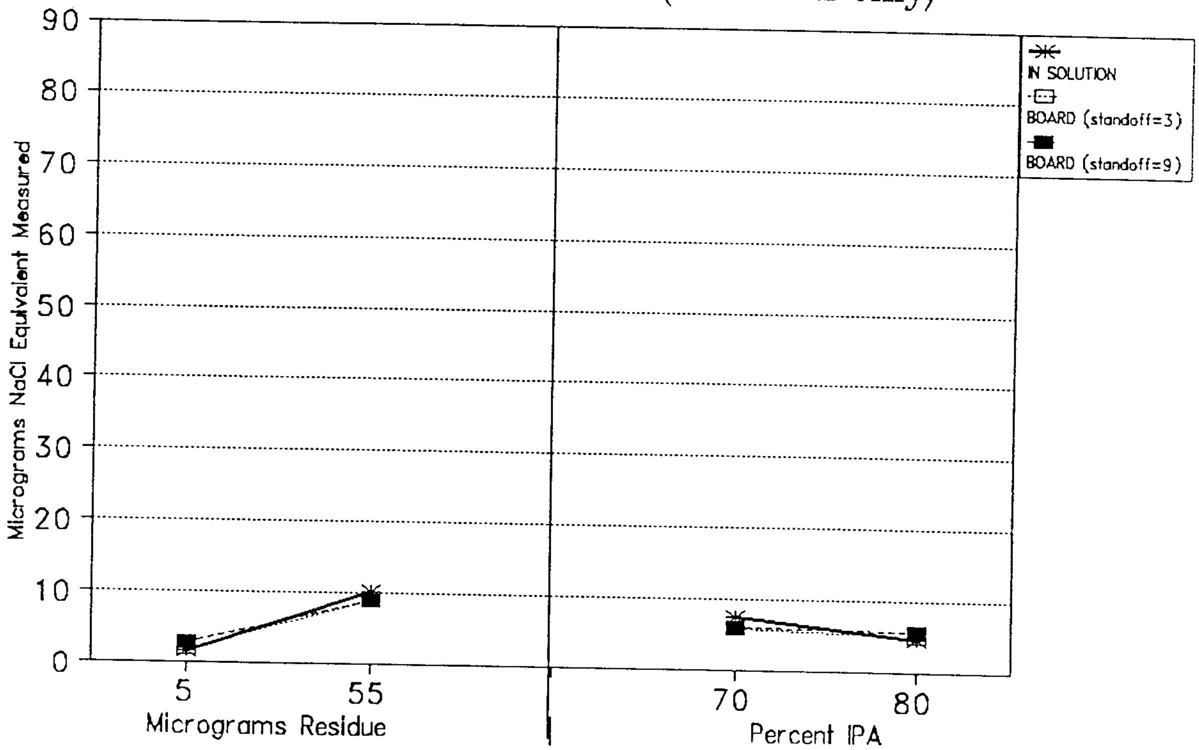
MAIN EFFECTS (weak flux only)



CONTAMINOMETER (dynamic): Board w/Block
2-WAY INTERACTIONS (weak flux only)

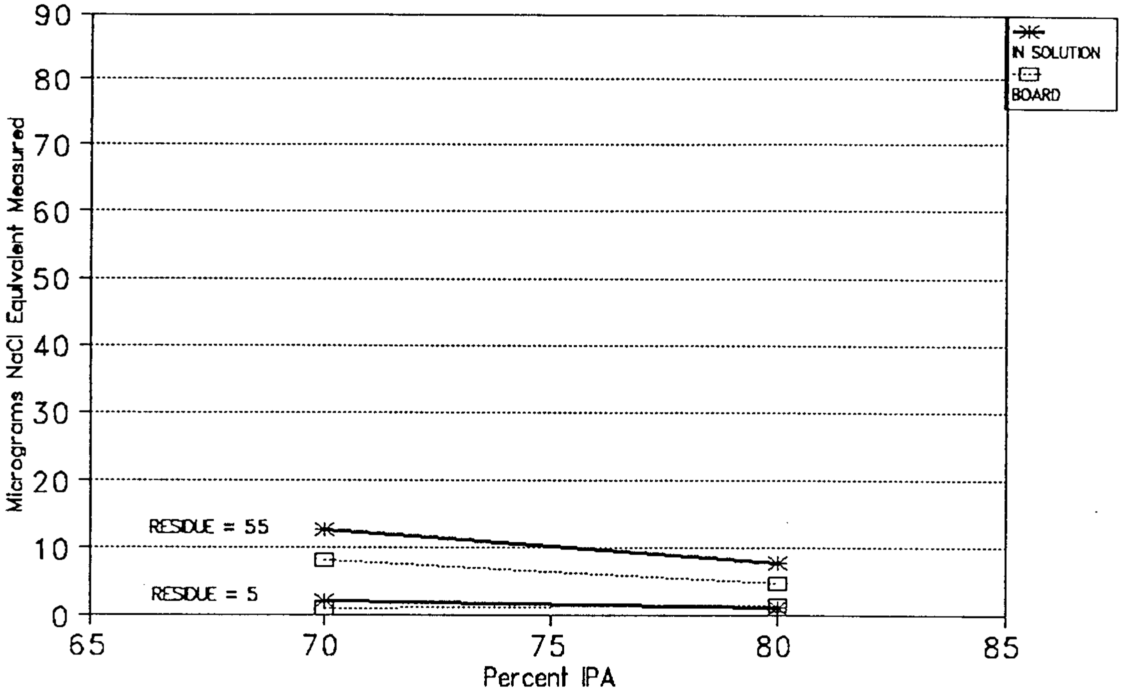


CONTAMINOMETER (dynamic) : Board Total
2-WAY INTERACTIONS (weak flux only)



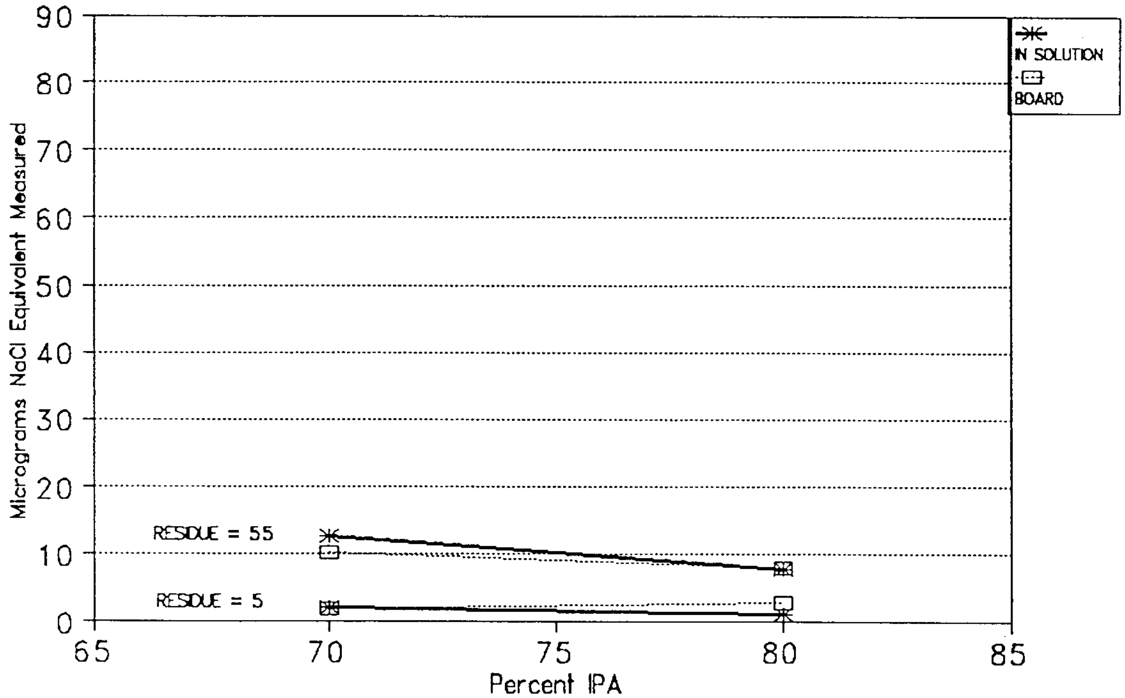
CONTAMINOMETER (dynamic): Board w/Block

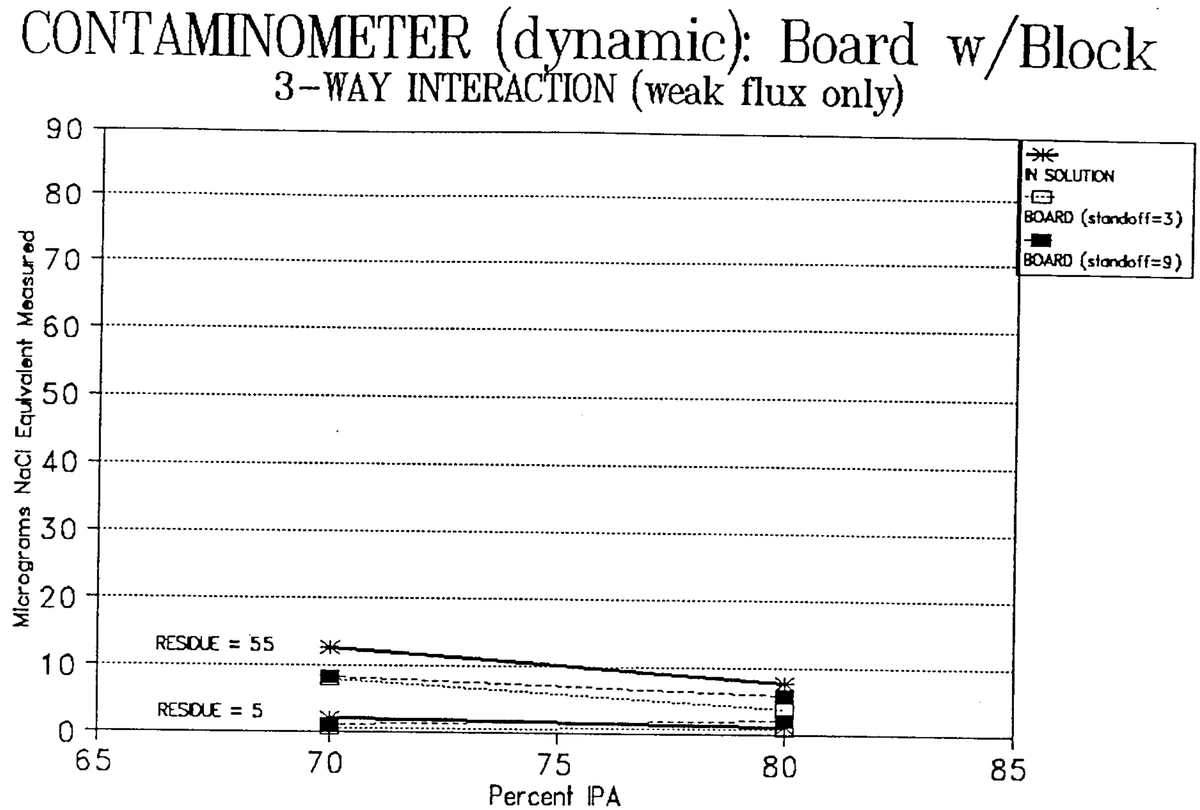
R*I INTERACTION (weak flux only)

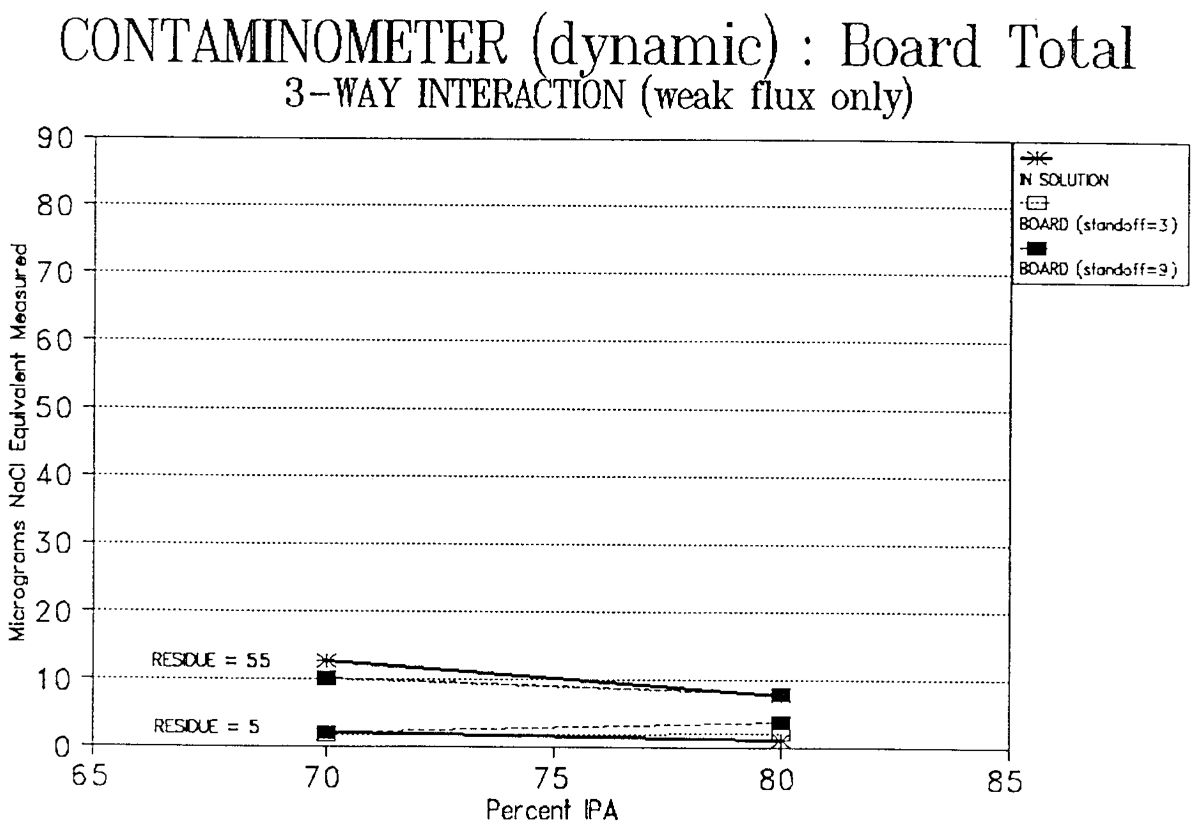


CONTAMINOMETER (dynamic) : Board Total

R*I INTERACTION (weak flux only)




CONTAMINOMETER (dynamic): Board w/Block
3-WAY INTERACTION (weak flux only)
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)
RESIDUE = 55
RESIDUE = 5
Micrograms NaCl Equivalent Measured
Percent IPA
0
10
20
30
40
50
60
70
80
90
65
70
75
80
85


CONTAMINOMETER (dynamic) : Board Total
3-WAY INTERACTION (weak flux only)
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)
RESIDUE = 55
RESIDUE = 5
Micrograms NaCl Equivalent Measured
Percent IPA
0
10
20
30
40
50
60
70
80
90
65
70
75
80
85

CONTAMINOMETER CM-5 (dynamic)
IN SOLUTION TEST (weak flux)

Predictor	Coef	Stdev	t-ratio	p	
Constant	5.887	0.9050	6.50	0.008	*
R	4.2375	0.9050	4.68	0.018	*
I	-1.4375	0.9050	-1.59	0.210	
R*I	-0.9875	0.9050	-1.09	0.355	
CTR.PT	6.413	1.733	3.70	0.034	*

s = 2.090 R-sq = 93.7% R-sq(adj) = 85.2%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	4	194.155	48.539	11.11	0.038
Error	3	13.105	4.368		
Total	7	207.260			

SOURCE	DF	SEQ SS
R	1	125.127
I	1	4.016
R*I	1	5.201
CTR.PT	1	59.811

CONTAMINOMETER CM-5 (dynamic)
BOARD TEST w/BLOCK

Predictor	Coef	Stdev	t-ratio	p	
Constant	3.807	0.9746	3.91	0.008	*
R	2.6313	0.9746	2.70	0.036	*
I	-0.7063	0.9746	-0.72	0.496	
C	0.5563	0.9746	0.57	0.589	
R*I	-0.9813	0.9746	-1.01	0.353	
R*C	0.1313	0.9746	0.13	0.897	
I*C	0.3437	0.9746	0.35	0.736	
R*I*C	0.1188	0.9746	0.12	0.907	
CTR.PT	2.360	2.080	1.13	0.300	

s = 3.183 R-sq = 69.0% R-sq(adj) = 27.7%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	135.30	16.91	1.67	0.274
Error	6	60.79	10.13		
Total	14	196.09			

SOURCE	DF	SEQ SS
R	1	105.02
I	1	3.11
C	1	2.34
R*I	1	10.27
R*C	1	0.10
I*C	1	1.26
R*I*C	1	0.15
CTR.PT	1	13.05

Unusual Observations

Obs.	R	CM5D.B	Fit	Stdev.Fit	Residual	St.Resid
1	1.00	2.500	7.900	2.251	-5.400	-2.40R
10	1.00	13.300	7.900	2.251	5.400	2.40R

CONTAMINOMETER CM-5 (dynamic)
BOARD TEST TOTAL

Predictor	Coef	Stdev	t-ratio	p	
Constant	5.682	0.7303	7.78	0.000	*
R	3.2938	0.7303	4.51	0.004	*
I	-0.3062	0.7303	-0.42	0.690	
C	0.2437	0.7303	0.33	0.750	
R*I	-0.7687	0.7303	-1.05	0.333	
R*C	-0.2188	0.7303	-0.30	0.775	
I*C	0.1313	0.7303	0.18	0.863	
R*I*C	-0.1562	0.7303	-0.21	0.838	
CTR.PT	1.785	1.559	1.15	0.296	

s = 2.385 R-sq = 83.0% R-sq(adj) = 60.3%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	166.592	20.824	3.66	0.066
Error	6	34.132	5.689		
Total	14	200.724			

SOURCE	DF	SEQ SS
R	1	151.230
I	1	0.337
C	1	0.480
R*I	1	6.304
R*C	1	0.333
I*C	1	0.184
R*I*C	1	0.260
CTR.PT	1	7.464

Unusual Observations

Obs.	R	CM5D.T	Fit	Stdev.Fit	Residual	St.Resid
1	1.00	6.000	10.000	1.687	-4.000	-2.37R
10	1.00	14.000	10.000	1.687	4.000	2.37R

ALPHA METALS

OMEGAMETER 600R

Static
Unheated
No spray

OMEGAMETER 600R
RANDOMIZED EXPERIMENTAL MATRIX
PWB/WEAK FLUX TESTS

RANDOMIZED RUN SEQUENCE	STANDARD ORDER	A B C D	A AMOUNT OF RESIDUE (μGR/IN²)	B IPA (VOL%)	D TEST CELL VOLUME (%FULL)	E CHANNEL DEPTH (MILS)	IONIC READING W/BLK	IONIC READING WO/BLK	TEST DURATION W/BLK	TEST DURATION WO/BLK	TEST CELL TEMP. W/BLK	TEST CELL TEMP. WO/BLK
1	1	- - - -	5	70	46.7	3	11.9	8.8	15:00	15:00	80°F	80°F
2	10	+ - - +	55	70	100	3	33.2	9.3	15:00	15:00	80°F	80°F
3	2	+ - - -	55	70	46.7	3	34.4	18.3	15:00	15:00	80°F	80°F
4	5	- - + -	5	70	46.7	9	9.7	7.1	15:00	15:00	78°F	78°F
5	6	+ - + -	55	70	46.7	9	30.4	7.5	15:00	15:00	80°F	80°F
6	13	- - + +	5	70	100	9	17.8	6.2	15:00	15:00	80°F	80°F
7	9	- - - +	5	70	100	3	25.2	3.9	15:00	15:00	78°F	78°F
8	14	+ - + +	55	70	100	9	39.9	2.6	15:00	15:00	80°F	80°F
9	19	0 0 0 0	30	75	73.3	6	35.3	0.9	15:00	15:00	80°F	80°F
10	17	0 0 0 0	30	75	73.3	6	35.3	0.0	15:00	15:00	80°F	80°F
11	18	0 0 0 0	30	75	73.3	6	23.7	0.0	15:00	15:00	78°F	78°F
12	16	+ + + +	55	80	100	9	0.0	5.3	9:00	9:00	79°F	79°F
13	3	- + - -	5	80	46.7	3	0.0	0.0	6:00	6:00	76°F	76°F
14	11	- + - +	5	80	100	3	0.0	2.0	7:00	7:00	77°F	77°F
15	4	+ + - -	55	80	46.7	3	14.0	8.0	15:00	15:00	78°F	78°F
16	15	- + + +	5	80	100	9	0.0	0.0	5:00	5:00	80°F	80°F
17	12	+ + - +	55	80	100	3	0.0	9.8	5:00	5:00	80°F	80°F
18	8	+ + + -	55	80	46.7	9	18.5	0.3	15:00	15:00	80°F	80°F
19	7	- + + -	5	80	46.7	9	8.1	0.0	15:00	15:00	80°F	80°F
20	1	- - - -	5	70	46.7	3	14.8	8.9	15:00	15:00	83°F	83°F
21	10	+ - - +	55	70	100	3	31.8	15.0	15:00	15:00	75°F	75°F
22	2	+ - - -	55	70	46.7	3	35.8	11.8	15:00	15:00	76°F	76°F
23	5	- - + -	5	70	46.7	9	13.9	8.5	15:00	15:00	78°F	78°F
24	6	+ - + -	55	70	46.7	9	30.5	11.9	15:00	15:00	78°F	78°F
25	13	- - + +	5	70	100	9	22.5	5.8	15:00	15:00	77°F	77°F
26	9	- - - +	5	70	100	3	15.0	9.4	15:00	15:00	78°F	78°F
27	14	+ - + +	55	70	100	9	42.5	28.0	15:00	15:00	80°F	80°F

TABLE OF EFFECTS (Board Tests with Blocks)

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Ionograph 500M	Ionograph 500SMD	CM-5 dynamic	Omegameter 600R	Omegameter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	32.59*	18.77*	27.21*	3.81*	15.33*	14.68*	10.73*	12.81*	9.29*
MAIN									
Residue (R)	50.88*	24.01*	37.81*	5.26*	12.28*	16.60*	10.19*	7.21*	11.83*
IPA (I)	-21.88*	-35.43*	-26.69*	-1.41	-20.51*	-11.30*		-4.39*	2.38
Volume (V)					-2.17	-4.63*	-0.93	3.18*	
Channel (C)	5.12	10.27*	0.12	1.11	1.89	0.88	0.05	-1.99	-1.05
Heat (H)						6.94*		2.12	
INTERACTION									
R*I	-17.27*	-22.08*	-20.52*	-1.96	-6.18*	-4.69*	-4.99*	-1.37	0.13
R*V					-3.92x	0.81	0.13	-0.49	
R*C	1.28	7.14	0.16	0.26	0.24	-3.16*	0.13	0.06	0.85
R*H						3.10*		1.86	
I*V					-7.98*	-3.39*	-0.48	1.54	
I*C	1.68	-8.29	-1.70	0.69	1.26	0.64	1.55	-0.89	-3.20
I*H						-0.30		2.88x	
V*C					0.29	1.19	-0.81	1.48	
V*H						1.28	0.13	-1.60	
C*H						-3.73*		-1.82	
R*I*V					-2.18		0.33		
R*I*C	3.83	-5.34	4.44	0.24	-1.14		0.34		0.10
R*V*C					1.92		0.56		
I*V*C					-3.44x		-0.74		
CENTER	53.68*	48.85*	6.48	2.36	16.11*	-0.05	10.00*	1.13	2.45

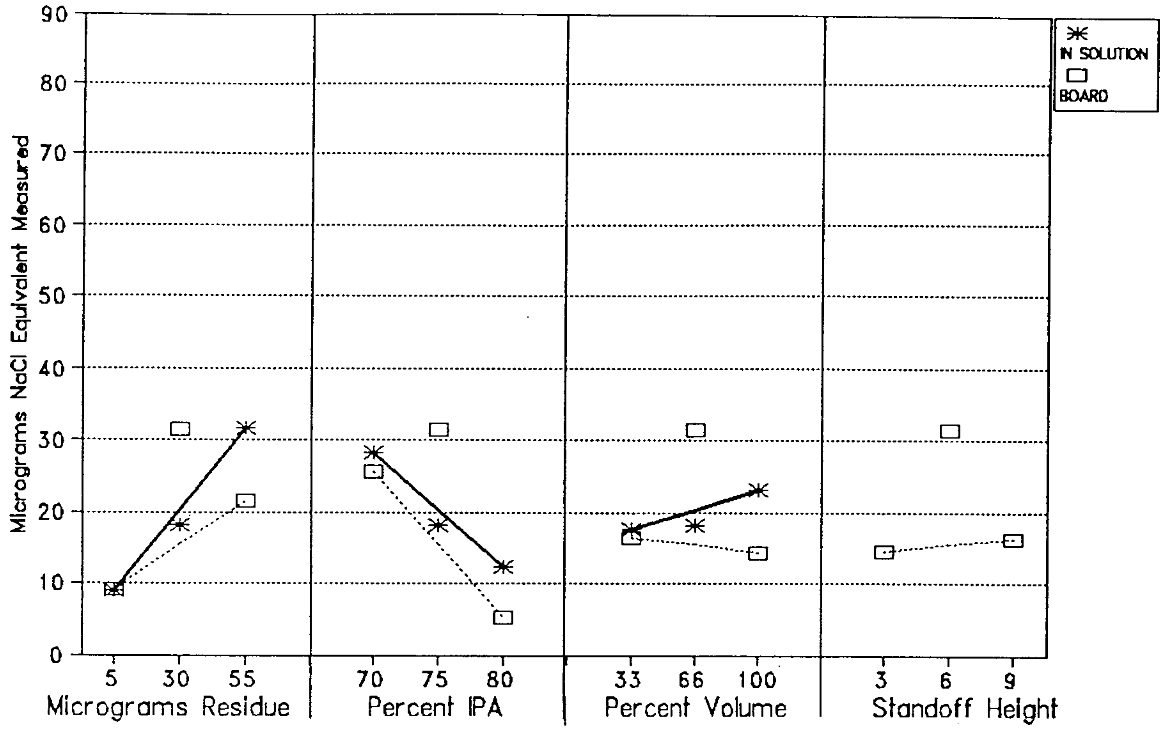
Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

TABLE OF EFFECTS (Board Tests: Total)

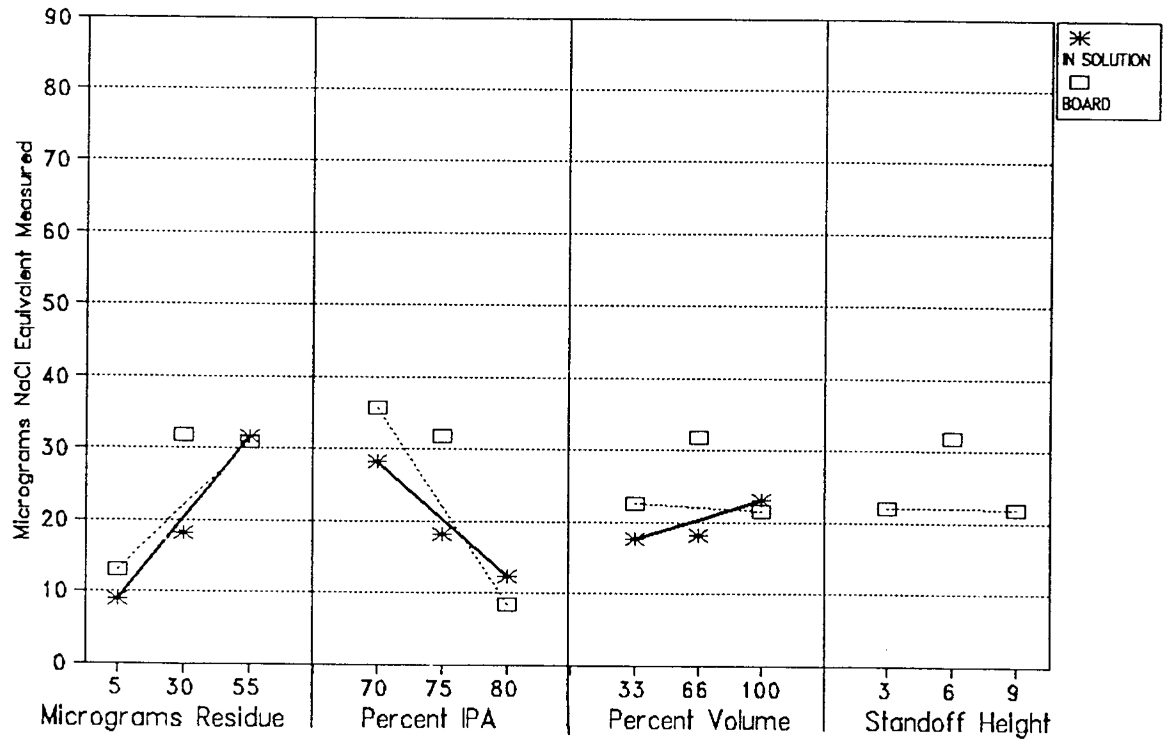
	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	34.01*	32.66*	31.03*	5.68*	22.01*	17.93*	13.14*	18.27*	15.06*
MAIN									
Residue (R)	51.55*	42.86*	38.89*	6.59*	17.82*	17.01*	11.33*	7.33*	13.66*
IPA (I)	-23.88*	-42.32*	-31.83*	-0.61	-27.52*	-14.33*		-4.79*	6.29x
Volume (V)					-1.23	-10.13*	-2.23	3.88	
Channel (C)	2.88	-1.90	-2.79	0.49	-0.37	0.69	0.12	-1.00	-4.49
Heat (H)						6.69*		1.61	
INTERACTION									
R*I	-18.80*	-23.04*	-20.27*	-1.54	-6.37x	-4.13*	-5.68*	-2.46	-3.66
R*V					-2.48	0.07	-0.01	-0.35	
R*C	0.00	-3.50	-0.30	-0.44	-1.09	-3.11x	-0.81	-1.21	4.51
R*H						3.14x		2.72	
I*V					-6.72x	-1.34	0.98	1.78	
I*C	3.38	-6.65	0.06	0.26	-0.03	0.43	1.63	-0.58	-2.31
I*H						0.13		4.85	
V*C					1.56	1.53	-1.54	2.20	
V*H						1.03		-3.12	
C*H						-3.94*		-2.53	
R*I*V					-2.42		1.96		
R*I*C	4.77	-3.11	3.99	-0.31	-2.36		-0.24		6.09x
R*V*C					3.58		0.36		
I*V*C					-4.41		-0.11		
CENTER	53.69*	47.23*	5.84	1.79	9.72x	1.53	8.26*	0.15	1.48

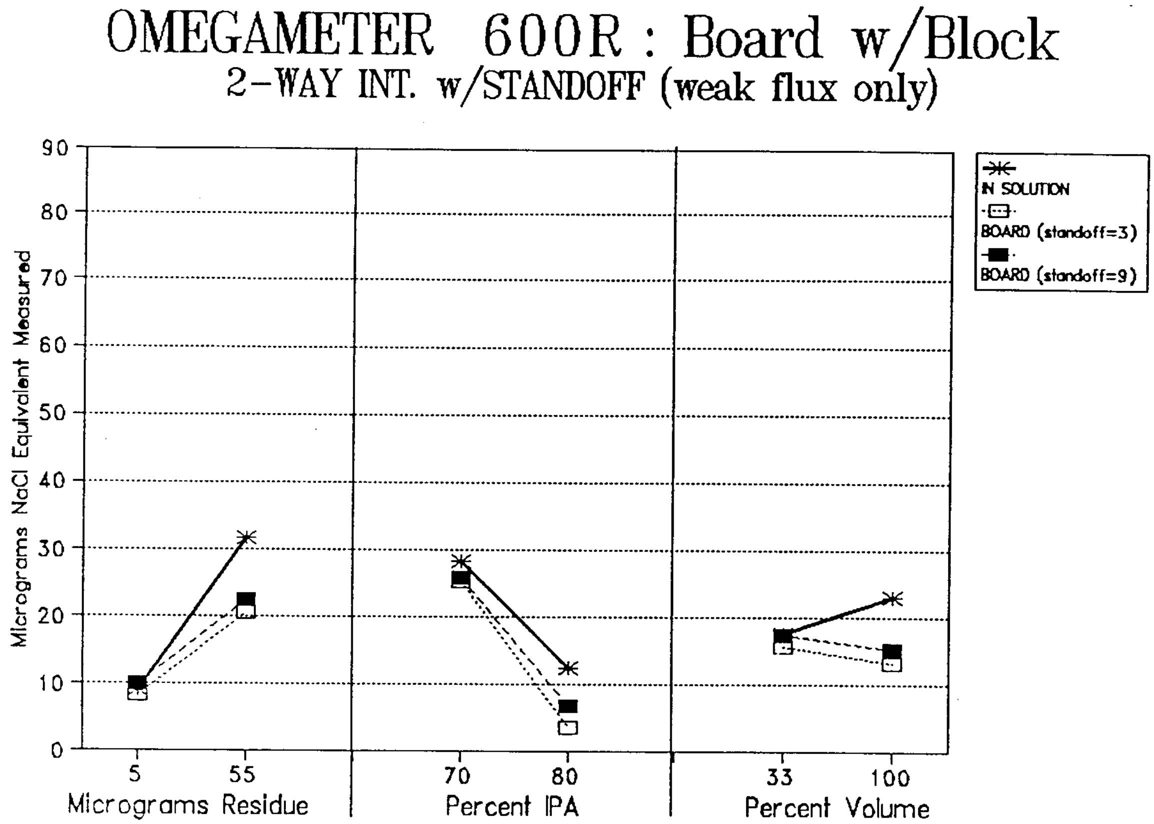
Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

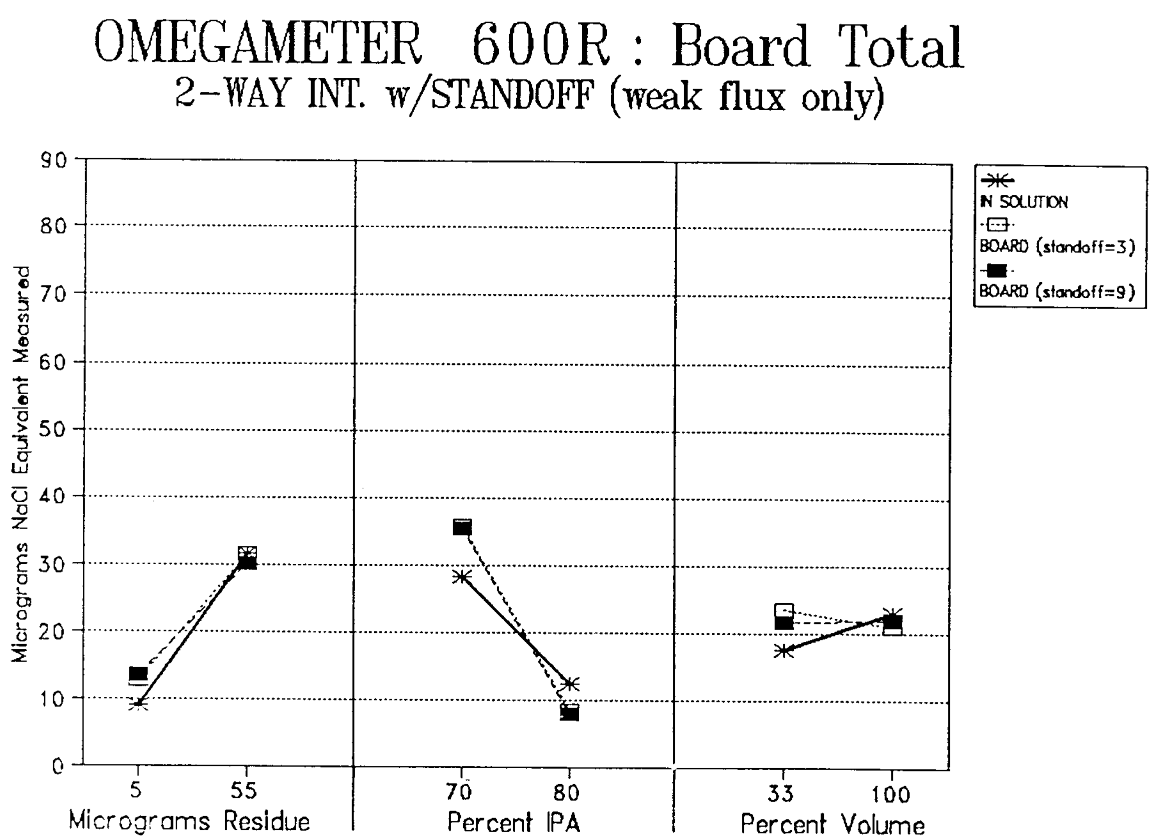
OMEGAMETER 600R : Board w/Block
MAIN EFFECTS (weak flux only)



OMEGAMETER 600R : Board Total
MAIN EFFECTS (weak flux only)

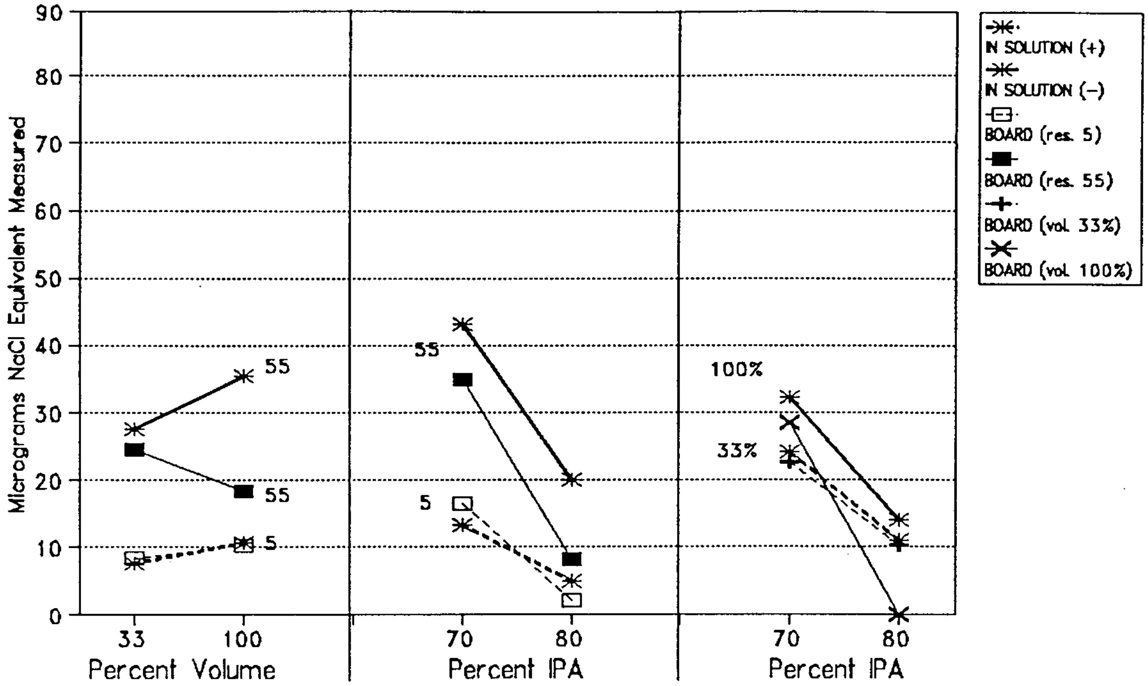



OMEGAMETER 600R : Board w/Block
2-WAY INT. w/STANDOFF (weak flux only)
Micrograms NaCl Equivalent Measured
0
10
20
30
40
50
60
70
80
90
5
55
Micrograms Residue
70
80
Percent IPA
33
100
Percent Volume
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)


OMEGAMETER 600R : Board Total
2-WAY INT. w/STANDOFF (weak flux only)
Micrograms NaCl Equivalent Measured
0
10
20
30
40
50
60
70
80
90
5
55
Micrograms Residue
70
80
Percent IPA
33
100
Percent Volume
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)

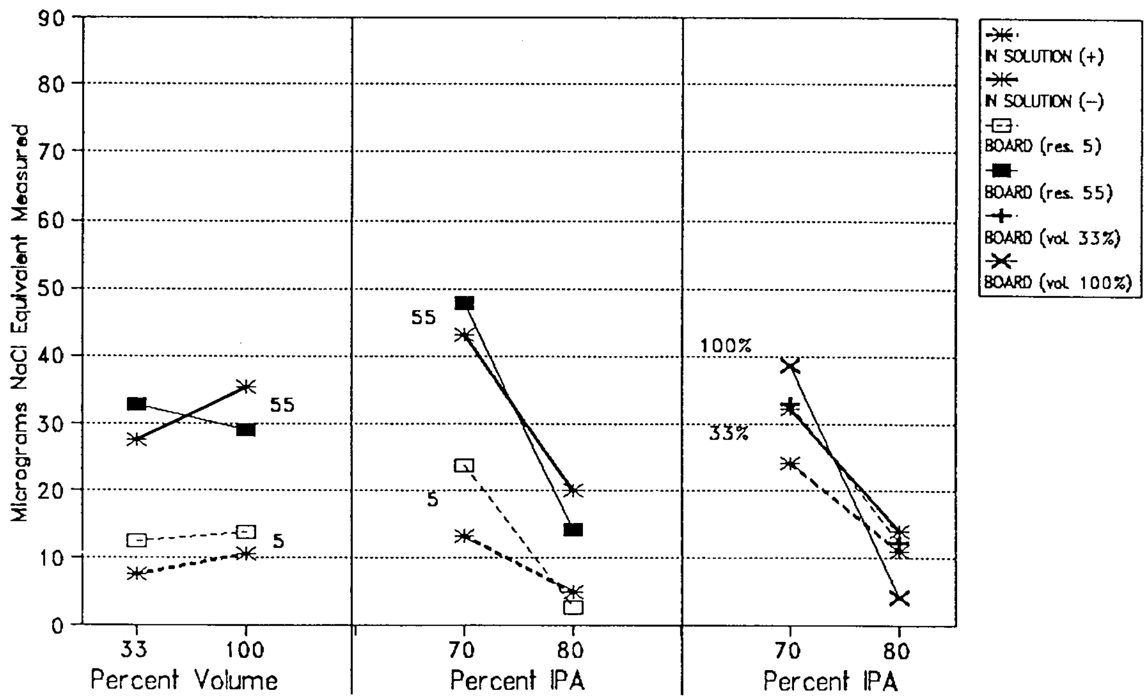
OMEGAMETER 600R : Board w/Block

OTHER 2-WAY INT. (weak flux only)



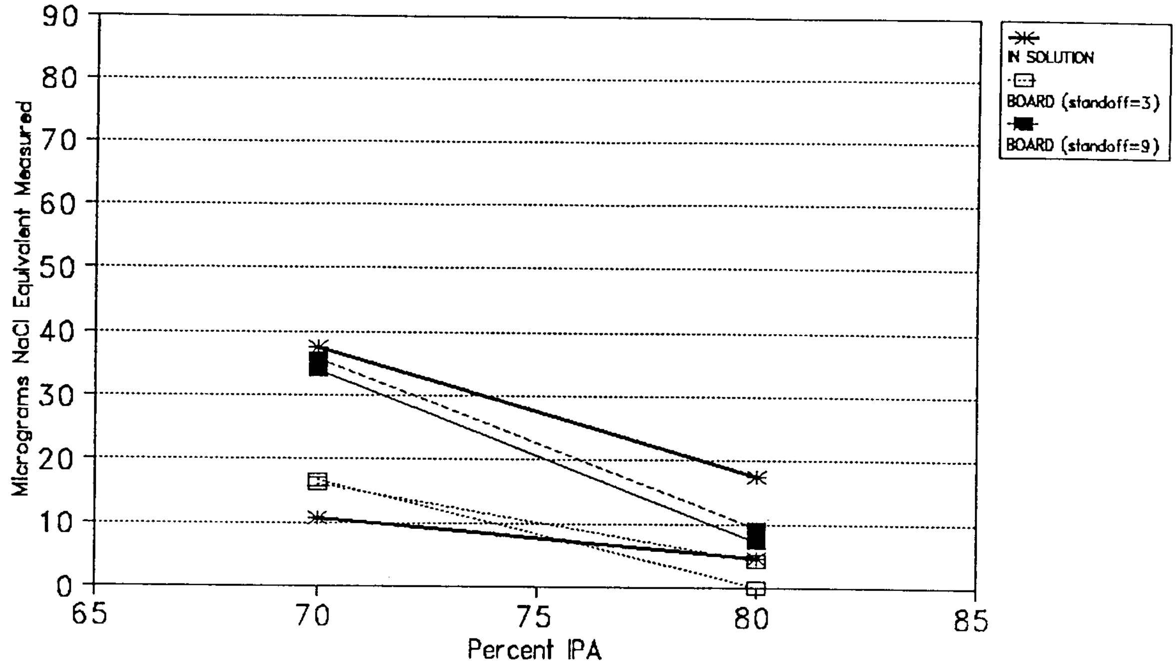
OMEGAMETER 600R : Board Total

OTHER 2-WAY INT. (weak flux only)



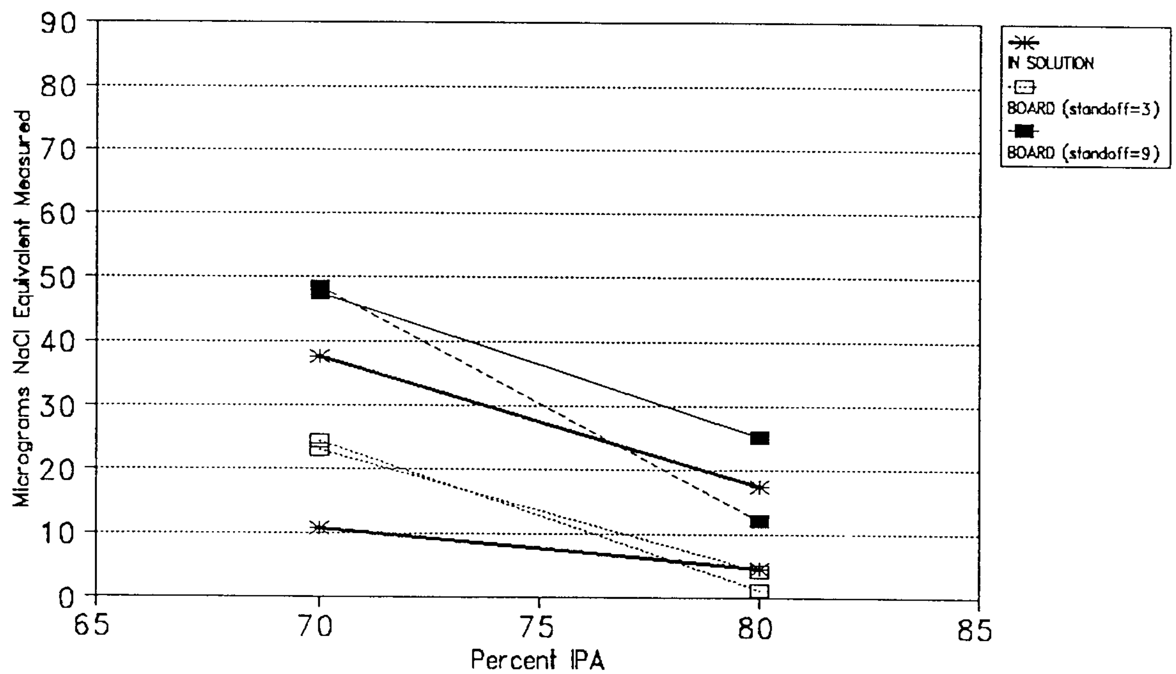
OMEGAMETER 600R : Board w/Block

3-WAY INTERACTION



OMEGAMETER 600R : Board Total

3-WAY INTERACTION



OMEGAMETER 600R
IN SOLUTION TEST (weak flux)

Predictor	Coef	Stdev	t-ratio	p	
Constant	20.3000	0.1719	118.09	0.000	*
R	11.2500	0.1719	65.44	0.000	*
I	-7.9000	0.1719	-45.95	0.000	*
V	2.7750	0.1719	16.14	0.000	*
R*I	-3.7500	0.1719	-21.81	0.000	*
R*V	1.3833	0.1621	8.53	0.000	*
I*V	-1.3250	0.1719	-7.71	0.000	*
CTR.PT	-2.1500	0.4327	-4.97	0.003	*

s = 0.5615 R-sq = 99.9% R-sq(adj) = 99.9%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	7	2895.78	413.68	1312.12	0.000
Error	6	1.89	0.32		
Total	13	2897.67			

SOURCE	DF	SEQ SS
R	1	1875.00
I	1	697.14
V	1	124.16
R*I	1	150.00
R*V	1	22.96
I*V	1	18.73
CTR.PT	1	7.79

OMEGAMETER 600R
BOARD TEST w/BLOCK

Predictor	Coef	Stdev	t-ratio	p	
Constant	15.328	0.8957	17.11	0.000	*
R	6.1406	0.8957	6.86	0.000	*
I	-10.2531	0.8957	-11.45	0.000	*
V	-1.0844	0.8957	-1.21	0.254	
C	0.9469	0.8957	1.06	0.315	
R*I	-3.0906	0.8957	-3.45	0.006	*
R*V	-1.9594	0.8957	-2.19	0.054	x
R*C	0.1219	0.8957	0.14	0.894	
I*V	-3.9906	0.8957	-4.46	0.001	*
I*C	0.6281	0.8957	0.70	0.499	
V*C	0.1469	0.8957	0.16	0.873	
R*I*V	-1.0906	0.8957	-1.22	0.251	
R*I*C	-0.5719	0.8957	-0.64	0.538	
R*V*C	0.9594	0.8957	1.07	0.309	
I*V*C	-1.7219	0.8957	-1.92	0.083	x
R*I*V*C	-0.5094	0.8957	-0.57	0.582	
CTR.PT	16.105	2.551	6.31	0.000	*

s = 4.137 R-sq = 96.5% R-sq(adj) = 90.8%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	16	4680.17	292.51	17.09	0.000
Error	10	171.14	17.11		
Total	26	4851.31			

SOURCE	DF	SEQ SS
R	1	1234.10
I	1	1989.76
V	1	1.45
C	1	13.05
R*I	1	203.78
R*V	1	61.12
R*C	1	2.34
I*V	1	339.74
I*C	1	8.42
V*C	1	12.47
R*I*V	1	25.38
R*I*C	1	6.98
R*V*C	1	30.60
I*V*C	1	63.25
R*I*V*C	1	5.54
CTR.PT	1	682.20

Unusual Observations

Obs.	R	OMR.B	Fit	Stdev.Fit	Residual	St.Resid
35	0.00	23.700	31.433	2.388	-7.733	-2.29R

R denotes an obs. with a large st. resid.

OMEGAMETER 600R
BOARD TEST TOTAL

Predictor	Coef	Stdev	t-ratio	p	
Constant	22.009	1.623	13.56	0.000	*
R	8.909	1.623	5.49	0.000	*
I	-13.759	1.623	-8.48	0.000	*
V	-0.616	1.623	-0.38	0.712	
C	-0.184	1.623	-0.11	0.912	
R*I	-3.184	1.623	-1.96	0.078	x
R*V	-1.241	1.623	-0.76	0.462	
R*C	-0.547	1.623	-0.34	0.743	
I*V	-3.359	1.623	-2.07	0.065	x
I*C	-0.016	1.623	-0.01	0.993	
V*C	0.778	1.623	0.48	0.642	
R*I*V	-1.209	1.623	-0.75	0.473	
R*I*C	-1.178	1.623	-0.73	0.485	
R*V*C	1.791	1.623	1.10	0.296	
I*V*C	-2.203	1.623	-1.36	0.205	
R*I*V*C	-0.691	1.623	-0.43	0.679	
CTR.PT	9.724	4.623	2.10	0.062	x

s = 7.497 R-sq = 92.9% R-sq(adj) = 81.4%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	16	7304.05	456.50	8.12	0.001
Error	10	562.05	56.21		
Total	26	7866.10			

SOURCE	DF	SEQ SS
R	1	2386.02
I	1	3860.53
V	1	6.10
C	1	0.77
R*I	1	216.33
R*V	1	16.83
R*C	1	0.57
I*V	1	240.76
I*C	1	0.01
V*C	1	54.90
R*I*V	1	31.20
R*I*C	1	29.61
R*V*C	1	98.01
I*V*C	1	103.55
R*I*V*C	1	10.18
CTR.PT	1	248.69

Unusual Observations

Obs.	R	OMR.T	Fit	Stdev.Fit	Residual	St.Resid
11	1.00	42.50	56.50	5.30	-14.00	-2.64R
28	1.00	70.50	56.50	5.30	14.00	2.64R

R denotes an obs. with a large st. resid.

ALPHA METALS

OMEGAMETER 600SMD

Static
Heated
Spray below immersion

OMEGAMETER 600SMD
RANDOMIZED EXPERIMENTAL MATRIX
PWB/WEAK FLUX TESTS

RANDOMIZED RUN SEQUENCE	STANDARD ORDER	A B C D E	A AMOUNT OF RESIDUE (μGR/IN²)	B IPA (VOL%)	C SOLUTION TEMP. (ON/OFF)	D TEST CELL VOLUME (%FULL)	E CHANNEL DEPTH (MILS)	IONIC READING W/BLK	IONIC READING WO/BLK	TEST DURATION W/BLK	TEST DURATION WO/BLK	TEST CELL TEMP. W/BLK	TEST CELL TEMP. WO/BLK
1	2	+ - - - -	55	70	OFF	33	3	26.8	8.3	15:00	15:00	96°F	96°F
2	1	- - - - +	5	70	OFF	33	9	11.8	10.2	15:00	15:00	96°F	97°F
3	9	- - - + -	5	70	OFF	100	3	0.0	3.3	15:00	15:00	95°F	96°F
4	10	+ - - + +	55	70	OFF	100	9	29.4	1.1	15:00	15:00	96°F	97°F
5	4	+ + - - +	55	80	OFF	33	9	15.4	5.0	15:00	15:00	95°F	96°F
6	3	- + - - -	5	80	OFF	33	3	3.6	5.2	15:00	15:00	96°F	96°F
7	11	- + - + +	5	80	OFF	100	9	2.1	0.0	15:00	15:00	98°F	98°F
8	12	+ + - + -	55	80	OFF	100	3	0.0	0.0	15:00	15:00	98°F	98°F
9	17	0 0 0 0 0	30	75	ON	66	6	17.5	2.2	15:00	15:00	111°F	113°F
10	19	0 0 0 0 0	30	75	ON	66	6	16.3	7.5	15:00	15:00	114°F	114°F
11	18	0 0 0 0 0	30	75	ON	66	6	20.5	4.4	15:00	15:00	115°F	115°F
12	6	+ - + - +	55	70	ON	33	9	31.8	8.4	15:00	15:00	108°F	115°F
13	14	+ - + + -	55	70	ON	100	3	39.3	0.0	15:00	15:00	113°F	112°F
14	5	- - + - -	5	70	ON	33	3	12.9	8.3	15:00	15:00	109°F	111°F
15	13	- - + + +	5	70	ON	100	9	11.8	1.0	15:00	15:00	110°F	114°F
16	8	+ + + - -	55	80	ON	33	3	26.1	5.0	15:00	15:00	110°F	111°F
17	15	- + + + -	5	80	ON	100	3	0.0	0.0	15:00	15:00	112°F	112°F
18	7	- + + - +	5	80	ON	33	9	8.5	2.3	15:00	15:00	114°F	115°F
19	16	+ + + + +	55	80	ON	100	9	14.8	0.0	15:00	15:00	116°F	116°F
20	2	+ - - - -	55	70	OFF	33	3	26.9	9.8	15:00	15:00	98°F	99°F
21	1	- - - - +	5	70	OFF	33	9	12.7	6.6	15:00	15:00	101°F	100°F
22	9	- - - + -	5	70	OFF	100	3	3.6	0.0	15:00	15:00	100°F	99°F
23	10	+ - - + +	55	70	OFF	100	9	22.5	1.5	15:00	15:00	98°F	98°F
24	4	+ + - - +	55	80	OFF	33	9	14.2	2.7	15:00	15:00	93°F	93°F
25	3	- + - - -	5	80	OFF	33	3	1.9	0.2	15:00	15:00	89°F	100°F
26	11	- + - + +	5	80	OFF	100	9	0.0	0.0	15:00	15:00	100°F	100°F
27	12	+ + - + -	55	80	OFF	100	3	8.5	0.0	15:00	15:00	100°F	100°F

TABLE OF EFFECTS (Board Tests with Blocks)

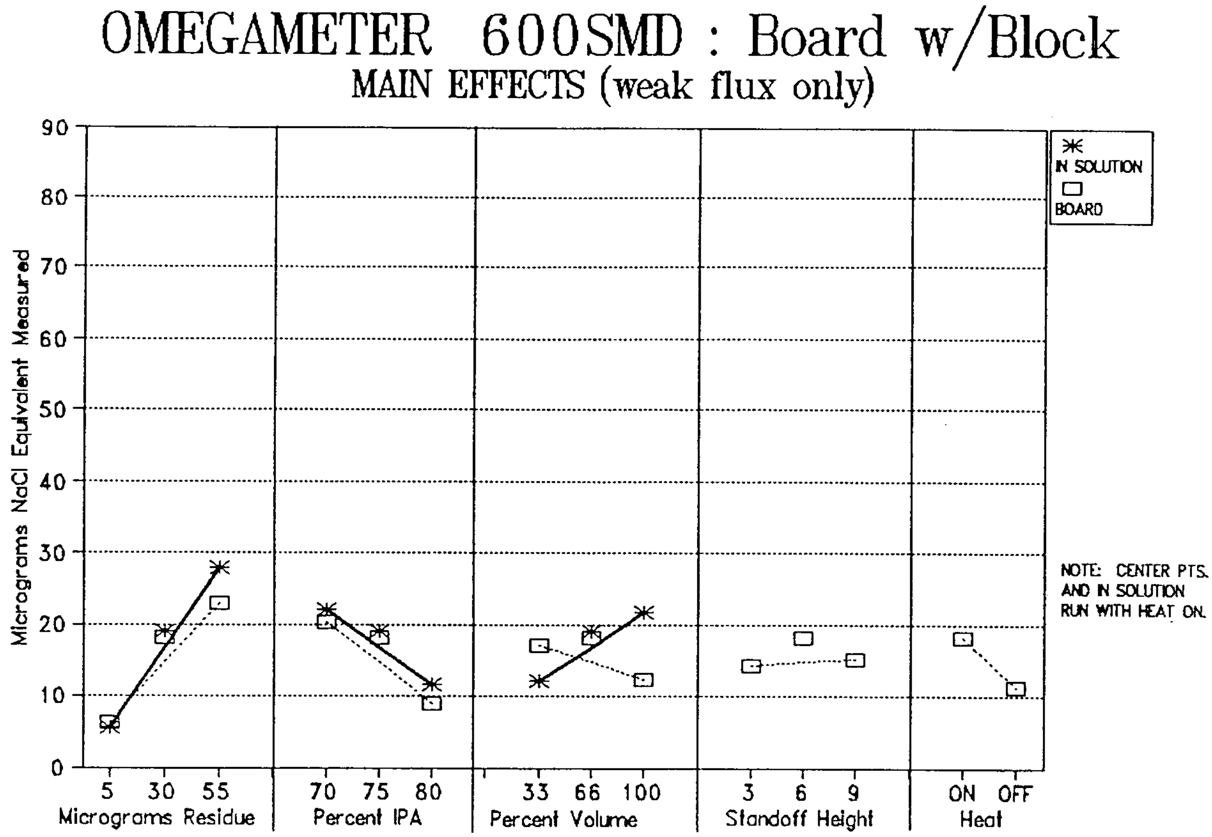
	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	32.59*	18.77*	27.21*	3.81*	15.33*	14.68*	10.73*	12.81*	9.29*
MAIN									
Residue (R)	50.88*	24.01*	37.81*	5.26*	12.28*	16.60*	10.19*	7.21*	11.83*
IPA (I)	-21.88*	-35.43*	-26.69*	-1.41	-20.51*	-11.30*		-4.39*	2.38
Volume (V)					-2.17	-4.63*	-0.93	3.18*	
Channel (C)	5.12	10.27*	0.12	1.11	1.89	0.88	0.05	-1.99	-1.05
Heat (H)						6.94*		2.12	
INTERACTION									
R*I	-17.27*	-22.08*	-20.52*	-1.96	-6.18*	-4.69*	-4.99*	-1.37	0.13
R*V					-3.92x	0.81	0.13	-0.49	
R*C	1.28	7.14	0.16	0.26	0.24	-3.16*	0.13	0.06	0.85
R*H						3.10*		1.86	
I*V					-7.98*	-3.39*	-0.48	1.54	
I*C	1.68	-8.29	-1.70	0.69	1.26	0.64	1.55	-0.89	-3.20
I*H						-0.30		2.88x	
V*C					0.29	1.19	-0.81	1.48	
V*H						1.28	0.13	-1.60	
C*H						-3.73*		-1.82	
R*I*V					-2.18		0.33		
R*I*C	3.83	-5.34	4.44	0.24	-1.14		0.34		0.10
R*V*C					1.92		0.56		
I*V*C					-3.44x		-0.74		
CENTER	53.68*	48.85*	6.48	2.36	16.11*	-0.05	10.00*	1.13	2.45

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

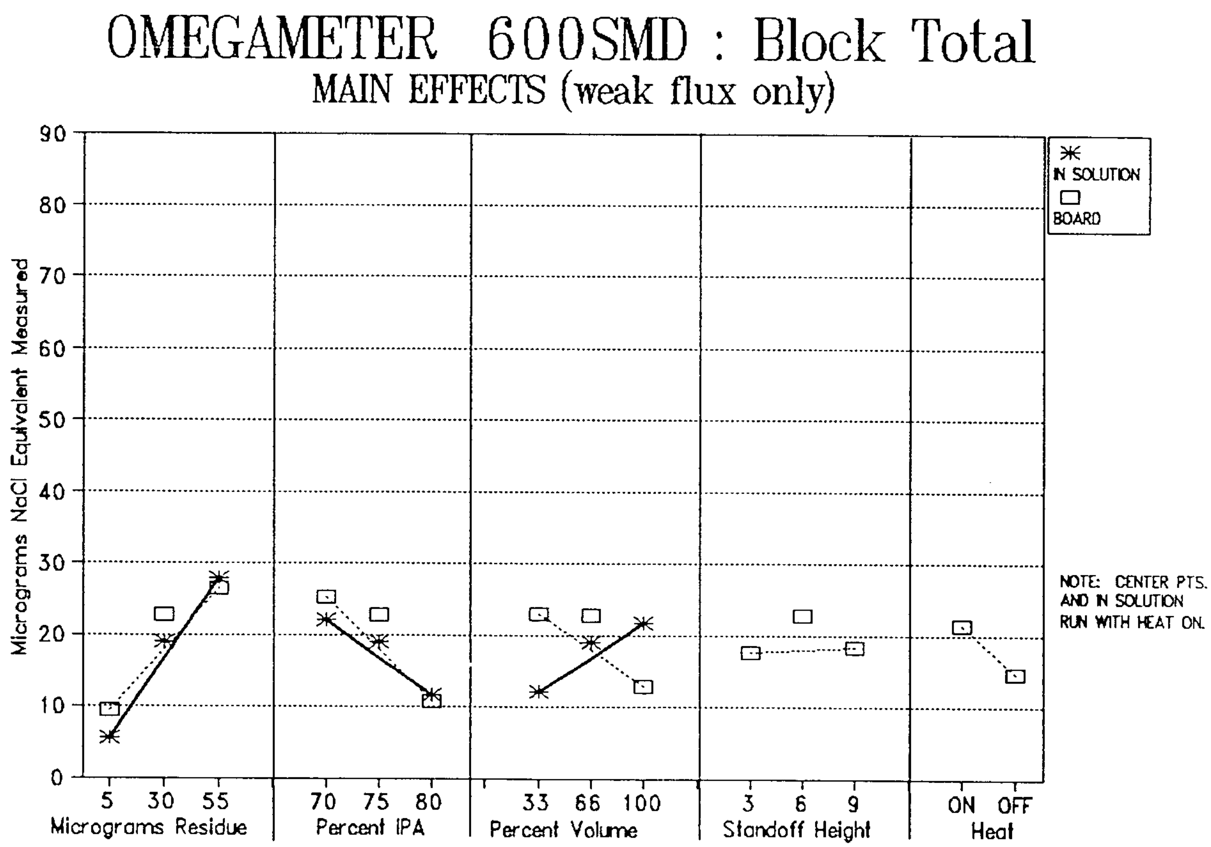
TABLE OF EFFECTS (Board Tests: Total)

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	34.01*	32.66*	31.03*	5.68*	22.01*	17.93*	13.14*	18.27*	15.06*
MAIN									
Residue (R)	51.55*	42.86*	38.89*	6.59*	17.82*	17.01*	11.33*	7.33*	13.66*
IPA (I)	-23.88*	-42.32*	-31.83*	-0.61	-27.52*	-14.33*		-4.79*	6.29x
Volume (V)					-1.23	-10.13*	-2.23	3.88	
Channel (C)	2.88	-1.90	-2.79	0.49	-0.37	0.69	0.12	-1.00	-4.49
Heat (H)						6.69*		1.61	
INTERACTION									
R*I	-18.80*	-23.04*	-20.27*	-1.54	-6.37x	-4.13*	-5.68*	-2.46	-3.66
R*V					-2.48	0.07	-0.01	-0.35	
R*C	0.00	-3.50	-0.30	-0.44	-1.09	-3.11x	-0.81	-1.21	4.51
R*H						3.14x		2.72	
I*V					-6.72x	-1.34	0.98	1.78	
I*C	3.38	-6.65	0.06	0.26	-0.03	0.43	1.63	-0.58	-2.31
I*H						0.13		4.85	
V*C					1.56	1.53	-1.54	2.20	
V*H						1.03		-3.12	
C*H						-3.94*		-2.53	
R*I*V					-2.42		1.96		
R*I*C	4.77	-3.11	3.99	-0.31	-2.36		-0.24		6.09x
R*V*C					3.58		0.36		
I*V*C					-4.41		-0.11		
CENTER	53.69*	47.23*	5.84	1.79	9.72x	1.53	8.26*	0.15	1.48

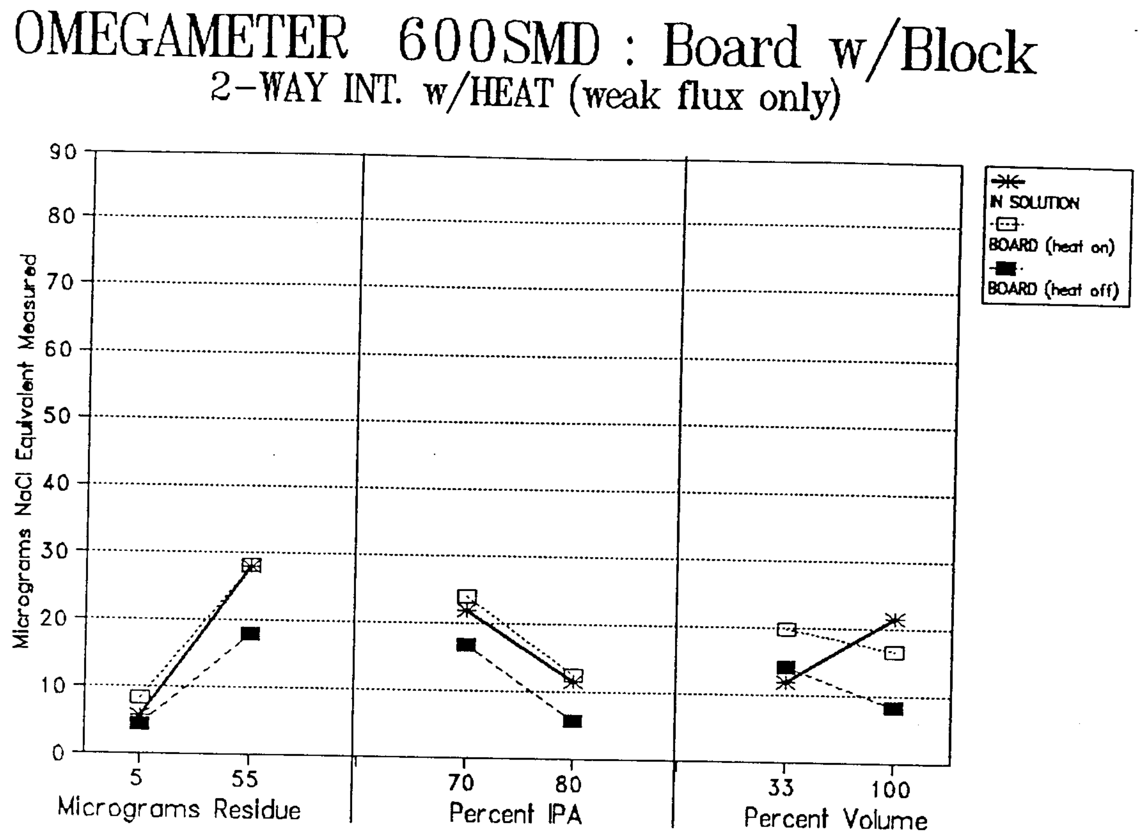
Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

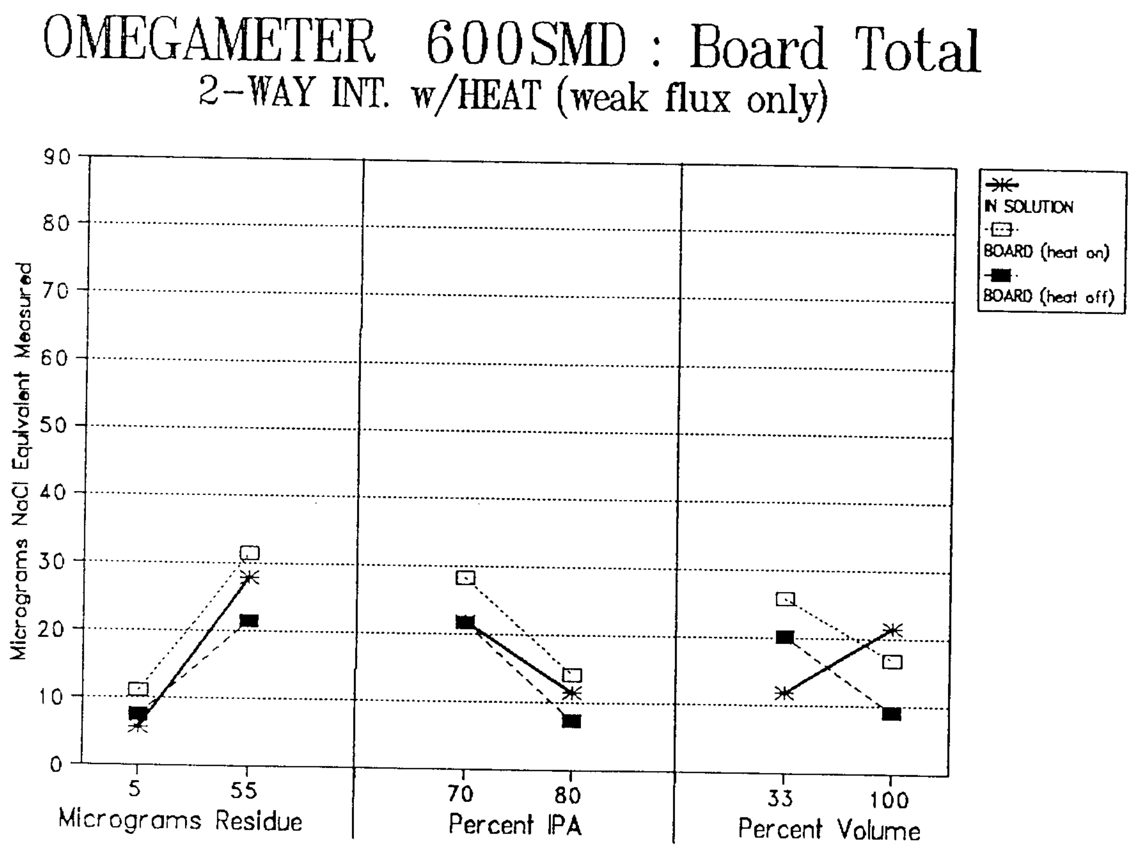


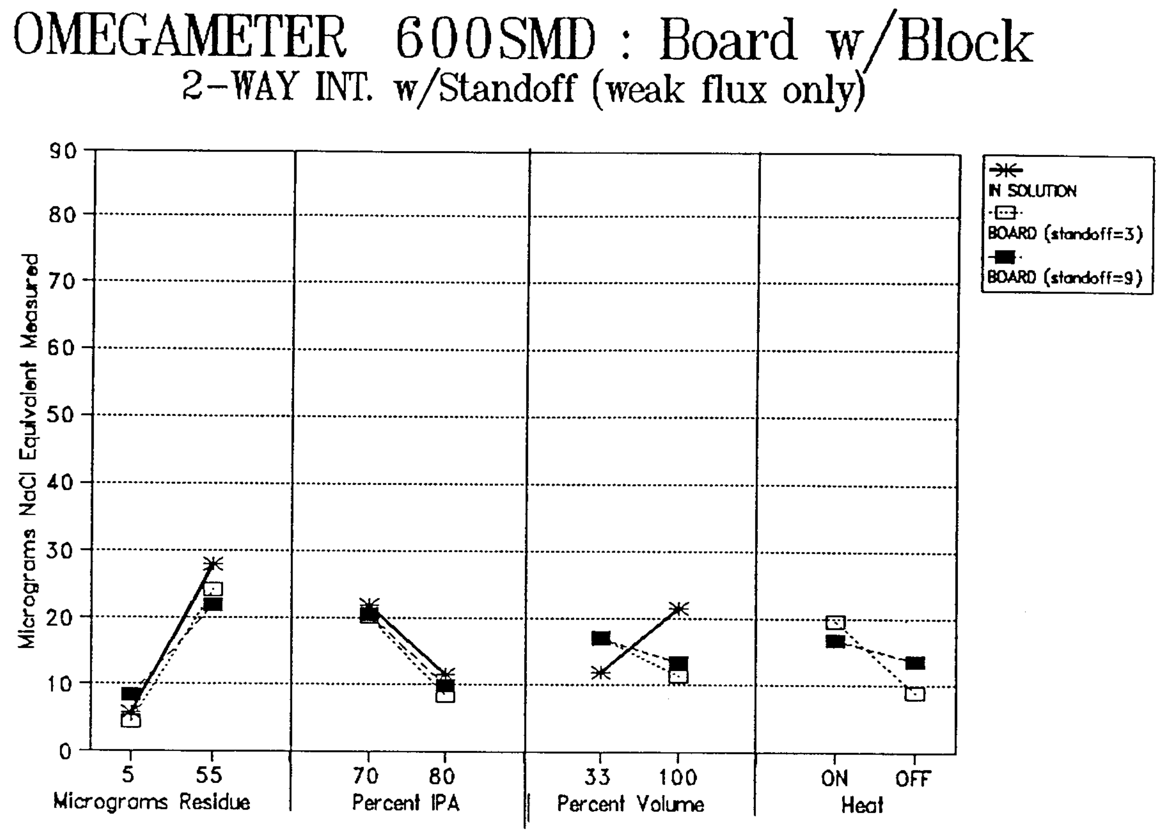
OMEGAMETER 600SMD : Board w/Block
MAIN EFFECTS (weak flux only)
Micrograms NaCl Equivalent Measured
0
10
20
30
40
50
60
70
80
90
5 30 55
Micrograms Residue
70 75 80
Percent IPA
33 66 100
Percent Volume
3 6 9
Standoff Height
ON OFF
Heat
IN SOLUTION
BOARD
NOTE: CENTER PTS. AND IN SOLUTION RUN WITH HEAT ON.

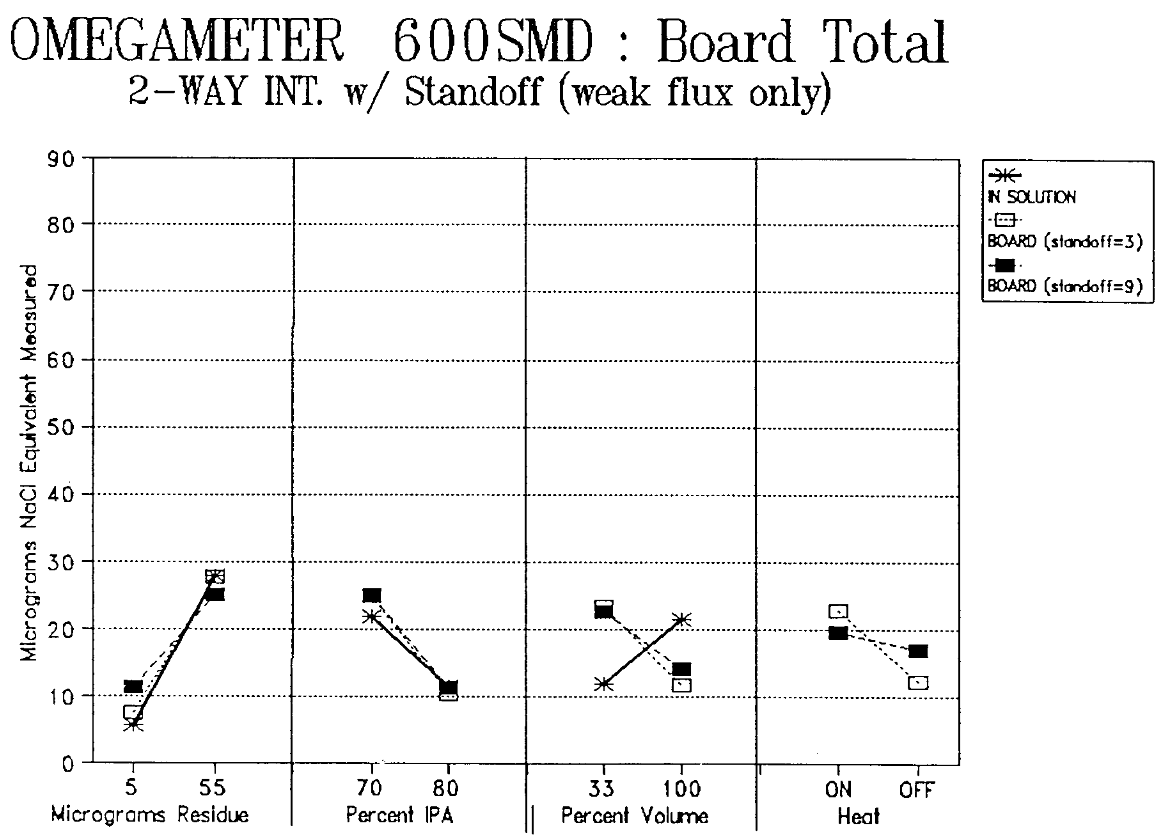


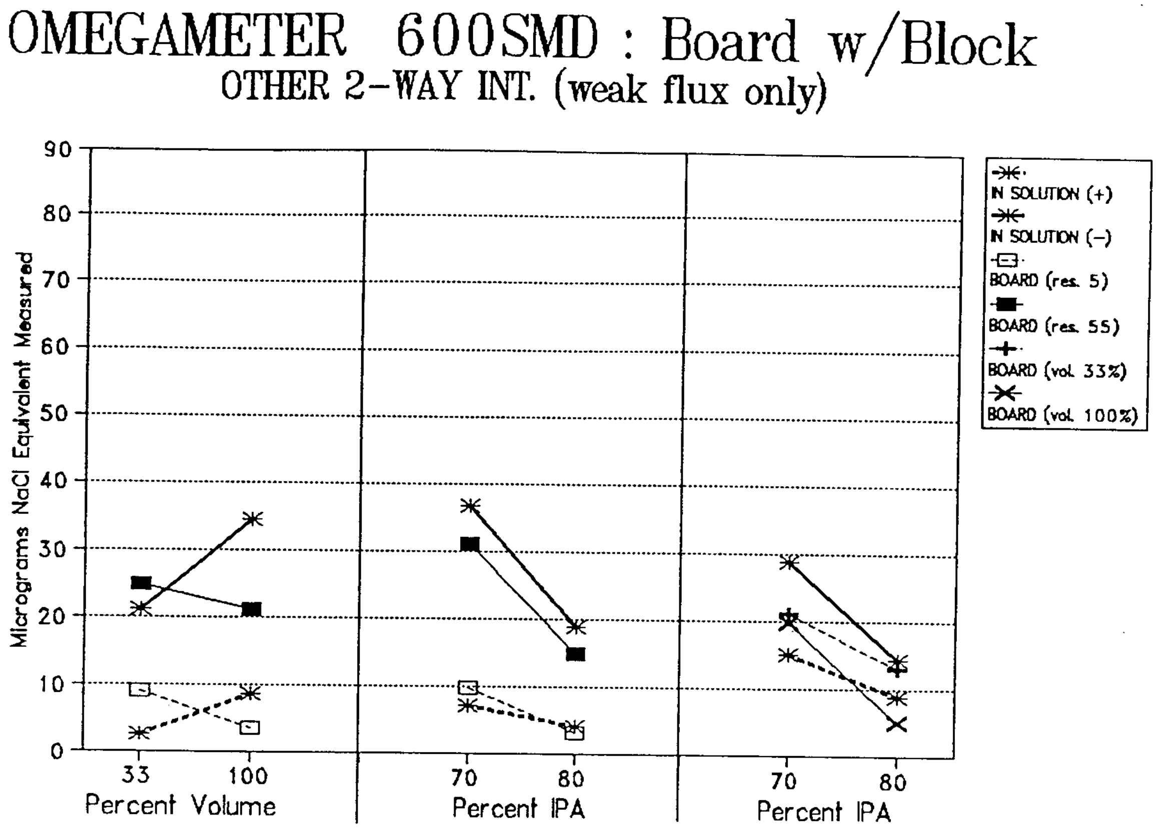
OMEGAMETER 600SMD : Block Total
MAIN EFFECTS (weak flux only)
Micrograms NaCl Equivalent Measured
0
10
20
30
40
50
60
70
80
90
5 30 55
Micrograms Residue
70 75 80
Percent IPA
33 66 100
Percent Volume
3 6 9
Standoff Height
ON OFF
Heat
IN SOLUTION
BOARD
NOTE: CENTER PTS. AND IN SOLUTION RUN WITH HEAT ON.


OMEGAMETER 600SMD : Board w/Block
2-WAY INT. w/HEAT (weak flux only)
Micrograms NaCl Equivalent Measured
0
10
20
30
40
50
60
70
80
90
5
55
Micrograms Residue
70
80
Percent IPA
33
100
Percent Volume
IN SOLUTION
BOARD (heat on)
BOARD (heat off)

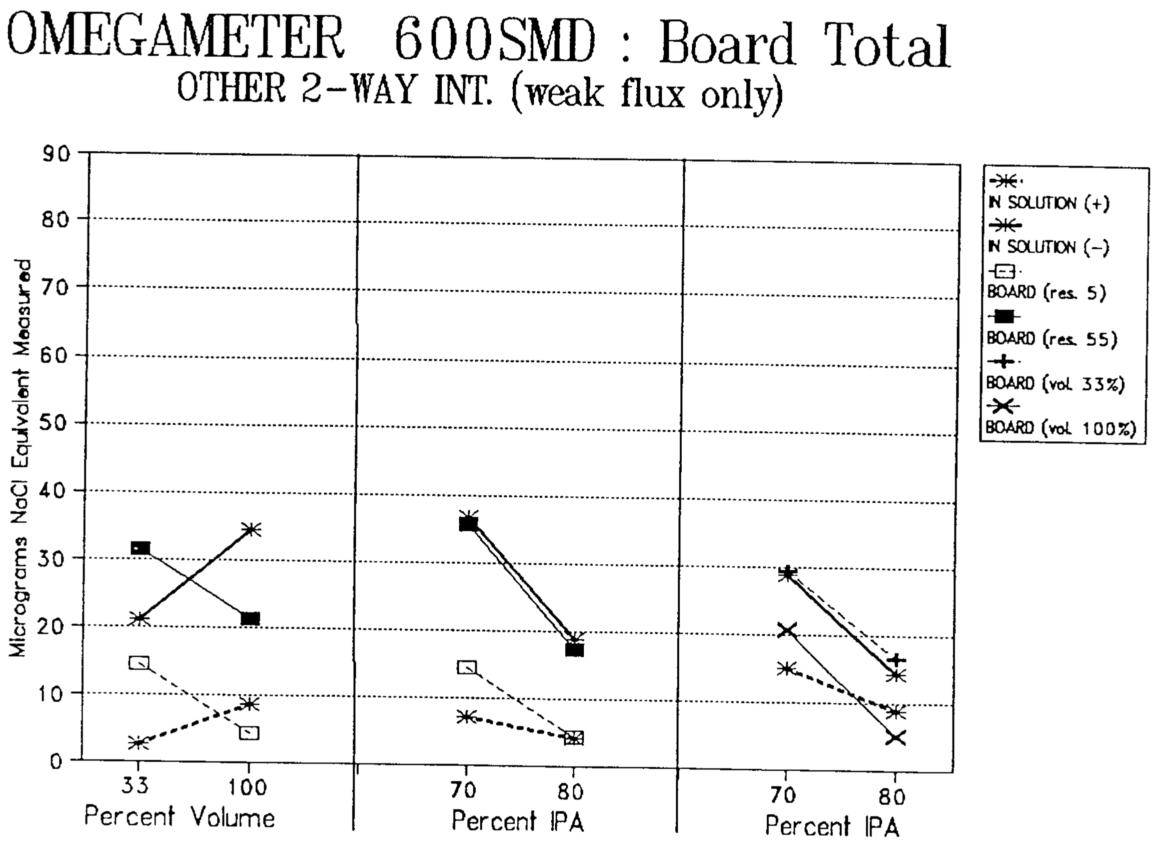

OMEGAMETER 600SMD : Board Total
2-WAY INT. w/HEAT (weak flux only)
Micrograms NaCl Equivalent Measured
0
10
20
30
40
50
60
70
80
90
5
55
Micrograms Residue
70
80
Percent IPA
33
100
Percent Volume
IN SOLUTION
BOARD (heat on)
BOARD (heat off)


OMEGAMETER 600SMD : Board w/Block
2-WAY INT. w/Standoff (weak flux only)
Micrograms NaCl Equivalent Measured
0
10
20
30
40
50
60
70
80
90
5
55
Micrograms Residue
70
80
Percent IPA
33
100
Percent Volume
ON
OFF
Heat
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)

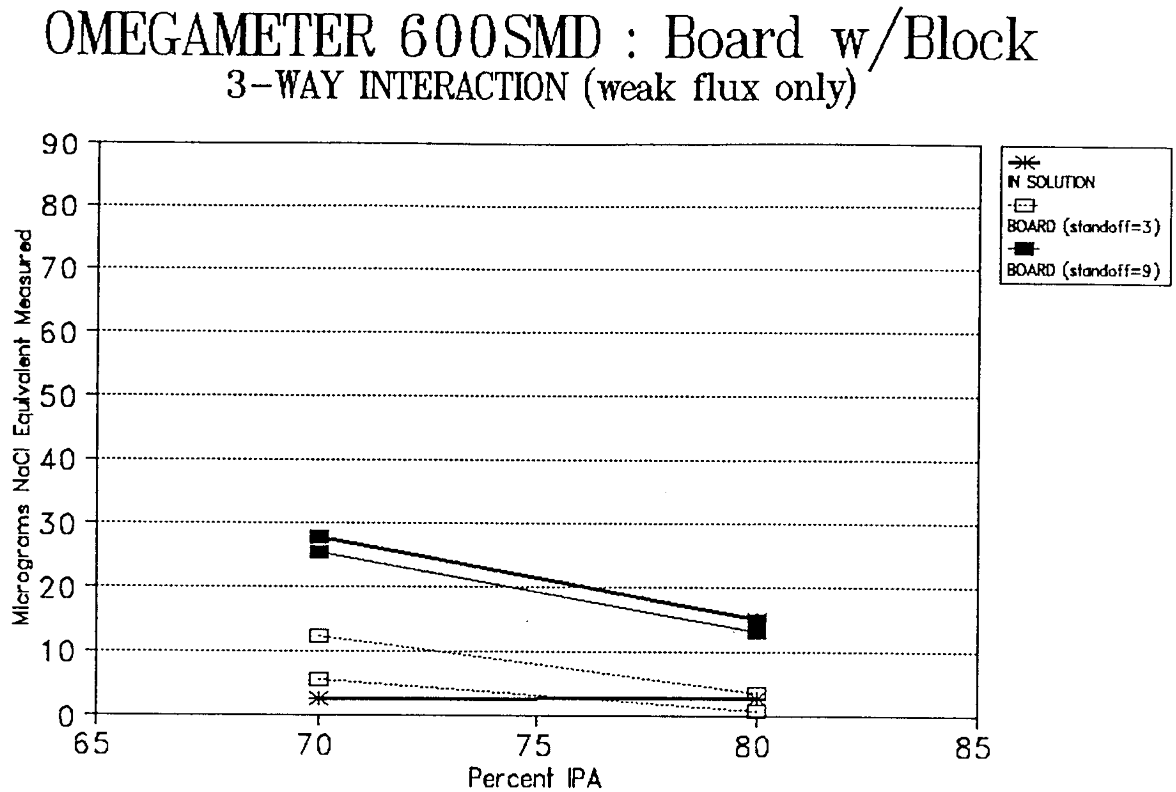

OMEGAMETER 600SMD : Board Total
2-WAY INT. w/ Standoff (weak flux only)
Micrograms NaCl Equivalent Measured
0
10
20
30
40
50
60
70
80
90
5
55
Micrograms Residue
70
80
Percent IPA
33
100
Percent Volume
ON
OFF
Heat
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)



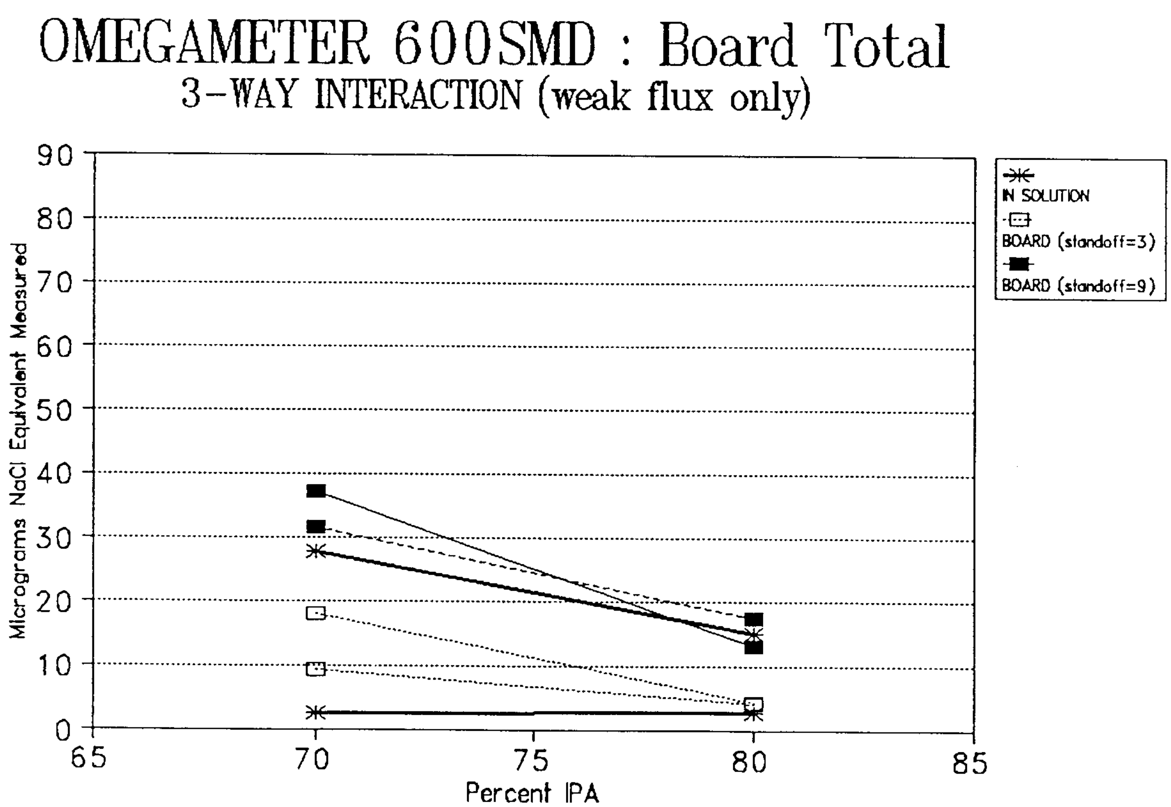
OMEGAMETER 600SMD : Board w/Block
OTHER 2-WAY INT. (weak flux only)
Micrograms NaCl Equivalent Measured
90
80
70
60
50
40
30
20
10
0
33
100
Percent Volume
70
80
Percent IPA
70
80
Percent IPA
IN SOLUTION (+)
IN SOLUTION (-)
BOARD (res. 5)
BOARD (res. 55)
BOARD (vol. 33%)
BOARD (vol. 100%)



OMEGAMETER 600SMD : Board Total
OTHER 2-WAY INT. (weak flux only)
Micrograms NaCl Equivalent Measured
90
80
70
60
50
40
30
20
10
0
33
100
Percent Volume
70
80
Percent IPA
70
80
Percent IPA
IN SOLUTION (+)
IN SOLUTION (-)
BOARD (res. 5)
BOARD (res. 55)
BOARD (vol. 33%)
BOARD (vol. 100%)



OMEGAMETER 600SMD : Board w/Block
3-WAY INTERACTION (weak flux only)
90
80
70
60
50
40
30
20
10
0
65
70
75
80
85
Percent IPA
Micrograms NaCl Equivalent Measured
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)



OMEGAMETER 600SMD : Board Total
3-WAY INTERACTION (weak flux only)
90
80
70
60
50
40
30
20
10
0
65
70
75
80
85
Percent IPA
Micrograms NaCl Equivalent Measured
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)

OMEGAMETER 600SMD
IN SOLUTION TEST (weak flux)

Predictor	Coef	Stdev	t-ratio	p	
Constant	16.769	0.9367	17.90	0.000	*
R	11.0688	0.9367	11.82	0.000	*
I	-5.1938	0.9367	-5.54	0.003	*
V	4.8063	0.9367	5.13	0.004	*
R*I	-3.7188	0.9367	-3.97	0.011	*
R*V	1.7563	0.9367	1.87	0.120	
I*V	-2.0563	0.9367	-2.20	0.080	x
R*I*V	-0.5313	0.9367	-0.57	0.595	
CTR.PT	2.381	2.357	1.01	0.359	

s = 3.059 R-sq = 98.2% R-sq(adj) = 95.3%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	2543.64	317.95	33.97	0.001
Error	5	46.80	9.36		
Total	13	2590.44			

SOURCE	DF	SEQ SS
R	1	1449.80
I	1	513.52
V	1	325.55
R*I	1	165.17
R*V	1	35.02
I*V	1	42.67
R*I*V	1	2.35
CTR.PT	1	9.55

Unusual Observations

Obs.	R	OMSMD.S	Fit	Stdev.Fit	Residual	St.Resid
3	1.00	41.400	45.900	2.163	-4.500	-2.08R
20	1.00	50.400	45.900	2.163	4.500	2.08R

R denotes an obs. with a large st. resid.

OMEGAMETER 600SMD
BOARD TEST w/BLOCK

Predictor	Coef	Stdev	t-ratio	p	
Constant	14.681	0.6145	23.89	0.000	*
R	8.3000	0.6145	13.51	0.000	*
I	-5.6500	0.6145	-9.19	0.000	*
V	-2.3125	0.6145	-3.76	0.004	*
C	0.4375	0.6145	0.71	0.493	
H	3.4687	0.6145	5.65	0.000	*
R*I	-2.3437	0.6145	-3.81	0.003	*
R*V	0.4062	0.6145	0.66	0.523	
R*C	-1.5813	0.6145	-2.57	0.028	*
R*H	1.5500	0.6145	2.52	0.030	*
I*V	-1.6938	0.6145	-2.76	0.020	*
I*C	0.3187	0.6145	0.52	0.615	
I*H	-0.1500	0.6145	-0.24	0.812	
V*C	0.5938	0.6145	0.97	0.357	
V*H	0.6375	0.6145	1.04	0.324	
C*H	-1.8625	0.6145	-3.03	0.013	*
CTR.PT	-0.050	1.921	-0.03	0.980	

s = 2.838   R-sq = 97.5%   R-sq(adj) = 93.4%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	16	3086.27	192.89	23.95	0.000
Error	10	80.55	8.05		
Total	26	3166.82			

SOURCE	DF	SEQ SS
R	1	1453.93
I	1	752.64
V	1	153.01
C	1	26.88
H	1	312.50
R*I	1	155.04
R*V	1	2.16
R*C	1	24.81
R*H	1	51.25
I*V	1	61.20
I*C	1	2.17
I*H	1	0.48
V*C	1	7.52
V*H	1	8.67
C*H	1	74.00
CTR.PT	1	0.01

Unusual Observations

Obs.	R	OMSMD.B	Fit	Stdev.Fit	Residual	St.Resid
7	1.00	0.000	4.250	2.007	-4.250	-2.12R
24	1.00	8.500	4.250	2.007	4.250	2.12R

R denotes an obs. with a large st. resid.

OMEGAMETER 600SMD
BOARD TEST TOTAL

Predictor	Coef	Stdev	t-ratio	p	
Constant	17.928	0.7116	25.19	0.000	*
R	8.5031	0.7116	11.95	0.000	*
I	-7.1656	0.7116	-10.07	0.000	*
V	-5.0656	0.7116	-7.12	0.000	*
C	0.3469	0.7116	0.49	0.636	
H	3.3469	0.7116	4.70	0.000	*
R*I	-2.0656	0.7116	-2.90	0.016	*
R*V	0.0344	0.7116	0.05	0.962	
R*C	-1.5531	0.7116	-2.18	0.054	x
R*H	1.5719	0.7116	2.21	0.052	x
I*V	-0.6719	0.7116	-0.94	0.367	
I*C	0.2156	0.7116	0.30	0.768	
I*H	0.0656	0.7116	0.09	0.928	
V*C	0.7656	0.7116	1.08	0.307	
V*H	0.5156	0.7116	0.72	0.485	
C*H	-1.9719	0.7116	-2.77	0.020	*
CTR.PT	1.525	2.225	0.69	0.509	

s = 3.287 R-sq = 97.4% R-sq(adj) = 93.4%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	16	4121.23	257.58	23.85	0.000
Error	10	108.01	10.80		
Total	26	4229.25			

SOURCE	DF	SEQ SS
R	1	1528.01
I	1	1239.84
V	1	658.35
C	1	24.20
H	1	329.49
R*I	1	129.27
R*V	1	0.03
R*C	1	42.40
R*H	1	52.71
I*V	1	9.63
I*C	1	0.99
I*H	1	0.09
V*C	1	12.51
V*H	1	5.67
C*H	1	82.95
CTR.PT	1	5.07

KESTER

IONEX 2000 (series 100)

Static
Unheated
Spray above immersion

IONEX 2000/100
RANDOMIZED EXPERIMENTAL MATRIX
PWB/WEAK FLUX TESTS

RANDOMIZED RUN SEQUENCE	STANDARD ORDER	A B C D	A AMOUNT OF RESIDUE (μGR/IN²)	B IPA (VOL%)	D TEST CELL VOLUME (%FULL)	E CHANNEL DEPTH (MILS)	IONIC READING W/BLK	IONIC READING WO/BLK	TEST DURATION W/BLK	TEST DURATION WO/BLK	TEST CELL TEMP. W/BLK	TEST CELL TEMP. WO/BLK
1	5	- - + -	5	70	33	9	11.0	3.7	15:00	15:00	100°F	104°F
2	14	+ - + +	55	70	100	9	22.0	3.2	15:00	15:00	103°F	105°F
3	6	+ - + -	55	70	33	9	24.3	9.5	15:00	15:00	107°F	106°F
4	10	+ - - +	55	70	100	3	24.5	1.8	15:00	15:00	105°F	106°F
5	13	- - + +	5	70	100	9	5.8	1.9	15:00	15:00	93°F	101°F
6	1	- - - -	5	70	33	3	6.4	3.4	15:00	15:00	106°F	106°F
7	2	+ - - -	55	70	33	3	25.8	11.8	15:00	15:00	104°F	105°F
8	9	- - - +	5	70	100	3	7.6	2.7	15:00	15:00	104°F	105°F
9	17	0 0 0 0	30	75	66	6	20.0	2.0	15:00	15:00	100°F	104°F
10	18	0 0 0 0	30	75	66	6	18.8	0.0	15:00	15:00	105°F	105°F
11	19	0 0 0 0	30	75	66	6	23.4	0.2	15:00	15:00	105°F	106°F
12	4	+ + - -	55	80	33	3	6.7	0.4	15:00	15:00	99°F	103°F
13	11	- + - +	5	80	100	3	0.8	0.0	15:00	15:00	103°F	104°F
14	8	+ + + -	55	80	33	9	9.4	0.3	15:00	15:00	105°F	106°F
15	15	- + + +	5	80	100	9	2.1	0.1	15:00	15:00	100°F	104°F
16	3	- + - -	5	80	33	3	2.6	0.0	15:00	15:00	105°F	106°F
17	16	+ + + +	55	80	100	9	7.6	0.9	15:00	15:00	103°F	105°F
18	7	- + + -	5	80	33	9	3.6	3.2	15:00	15:00	100°F	103°F
19	12	+ + - +	55	80	100	3	6.2	3.5	15:00	15:00	103°F	105°F
20	5	- - + -	5	70	33	9	8.6	3.1	15:00	15:00	106°F	106°F
21	14	+ - + +	55	70	100	9	23.9	0.9	15:00	15:00	103°F	105°F
22	6	+ - + -	55	70	33	9	23.1	4.4	15:00	15:00	105°F	106°F
23	10	+ - - +	55	70	100	3	25.4	3.4	15:00	15:00	104°F	105°F
24	13	- - + +	5	70	100	9	8.0	3.4	15:00	15:00	101°F	104°F
25	1	- - - -	5	70	33	3	10.9	2.8	15:00	15:00	105°F	106°F
26	2	+ - - -	55	70	33	3	24.4	2.5	15:00	15:00	102°F	105°F
27	9	- - - +	5	70	100	3	13.7	1.8	15:00	15:00	103°F	105°F

TABLE OF EFFECTS (Board Tests with Blocks)

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	32.59*	18.77*	27.21*	3.81*	15.33*	14.68*	10.73*	12.81*	9.29*
MAIN									
Residue (R)	50.88*	24.01*	37.81*	5.26*	12.28*	16.60*	10.19*	7.21*	11.83*
IPA (I)	-21.88*	-35.43*	-26.69*	-1.41	-20.51*	-11.30*		-4.39*	2.38
Volume (V)					-2.17	-4.63*	-0.93	3.18*	
Channel (C)	5.12	10.27*	0.12	1.11	1.89	0.88	0.05	-1.99	-1.05
Heat (H)						6.94*		2.12	
INTERACTION									
R*I	-17.27*	-22.08*	-20.52*	-1.96	-6.18*	-4.69*	-4.99*	-1.37	0.13
R*V					-3.92x	0.81	0.13	-0.49	
R*C	1.28	7.14	0.16	0.26	0.24	-3.16*	0.13	0.06	0.85
R*H						3.10*		1.86	
I*V					-7.98*	-3.39*	-0.48	1.54	
I*C	1.68	-8.29	-1.70	0.69	1.26	0.64	1.55	-0.89	-3.20
I*H						-0.30		2.88x	
V*C					0.29	1.19	-0.81	1.48	
V*H						1.28	0.13	-1.60	
C*H						-3.73*		-1.82	
R*I*V					-2.18		0.33		
R*I*C	3.83	-5.34	4.44	0.24	-1.14		0.34		0.10
R*V*C					1.92		0.56		
I*V*C					-3.44x		-0.74		
CENTER	53.68*	48.85*	6.48	2.36	16.11*	-0.05	10.00*	1.13	2.45

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

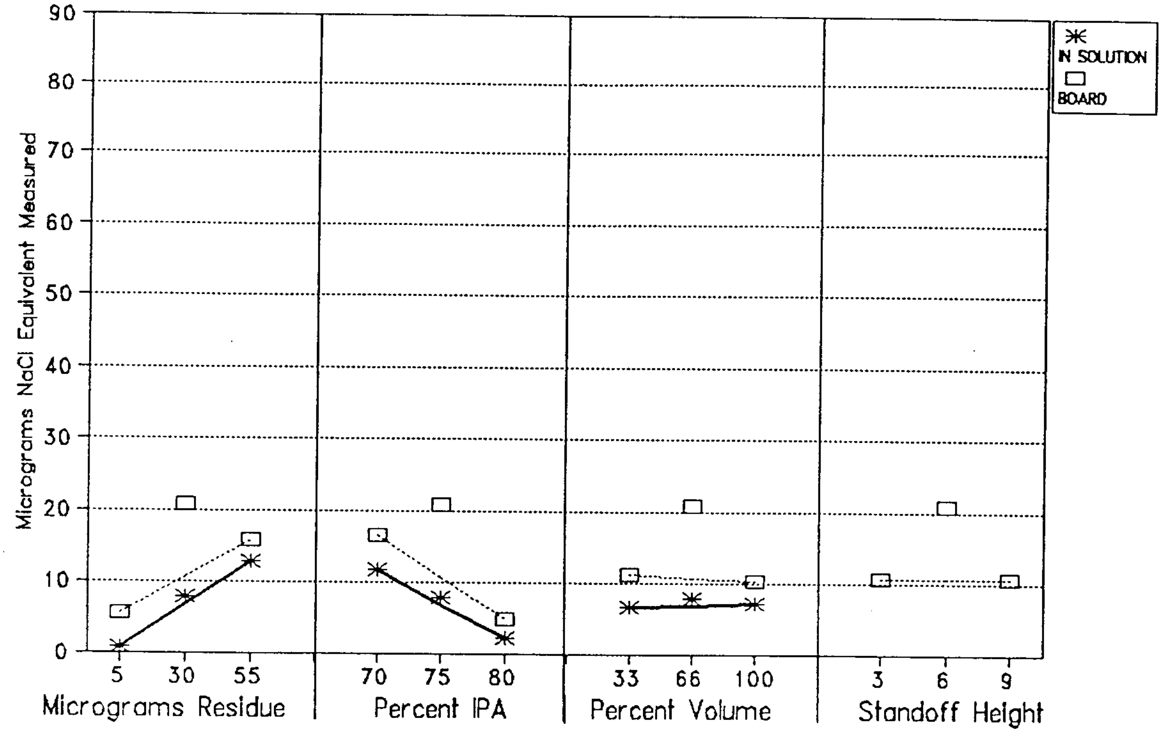
TABLE OF EFFECTS (Board Tests: Total)

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	34.01*	32.66*	31.03*	5.68*	22.01*	17.93*	13.14*	18.27*	15.06*
MAIN									
Residue (R)	51.55*	42.86*	38.89*	6.59*	17.82*	17.01*	11.33*	7.33*	13.66*
IPA (I)	-23.88*	-42.32*	-31.83*	-0.61	-27.52*	-14.33*		-4.79*	6.29x
Volume (V)					-1.23	-10.13*	-2.23	3.88	
Channel (C)	2.88	-1.90	-2.79	0.49	-0.37	0.69	0.12	-1.00	-4.49
Heat (H)						6.69*		1.61	
INTERACTION									
R*I	-18.80*	-23.04*	-20.27*	-1.54	-6.37x	-4.13*	-5.68*	-2.46	-3.66
R*V					-2.48	0.07	-0.01	-0.35	
R*C	0.00	-3.50	-0.30	-0.44	-1.09	-3.11x	-0.81	-1.21	4.51
R*H						3.14x		2.72	
I*V					-6.72x	-1.34	0.98	1.78	
I*C	3.38	-6.65	0.06	0.26	-0.03	0.43	1.63	-0.58	-2.31
I*H						0.13		4.85	
V*C					1.56	1.53	-1.54	2.20	
V*H						1.03		-3.12	
C*H						-3.94*		-2.53	
R*I*V					-2.42		1.96		
R*I*C	4.77	-3.11	3.99	-0.31	-2.36		-0.24		6.09x
R*V*C					3.58		0.36		
I*V*C					-4.41		-0.11		
CENTER	53.69*	47.23*	5.84	1.79	9.72x	1.53	8.26*	0.15	1.48

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

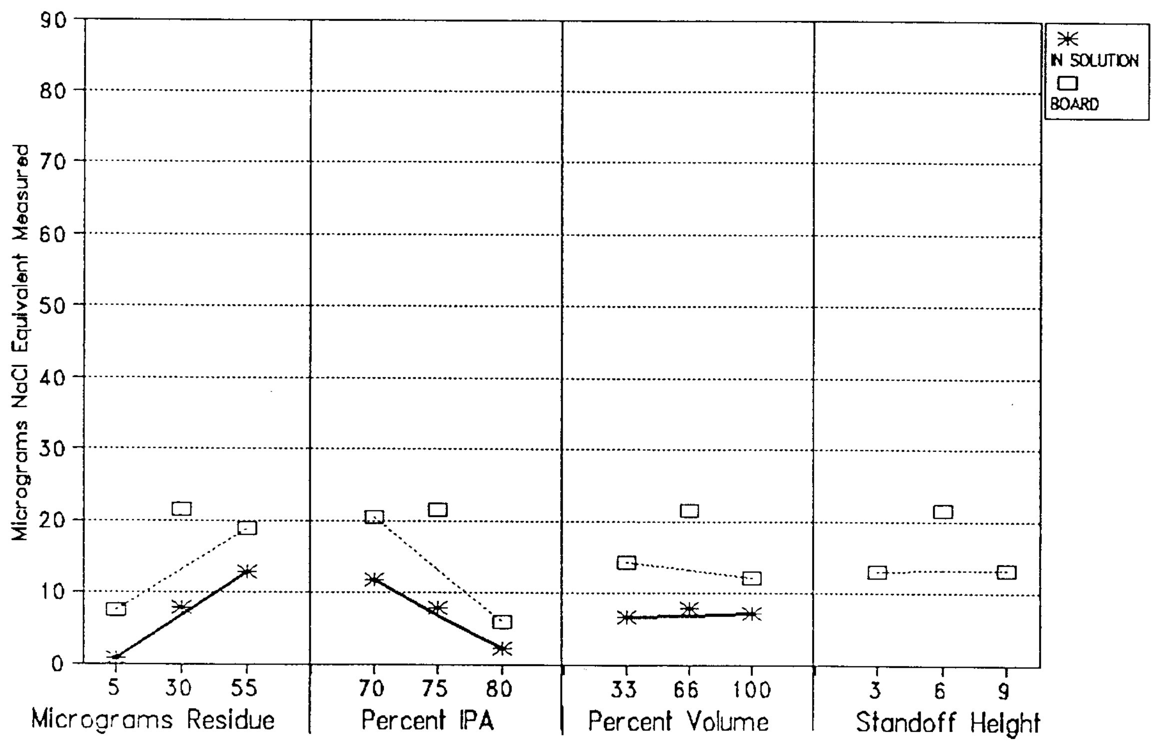
IONEX 2000 : Board w/Block

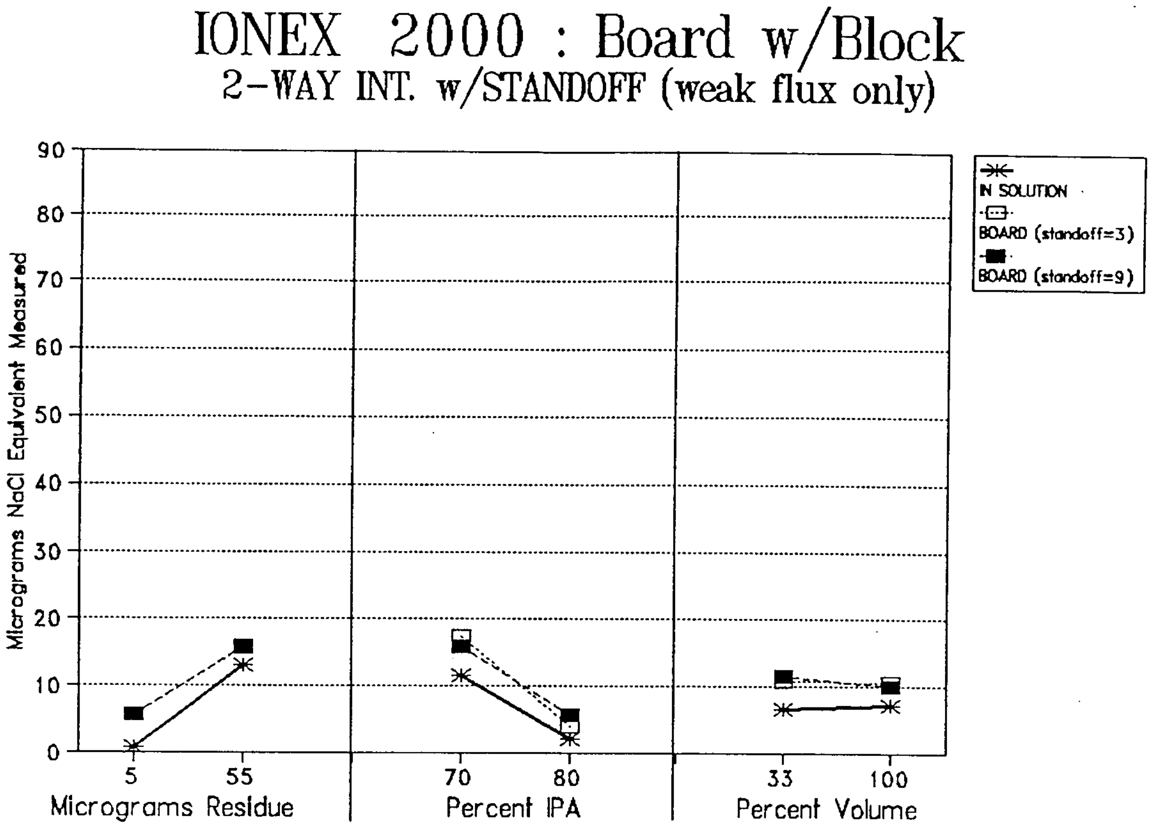
MAIN EFFECTS (weak flux only)

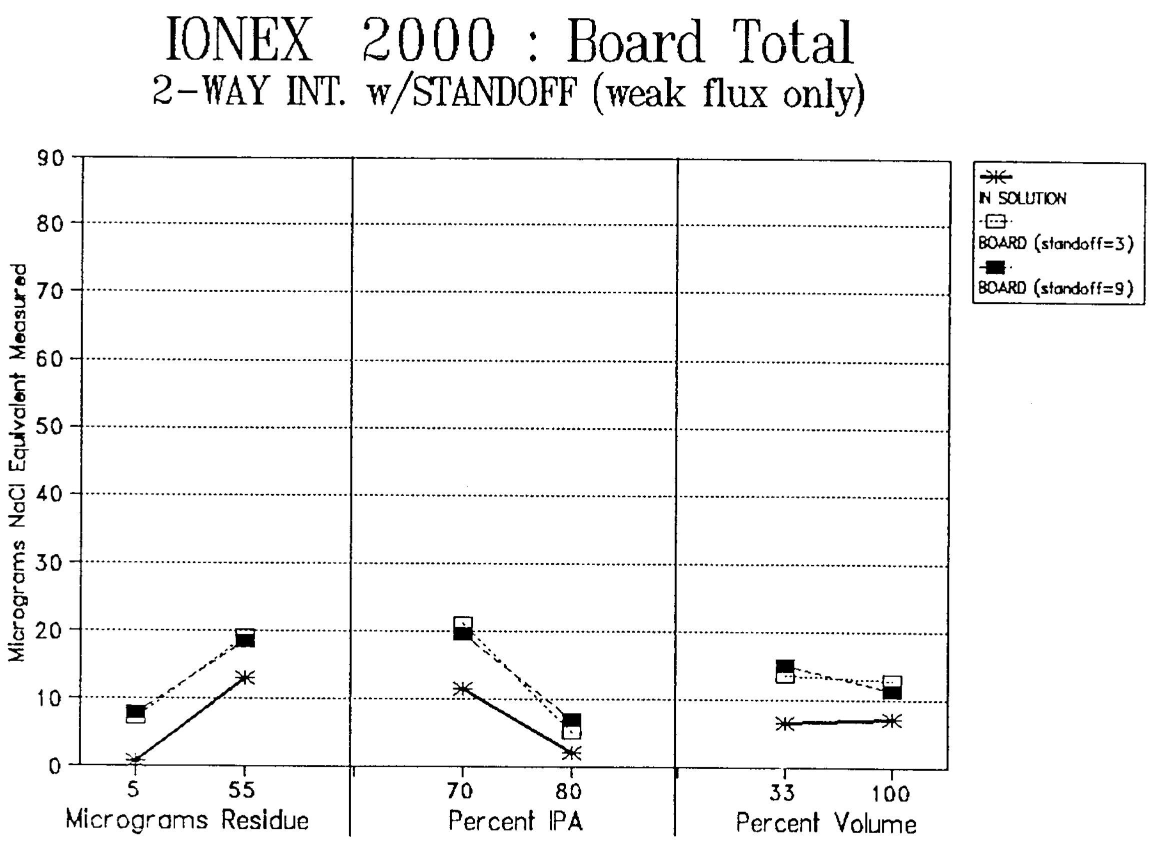


IONEX 2000 : Board Total

MAIN EFFECTS (weak flux only)

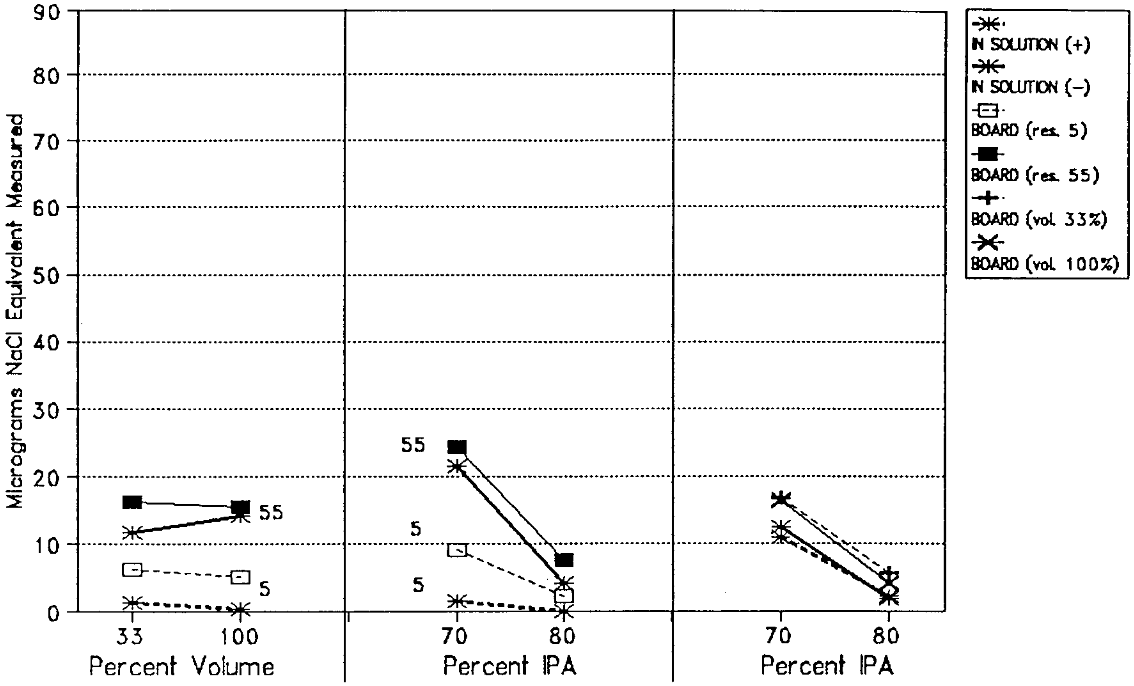



IONEX 2000 : Board w/Block
2-WAY INT. w/STANDOFF (weak flux only)
Micrograms NaCl Equivalent Measured
90
80
70
60
50
40
30
20
10
0
5
55
Micrograms Residue
70
80
Percent IPA
33
100
Percent Volume
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)


IONEX 2000 : Board Total
2-WAY INT. w/STANDOFF (weak flux only)
Micrograms NaCl Equivalent Measured
90
80
70
60
50
40
30
20
10
0
5
55
Micrograms Residue
70
80
Percent IPA
33
100
Percent Volume
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)

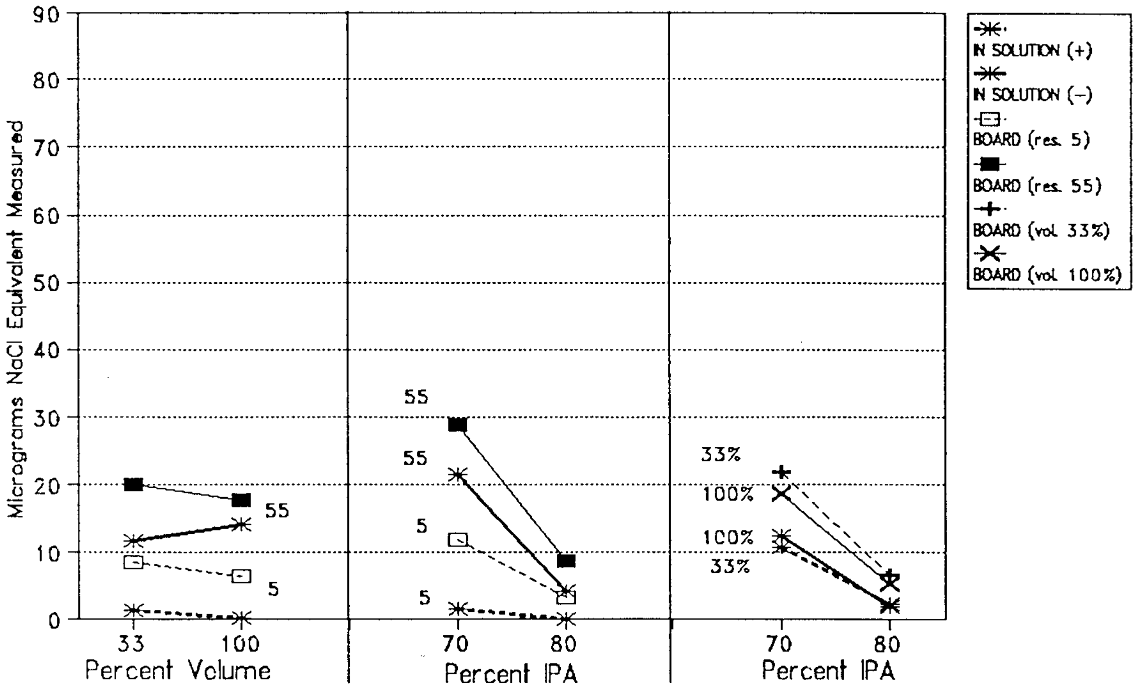
IONEX 2000 : Board w/Block

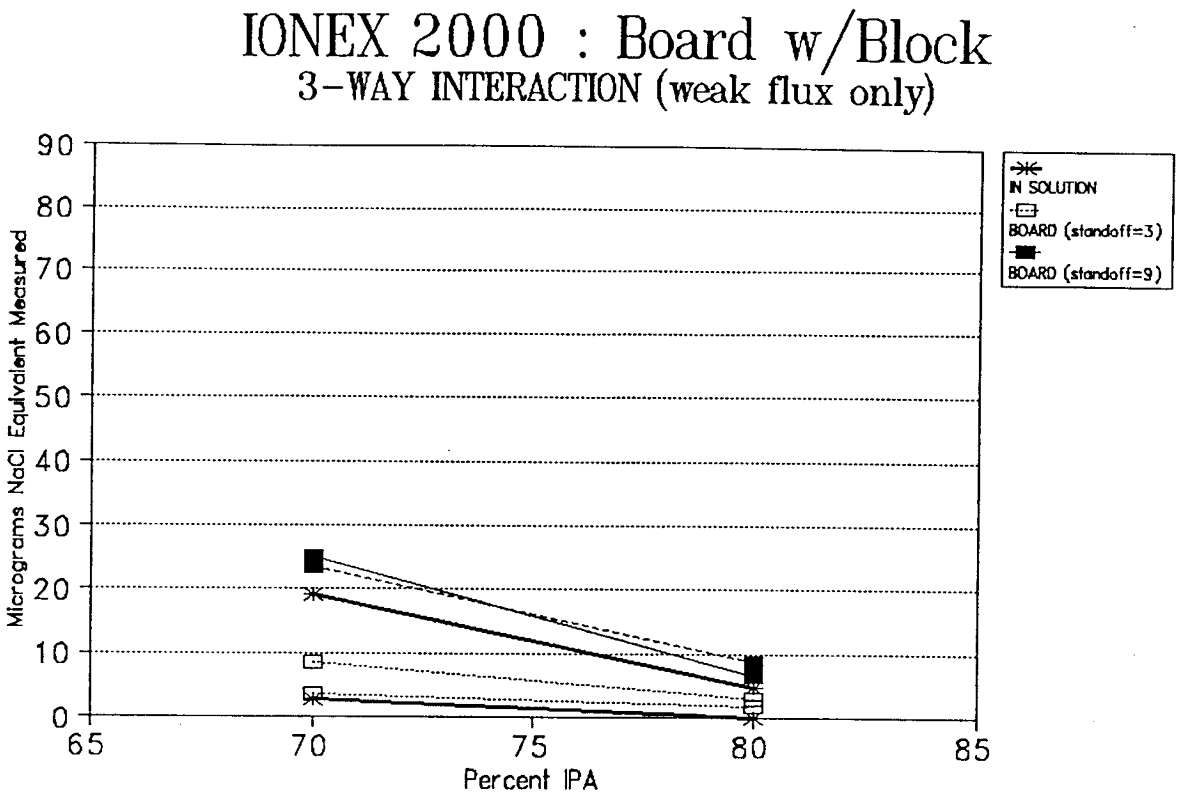
OTHER 2-WAY INT. (weak flux only)

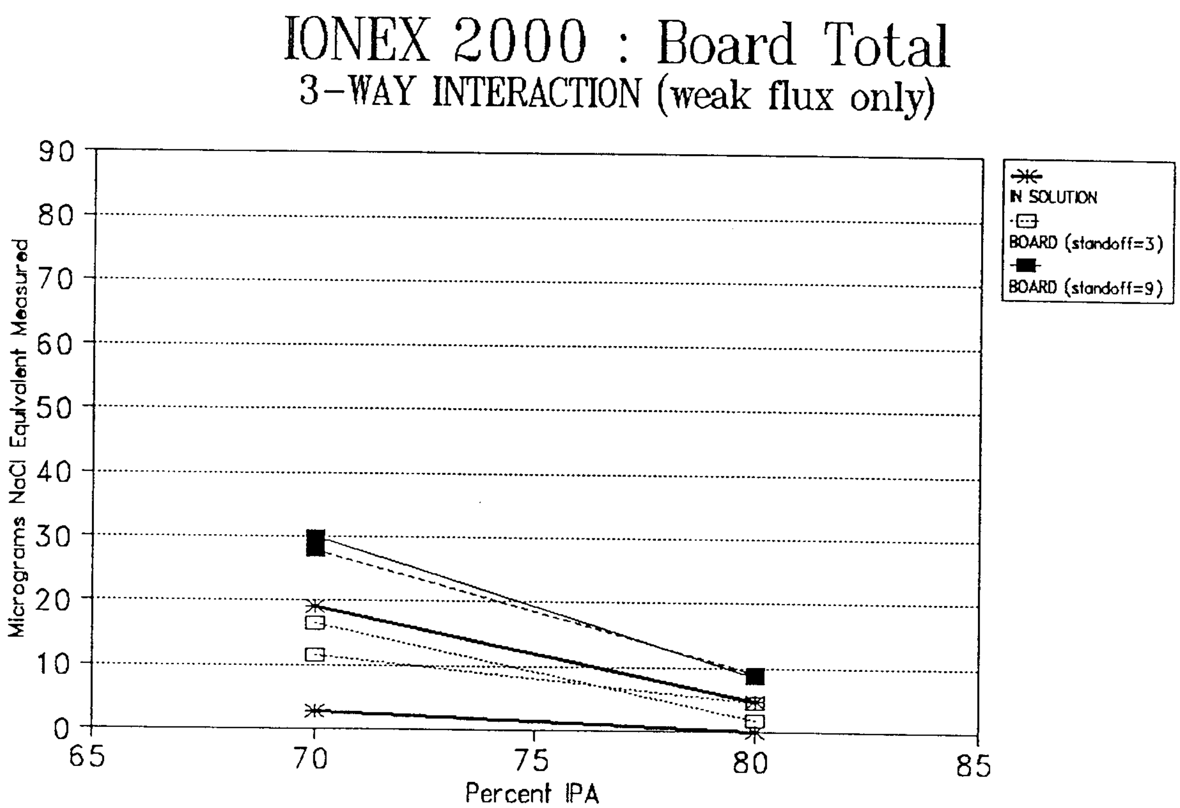


IONEX 2000 : Board Total

OTHER 2-WAY INT. (weak flux only)




IONEX 2000 : Board w/Block
3-WAY INTERACTION (weak flux only)
Micrograms NaCl Equivalent Measured
0
10
20
30
40
50
60
70
80
90
65
70
75
80
85
Percent IPA
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)


IONEX 2000 : Board Total
3-WAY INTERACTION (weak flux only)
Micrograms NaCl Equivalent Measured
0
10
20
30
40
50
60
70
80
90
65
70
75
80
85
Percent IPA
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)

IONEX 2000
IN SOLUTION TEST (weak flux)

Predictor	Coef	Stdev	t-ratio	p	
Constant	6.8690	0.4238	16.21	0.000	*
R	6.0812	0.4238	14.35	0.000	*
I	-4.7438	0.4238	-11.19	0.000	*
V	0.2937	0.4238	0.69	0.519	
R*I	-3.9562	0.4238	-9.33	0.000	*
R*V	0.8812	0.4238	2.08	0.092	x
I*V	-0.4687	0.4238	-1.11	0.319	
R*I*V	-1.0562	0.4238	-2.49	0.055	x
CTR.PT	0.881	1.067	0.83	0.446	

s = 1.384 R-sq = 99.1% R-sq(adj) = 97.8%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	1099.88	137.48	71.76	0.000
Error	5	9.58	1.92		
Total	13	1109.45			

SOURCE	DF	SEQ SS
R	1	657.12
I	1	239.57
V	1	2.43
R*I	1	166.95
R*V	1	18.25
I*V	1	2.34
R*I*V	1	11.90
CTR.PT	1	1.31

Unusual Observations

Obs.	R	IONX.S	Fit	Stdev.Fit	Residual	St.Resid
3	1.00	22.300	24.350	0.979	-2.050	-2.09R
20	1.00	26.400	24.350	0.979	2.050	2.09R

R denotes an obs. with a large st. resid.

IONEX 2000
BOARD TEST w/BLOCK

Predictor	Coef	Stdev	t-ratio	p	
Constant	10.731	0.4809	22.31	0.000	*
R	5.0938	0.4809	10.59	0.000	*
I	-5.8562	0.4809	-12.18	0.000	*
V	-0.4625	0.4809	-0.96	0.359	
C	0.0250	0.4809	0.05	0.960	
R*I	-2.4937	0.4809	-5.19	0.000	*
R*V	0.0625	0.4809	0.13	0.899	
R*C	0.0625	0.4809	0.13	0.899	
I*V	-0.2375	0.4809	-0.49	0.632	
I*C	0.7750	0.4809	1.61	0.138	
V*C	-0.4063	0.4809	-0.84	0.418	
R*I*V	0.0625	0.4809	0.13	0.899	
R*I*C	0.1625	0.4809	0.34	0.742	
R*V*C	0.1688	0.4809	0.35	0.733	
I*V*C	0.2813	0.4809	0.58	0.572	
R*I*V*C	-0.3687	0.4809	-0.77	0.461	
CTR.PT	10.002	1.369	7.30	0.000	*

s = 2.221   R-sq = 97.5%   R-sq(adj) = 93.5%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	16	1911.82	119.49	24.22	0.000
Error	10	49.33	4.93		
Total	26	1961.15			

SOURCE	DF	SEQ SS
R	1	842.53
I	1	641.32
V	1	3.53
C	1	1.31
R*I	1	132.67
R*V	1	0.04
R*C	1	0.00
I*V	1	1.20
I*C	1	12.81
V*C	1	6.00
R*I*V	1	0.08
R*I*C	1	0.56
R*V*C	1	2.04
I*V*C	1	1.69
R*I*V*C	1	2.90
CTR.PT	1	263.12

IONEX 2000
BOARD TEST TOTAL

Predictor	Coef	Stdev	t-ratio	p	
Constant	13.141	0.7620	17.25	0.000	*
R	5.6656	0.7620	7.43	0.000	*
I	-7.2156	0.7620	-9.47	0.000	*
V	-1.1156	0.7620	-1.46	0.174	
C	0.0594	0.7620	0.08	0.939	
R*I	-2.8406	0.7620	-3.73	0.004	*
R*V	-0.0031	0.7620	-0.00	0.997	
R*C	-0.4031	0.7620	-0.53	0.608	
I*V	0.4906	0.7620	0.64	0.534	
I*C	0.8156	0.7620	1.07	0.310	
V*C	-0.7719	0.7620	-1.01	0.335	
R*I*V	0.9781	0.7620	1.28	0.228	
R*I*C	-0.1219	0.7620	-0.16	0.876	
R*V*C	0.1781	0.7620	0.23	0.820	
I*V*C	-0.0531	0.7620	-0.07	0.946	
R*I*V*C	-0.3031	0.7620	-0.40	0.699	
CTR.PT	8.259	2.170	3.81	0.003	*

s = 3.520   R-sq = 95.3%   R-sq(adj) = 87.9%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	16	2527.36	157.96	12.75	0.000
Error	10	123.88	12.39		
Total	26	2651.25			

SOURCE	DF	SEQ SS
R	1	1049.40
I	1	1022.69
V	1	39.27
C	1	1.08
R*I	1	172.14
R*V	1	2.60
R*C	1	3.15
I*V	1	5.14
I*C	1	14.19
V*C	1	13.65
R*I*V	1	20.41
R*I*C	1	0.32
R*V*C	1	1.87
I*V*C	1	0.06
R*I*V*C	1	1.96
CTR.PT	1	179.42

Unusual Observations

Obs.	R	IONX.T	Fit	Stdev.Fit	Residual	St.Resid
1	1.00	37.600	32.250	2.489	5.350	2.15R
18	1.00	26.900	32.250	2.489	-5.350	-2.15R

R denotes an obs. with a large st. resid.

WESTEK

ICOM 5000

Static
Heated or Unheated
Spray above immersion

ICOM 5000 RGS
RANDOMIZED EXPERIMENTAL MATRIX
PWB/WEAK FLUX TESTS

RANDOMIZED RUN SEQUENCE	STANDARD ORDER	A B C D E	A AMOUNT OF RESIDUE (µGR/IN²)	B IPA (VOL%)	C SOLUTION TEMP. (ON/OFF)	D TEST CELL VOLUME (ML/SQ IN.)	E CHANNEL DEPTH (MILS)	IONIC READING W/BLK	IONIC READING WO/BLK	TEST DURATION W/BLK	TEST DURATION WO/BLK	TEST CELL TEMP. W/BLK	TEST CELL TEMP. WO/BLK
1	2	+ - - - -	55	70	OFF	160	3	15.82	3.62	15:00	15:00	83°F	84°F
2	1	- - - - +	5	70	OFF	160	9	8.12	5.08	15:00	15:00	87°F	88°F
3	10	+ - - + +	55	70	OFF	320	9	18.33	5.96	15:00	15:00	85°F	85°F
4	9	- - - + -	5	70	OFF	320	3	9.33	5.00	15:00	15:00	75°F	79°F
5	12	+ + - + -	55	80	OFF	320	3	10.51	1.99	15:00	15:00	80°F	82°F
6	11	- + - + +	5	80	OFF	320	9	6.02	1.88	15:00	15:00	84°F	85°F
7	3	- + - - -	5	80	OFF	160	3	3.82	1.97	15:00	15:00	87°F	88°F
8	4	+ + - - +	55	80	OFF	160	9	3.77	2.30	15:00	15:00	89°F	91°F
9	18	0 0 0 0 0	30	75	ON	160	6	14.16	3.36	15:00	15:00	107°F	108°F
10	17	0 0 0 0 0	30	75	ON	160	6	13.69	4.21	15:00	15:00	108°F	108°F
11	19	0 0 0 0 0	30	75	ON	160	6	17.15	5.08	15:00	15:00	109°F	109°F
12	6	+ - + - +	55	70	ON	160	9	17.90	4.91	15:00	15:00	107°F	107°F
13	5	- - + - -	5	70	ON	160	3	11.37	3.72	15:00	15:00	107°F	108°F
14	14	+ - + + -	55	70	ON	320	3	20.3	5.29	15:00	15:00	108°F	108°F
15	13	- - + + +	5	70	ON	320	9	8.92	3.76	15:00	15:00	108°F	108°F
16	8	+ + + - -	55	80	ON	160	3	18.71	6.85	15:00	15:00	107°F	108°F
17	16	+ + + + +	55	80	ON	320	9	16.70	5.72	15:00	15:00	110°F	108°F
18	7	- + + - +	5	80	ON	160	9	4.34	6.97	15:00	15:00	110°F	110°F
19	15	- + + + -	5	80	ON	320	3	12.70	4.40	15:00	15:00	110°F	110°F
20	2	+ - - - -	55	70	OFF	160	3	19.60	9.05	15:00	15:00	86.8°F	86.4°F
21	1	- - - - +	5	70	OFF	160	9	11.37	8.47	15:00	15:00	78.6°F	78.6°F
22	10	+ - - + +	55	70	OFF	320	9	24.16	11.15	15:00	15:00	83°F	83.8°F
23	9	- - - + -	5	70	OFF	320	3	16.34	6.88	15:00	15:00	87°F	87.4°F
24	12	+ + - + -	55	80	OFF	320	3	15.02	6.42	15:00	15:00	84.4°F	84.2°F
25	11	- + - + +	5	80	OFF	320	9	13.39	15.33	15:00	15:00	87°F	86.4°F
26	3	- + - - -	5	80	OFF	160	3	4.21	4.03	15:00	15:00	74.6°F	79.6°F
27	4	+ + - - +	55	80	OFF	160	9	8.12	2.36	15:00	15:00	79.0°F	79.4°F

TABLE OF EFFECTS (Board Tests with Blocks)

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	32.59*	18.77*	27.21*	3.81*	15.33*	14.68*	10.73*	12.81*	9.29*
MAIN									
Residue (R)	50.88*	24.01*	37.81*	5.26*	12.28*	16.60*	10.19*	7.21*	11.83*
IPA (I)	-21.88*	-35.43*	-26.69*	-1.41	-20.51*	-11.30*		-4.39*	2.38
Volume (V)					-2.17	-4.63*	-0.93	3.18*	
Channel (C)	5.12	10.27*	0.12	1.11	1.89	0.88	0.05	-1.99	-1.05
Heat (H)						6.94*		2.12	
INTERACTION									
R*I	-17.27*	-22.08*	-20.52*	-1.96	-6.18*	-4.69*	-4.99*	-1.37	0.13
R*V					-3.92x	0.81	0.13	-0.49	
R*C	1.28	7.14	0.16	0.26	0.24	-3.16*	0.13	0.06	0.85
R*H						3.10*		1.86	
I*V					-7.98*	-3.39*	-0.48	1.54	
I*C	1.68	-8.29	-1.70	0.69	1.26	0.64	1.55	-0.89	-3.20
I*H						-0.30		2.88x	
V*C					0.29	1.19	-0.81	1.48	
V*H						1.28	0.13	-1.60	
C*H						-3.73*		-1.82	
R*I*V					-2.18		0.33		
R*I*C	3.83	-5.34	4.44	0.24	-1.14		0.34		0.10
R*V*C					1.92		0.56		
I*V*C					-3.44x		-0.74		
CENTER	53.68*	48.85*	6.48	2.36	16.11*	-0.05	10.00*	1.13	2.45

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

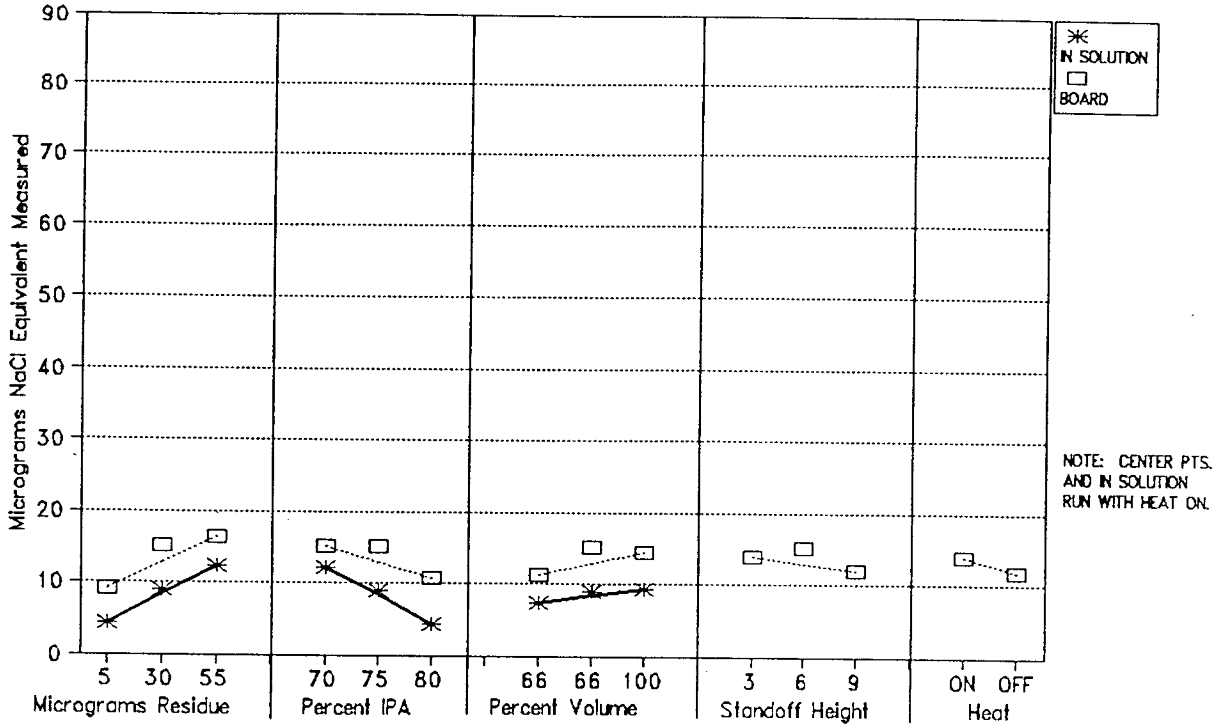
TABLE OF EFFECTS (Board Tests: Total)

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	34.01*	32.66*	31.03*	5.68*	22.01*	17.93*	13.14*	18.27*	15.06*
MAIN									
Residue (R)	51.55*	42.86*	38.89*	6.59*	17.82*	17.01*	11.33*	7.33*	13.66*
IPA (I)	-23.88*	-42.32*	-31.83*	-0.61	-27.52*	-14.33*		-4.79*	6.29x
Volume (V)					-1.23	-10.13*	-2.23	3.88	
Channel (C)	2.88	-1.90	-2.79	0.49	-0.37	0.69	0.12	-1.00	-4.49
Heat (H)						6.69*		1.61	
INTERACTION									
R*I	-18.80*	-23.04*	-20.27*	-1.54	-6.37x	-4.13*	-5.68*	-2.46	-3.66
R*V					-2.48	0.07	-0.01	-0.35	
R*C	0.00	-3.50	-0.30	-0.44	-1.09	-3.11x	-0.81	-1.21	4.51
R*H						3.14x		2.72	
I*V					-6.72x	-1.34	0.98	1.78	
I*C	3.38	-6.65	0.06	0.26	-0.03	0.43	1.63	-0.58	-2.31
I*H						0.13		4.85	
V*C					1.56	1.53	-1.54	2.20	
V*H						1.03		-3.12	
C*H						-3.94*		-2.53	
R*I*V					-2.42		1.96		
R*I*C	4.77	-3.11	3.99	-0.31	-2.36		-0.24		6.09x
R*V*C					3.58		0.36		
I*V*C					-4.41		-0.11		
CENTER	53.69*	47.23*	5.84	1.79	9.72x	1.53	8.26*	0.15	1.48

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

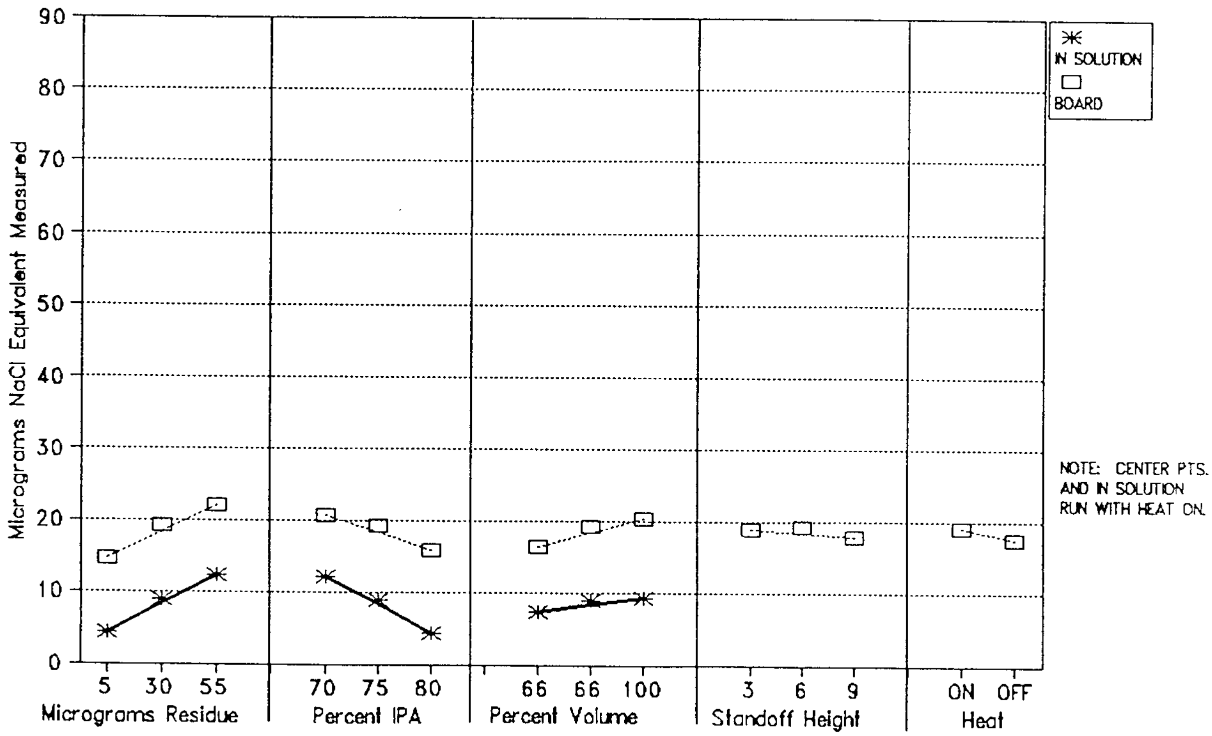
ICOM 5000 : Board w/Block

MAIN EFFECTS (weak flux only)

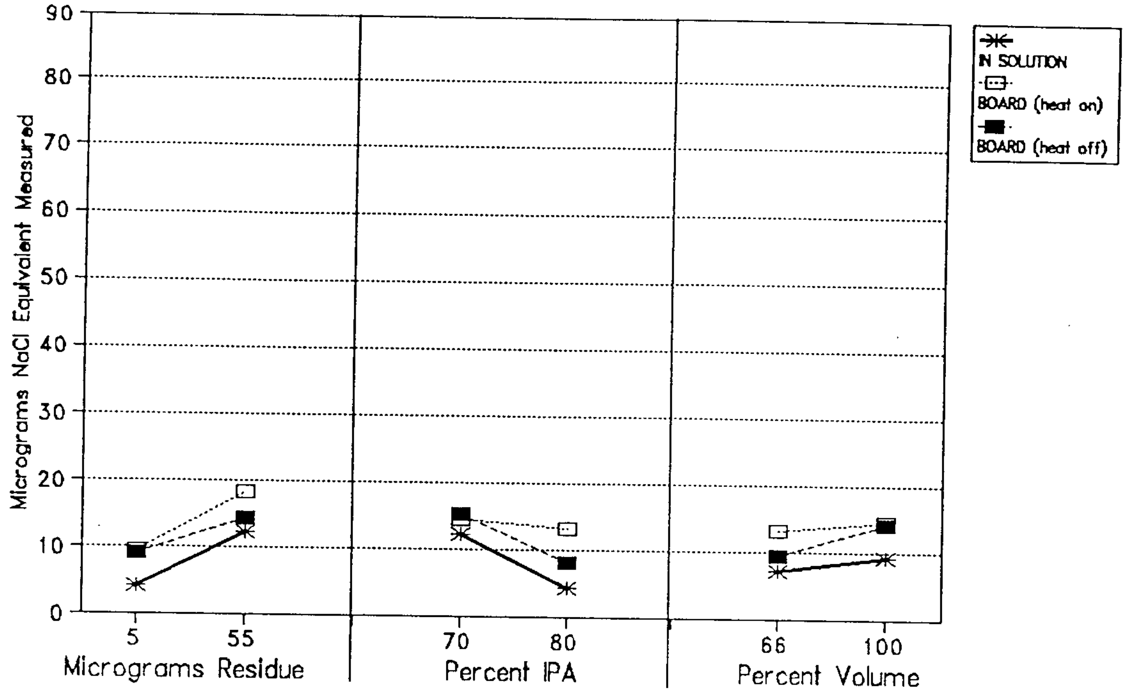


ICOM 5000 : Board Total

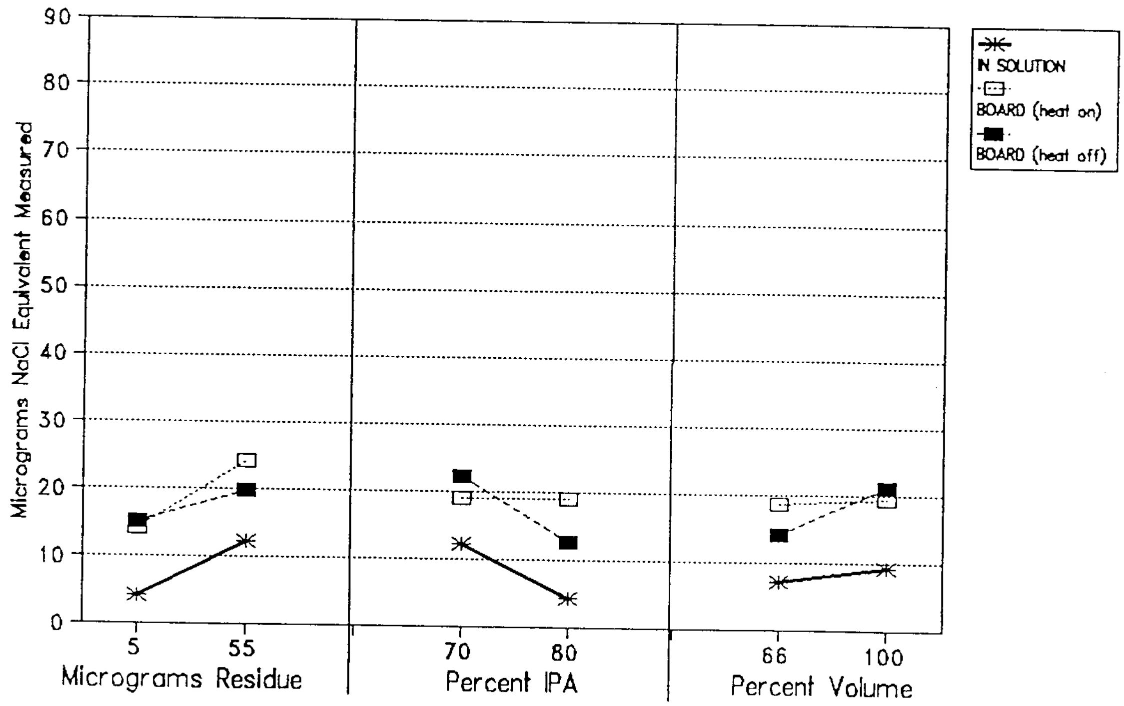
MAIN EFFECTS (weak flux only)



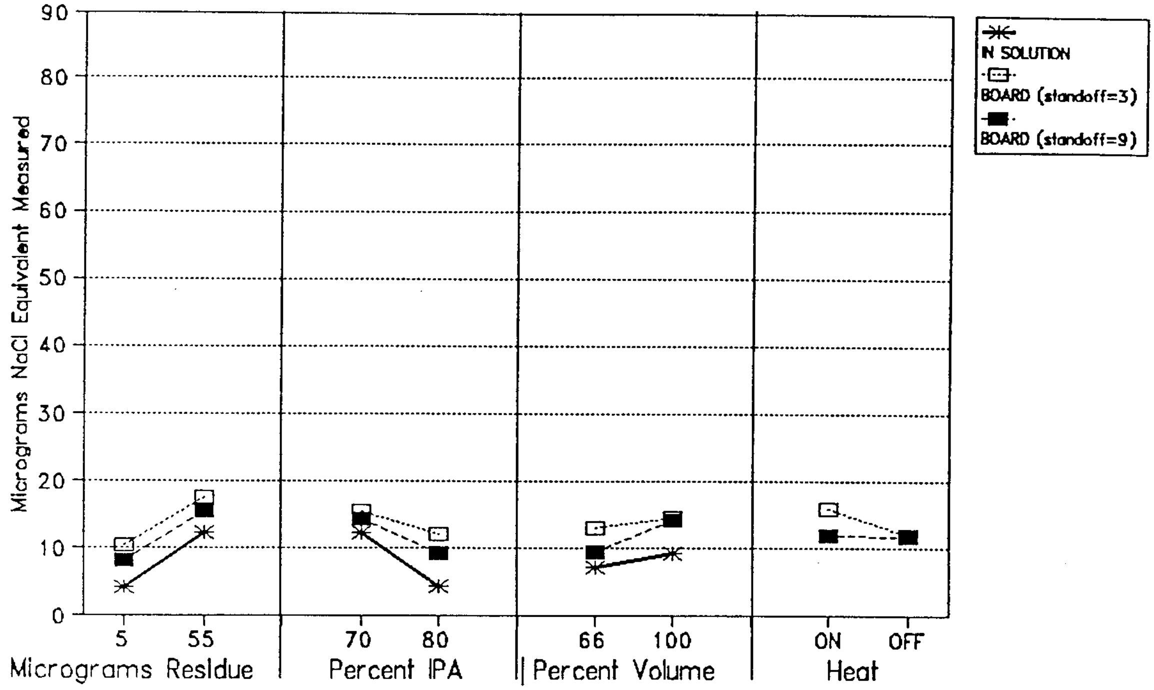
ICOM 5000 : Board w/Block
2-WAY INT. w/HEAT (weak flux only)



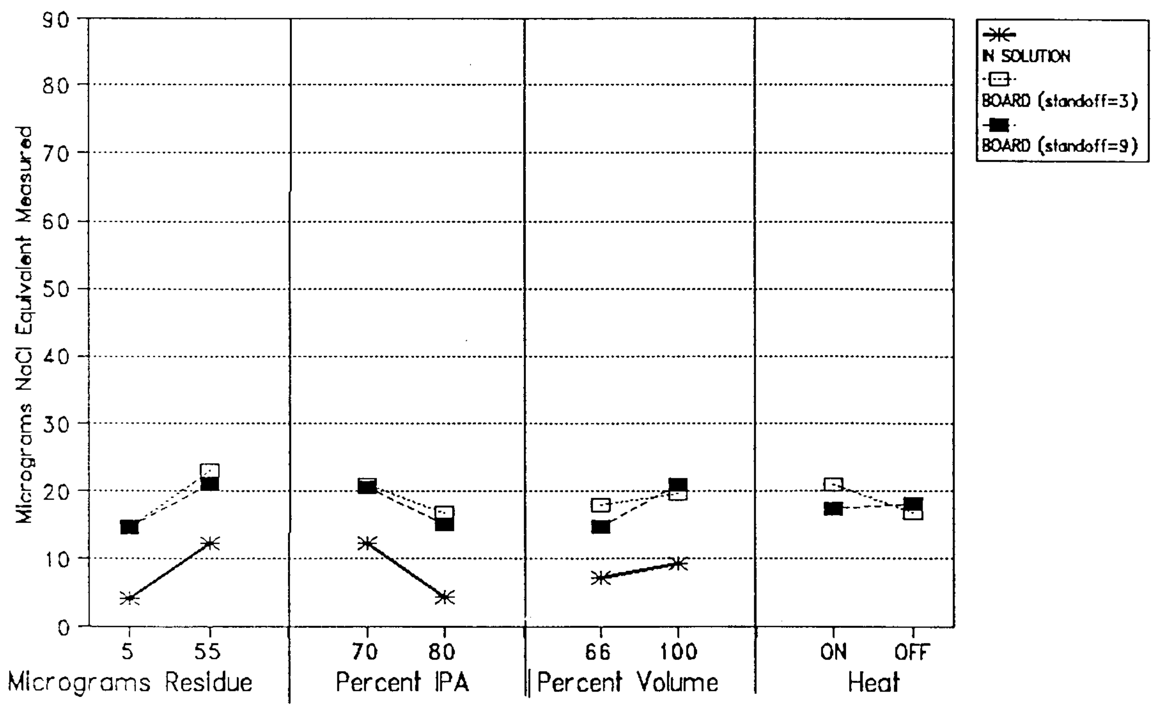
ICOM 5000 : Board Total
2-WAY INT. w/HEAT (weak flux only)



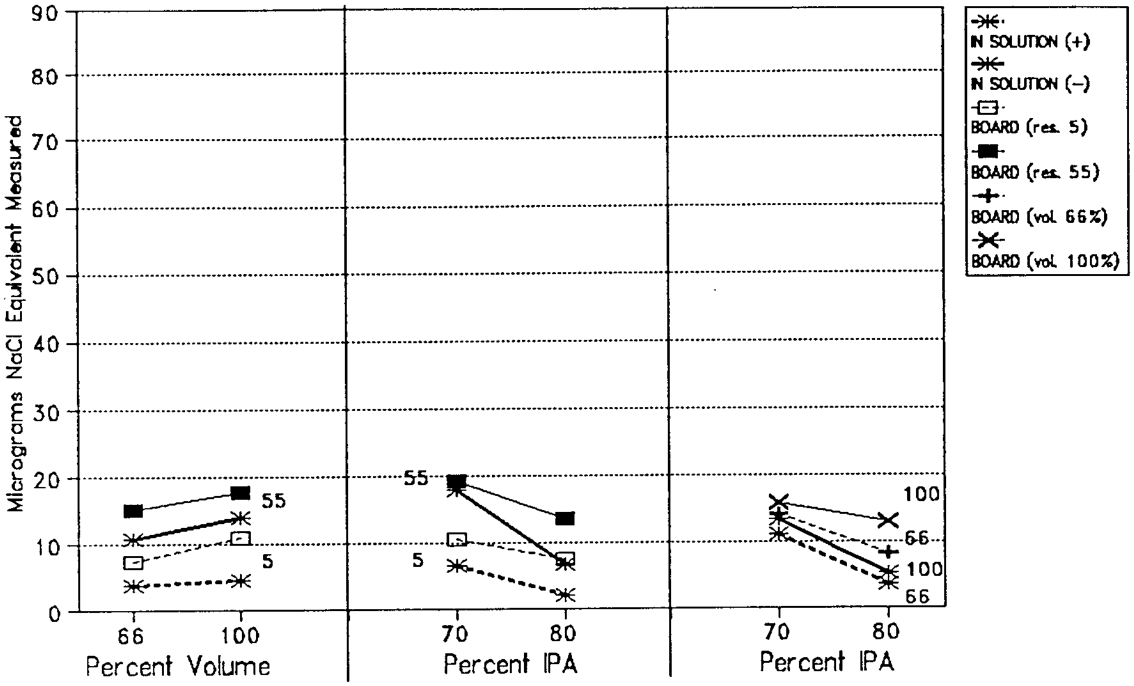
ICOM 5000 : Board w/Block
2-WAY INT. w/STANDOFF (weak flux only)



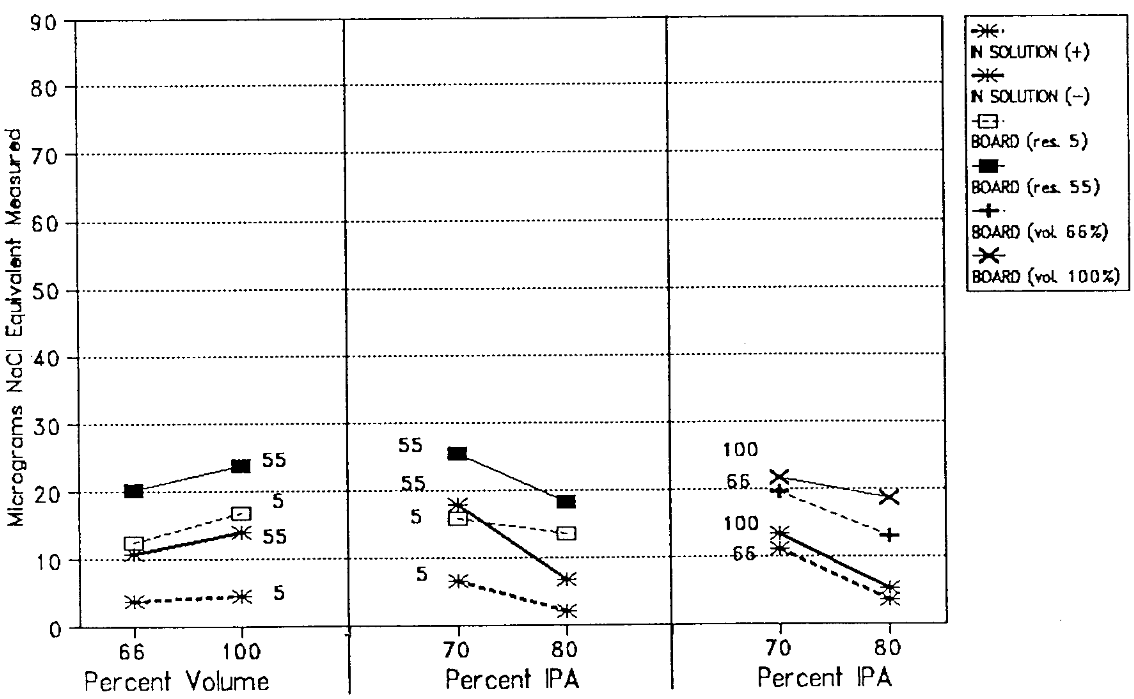
ICOM 5000 : Board Total
2-WAY INT. w/STANDOFF (weak flux only)

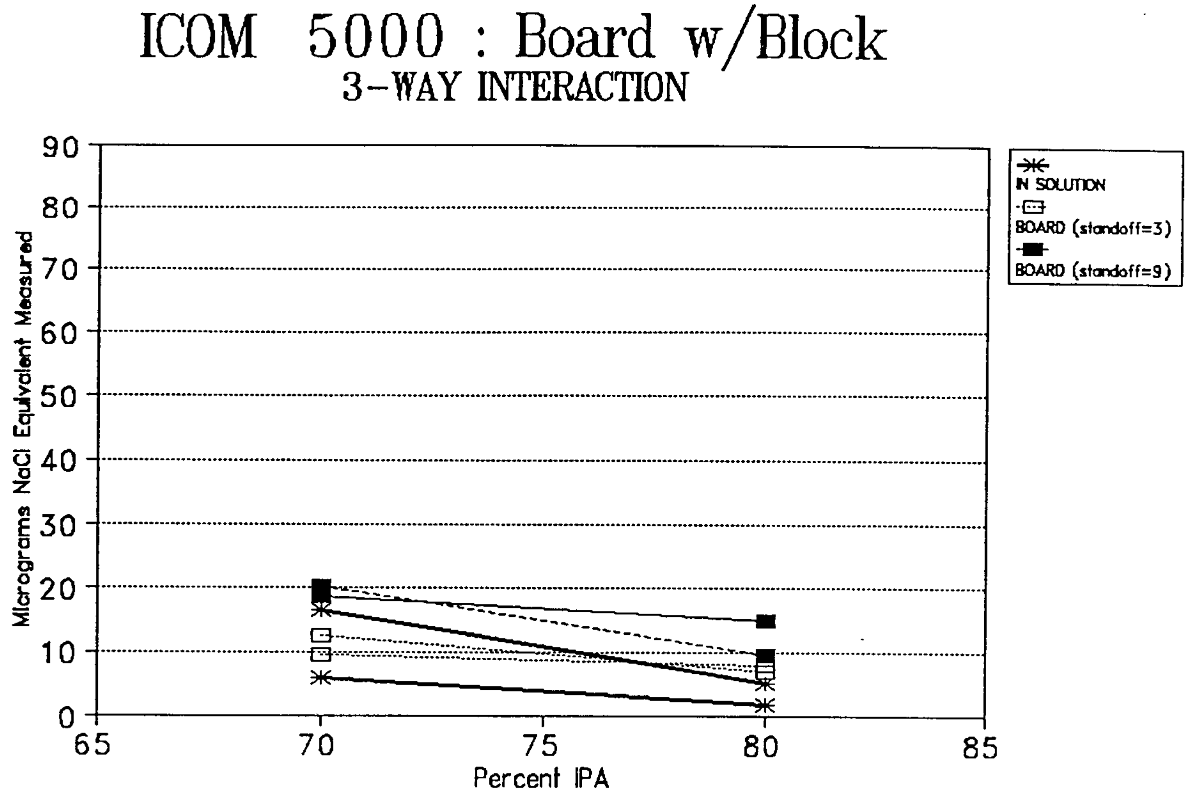


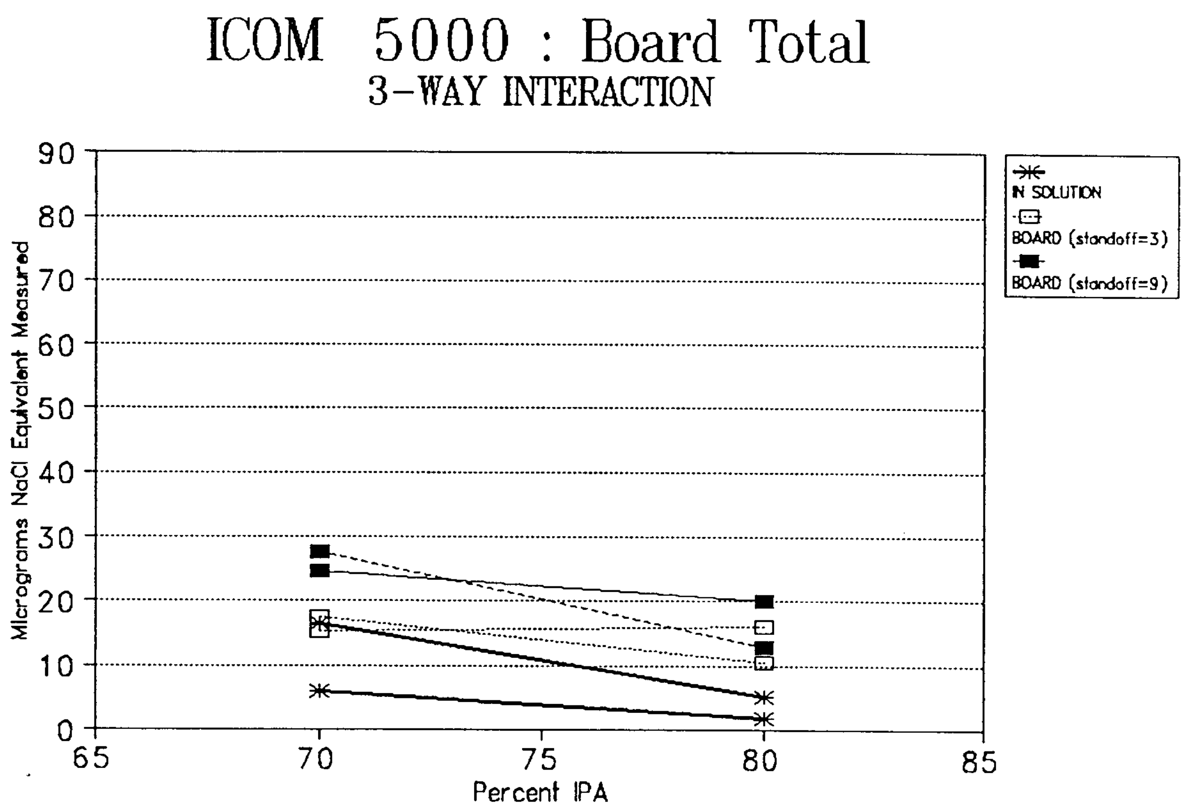
ICOM 5000 : Board w/Block
OTHER 2-WAY INT. (weak flux only)



ICOM 5000 : Board Total
OTHER 2-WAY INT. (weak flux only)




ICOM 5000 : Board w/Block
3-WAY INTERACTION
Micrograms NaCl Equivalent Measured
90
80
70
60
50
40
30
20
10
0
65
70
75
80
85
Percent IPA
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)


ICOM 5000 : Board Total
3-WAY INTERACTION
Micrograms NaCl Equivalent Measured
90
80
70
60
50
40
30
20
10
0
65
70
75
80
85
Percent IPA
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)

ICOM 5000
IN SOLUTION TEST (weak flux)

Predictor	Coef	Stdev	t-ratio	p	
Constant	8.2969	0.1676	49.50	0.000	*
R	4.0431	0.1676	24.13	0.000	*
I	-3.9644	0.1676	-23.66	0.000	*
V	0.9906	0.1676	5.91	0.002	*
R*I	-1.6981	0.1676	-10.13	0.000	*
R*V	0.6019	0.1676	3.59	0.016	*
I*V	-0.1156	0.1676	-0.69	0.521	
R*I*V	0.1656	0.1676	0.99	0.368	
CTR.PT	0.4581	0.4217	1.09	0.327	

s = 0.5473 R-sq = 99.7% R-sq(adj) = 99.2%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	467.736	58.467	195.20	0.000
Error	5	1.498	0.300		
Total	13	469.234			

SOURCE	DF	SEQ SS
R	1	189.131
I	1	219.479
V	1	18.472
R*I	1	35.808
R*V	1	4.043
I*V	1	0.113
R*I*V	1	0.338
CTR.PT	1	0.353

ICOM 5000
BOARD TEST w/BLOCK

Predictor	Coef	Stdev	t-ratio	p	
Constant	12.807	0.7112	18.01	0.000	*
R	3.6028	0.7112	5.07	0.000	*
I	-2.1966	0.7112	-3.09	0.011	*
V	1.5897	0.7112	2.24	0.049	*
C	-0.9941	0.7112	-1.40	0.192	
H	1.0609	0.7112	1.49	0.167	
R*I	-0.6828	0.7112	-0.96	0.360	
R*V	-0.2466	0.7112	-0.35	0.736	
R*C	0.0322	0.7112	0.05	0.965	
R*H	0.9322	0.7112	1.31	0.219	
I*V	0.7678	0.7112	1.08	0.306	
I*C	-0.4434	0.7112	-0.62	0.547	
I*H	1.4416	0.7112	2.03	0.070	x
V*C	0.7403	0.7112	1.04	0.322	
V*H	-0.8022	0.7112	-1.13	0.286	
C*H	-0.9084	0.7112	-1.28	0.230	
CTR.PT	1.132	2.224	0.51	0.622	

s = 3.285   R-sq = 86.8%   R-sq(adj) = 65.8%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	16	712.50	44.53	4.13	0.014
Error	10	107.90	10.79		
Total	26	820.40			

SOURCE	DF	SEQ SS
R	1	260.11
I	1	172.00
V	1	82.77
C	1	11.47
H	1	38.51
R*I	1	20.74
R*V	1	0.23
R*C	1	1.20
R*H	1	18.54
I*V	1	12.58
I*C	1	4.19
I*H	1	44.33
V*C	1	11.69
V*H	1	13.73
C*H	1	17.61
CTR.PT	1	2.80

ICOM 5000
BOARD TEST TOTAL

Predictor	Coef	Stdev	t-ratio	p	
Constant	18.267	1.449	12.61	0.000	*
R	3.667	1.449	2.53	0.030	*
I	-2.397	1.449	-1.65	0.129	
V	1.939	1.449	1.34	0.210	
C	-0.501	1.449	-0.35	0.737	
H	0.803	1.449	0.55	0.592	
R*I	-1.231	1.449	-0.85	0.416	
R*V	-0.177	1.449	-0.12	0.905	
R*C	-0.606	1.449	-0.42	0.684	
R*H	1.358	1.449	0.94	0.371	
I*V	0.891	1.449	0.62	0.552	
I*C	-0.290	1.449	-0.20	0.845	
I*H	2.424	1.449	1.67	0.125	
V*C	1.098	1.449	0.76	0.466	
V*H	-1.561	1.449	-1.08	0.307	
C*H	-1.264	1.449	-0.87	0.404	
CTR.PT	0.147	4.530	0.03	0.975	

s = 6.692 R-sq = 69.8% R-sq(adj) = 21.4%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	16	1033.68	64.60	1.44	0.282
Error	10	447.81	44.78		
Total	26	1481.48			

SOURCE	DF	SEQ SS
R	1	247.94
I	1	246.53
V	1	145.14
C	1	0.15
H	1	17.67
R*I	1	61.18
R*V	1	0.16
R*C	1	19.58
R*H	1	39.35
I*V	1	16.95
I*C	1	1.79
I*H	1	125.39
V*C	1	25.73
V*H	1	52.00
C*H	1	34.07
CTR.PT	1	0.05

Unusual Observations

Obs.	R	ICOM.T	Fit	Stdev.Fit	Residual	St.Resid
16	-1.00	7.90	18.31	4.73	-10.41	-2.20R
33	-1.00	28.72	18.31	4.73	10.41	2.20R

R denotes an obs. with a large st. resid.

PROTONIQUE

CONTAMINOMETER CM5 (static)

Static
Unheated
No spray

CONTAMINOMETER CM5/STATIC MODE
RANDOMIZED EXPERIMENTAL MATRIX
PWB/WEAK FLUX TESTS

RANDOMIZED RUN SEQUENCE	STANDARD ORDER	A B C	A AMOUNT OF RESIDUE (μGR/IN^2)	B IPA (VOL%)	C CHANNEL DEPTH (MILS)	IONIC READING W/BLOCK	IONIC READING WO/BLOCK	TEST DURATION W/BLK	TEST DURATION WO/BLK	TEST CELL TEMP.
1	1	- - -	5	70	3	2.5	4.0	3:12	3:00	75°F
2	2	+ - -	55	70	3	21.1	5.1	8:40	3:00	75°F
3	6	+ - +	55	70	9	7.6	6.6	6:24	3:00	75°F
4	5	- - +	5	70	9	3.3	0.0	3:00	3:00	76°F
5	9	0 0 0	30	75	6	11.8	4.4	4:48	3:00	75°F
6	10	0 0 0	30	75	6	8.0	4.8	5:40	3:00	75°F
7	11	0 0 0	30	75	6	15.4	5.2	3:00	3:00	75°F
8	8	+ + +	55	80	9	14.8	10.3	4:16	3:24	75°F
9	3	- + -	5	80	3	7.1	14.8	3:00	3:24	75°F
10	4	+ + -	55	80	3	18.1	3.2	3:00	3:12	76°F
11	7	- + +	5	80	9	1.9	2.6	6:28	3:00	75°F
12	1	- - -	5	70	3	0.6	0.0	3:00	3:00	75°F
13	2	+ - -	55	70	3	3.9	14.8	4:24	8:32	75°F
14	6	+ - +	55	70	9	23.2	0.0	3:00	3:00	76°F
15	5	- - +	5	70	9	2.6	0.0	3:00	3:00	76°F

TABLE OF EFFECTS (Board Tests with Blocks)

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	32.59*	18.77*	27.21*	3.81*	15.33*	14.68*	10.73*	12.81*	9.29*
MAIN									
Residue (R)	50.88*	24.01*	37.81*	5.26*	12.28*	16.60*	10.19*	7.21*	11.83*
IPA (I)	-21.88*	-35.43*	-26.69*	-1.41	-20.51*	-11.30*		-4.39*	2.38
Volume (V)					-2.17	-4.63*	-0.93	3.18*	
Channel (C)	5.12	10.27*	0.12	1.11	1.89	0.88	0.05	-1.99	-1.05
Heat (H)						6.94*		2.12	
INTERACTION									
R*I	-17.27*	-22.08*	-20.52*	-1.96	-6.18*	-4.69*	-4.99*	-1.37	0.13
R*V					-3.92x	0.81	0.13	-0.49	
R*C	1.28	7.14	0.16	0.26	0.24	-3.16*	0.13	0.06	0.85
R*H						3.10*		1.86	
I*V					-7.98*	-3.39*	-0.48	1.54	
I*C	1.68	-8.29	-1.70	0.69	1.26	0.64	1.55	-0.89	-3.20
I*H						-0.30		2.88x	
V*C					0.29	1.19	-0.81	1.48	
V*H						1.28	0.13	-1.60	
C*H						-3.73*		-1.82	
R*I*V					-2.18		0.33		
R*I*C	3.83	-5.34	4.44	0.24	-1.14		0.34		0.10
R*V*C					1.92		0.56		
I*V*C					-3.44x		-0.74		
CENTER	53.68*	48.85*	6.48	2.36	16.11*	-0.05	10.00*	1.13	2.45

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

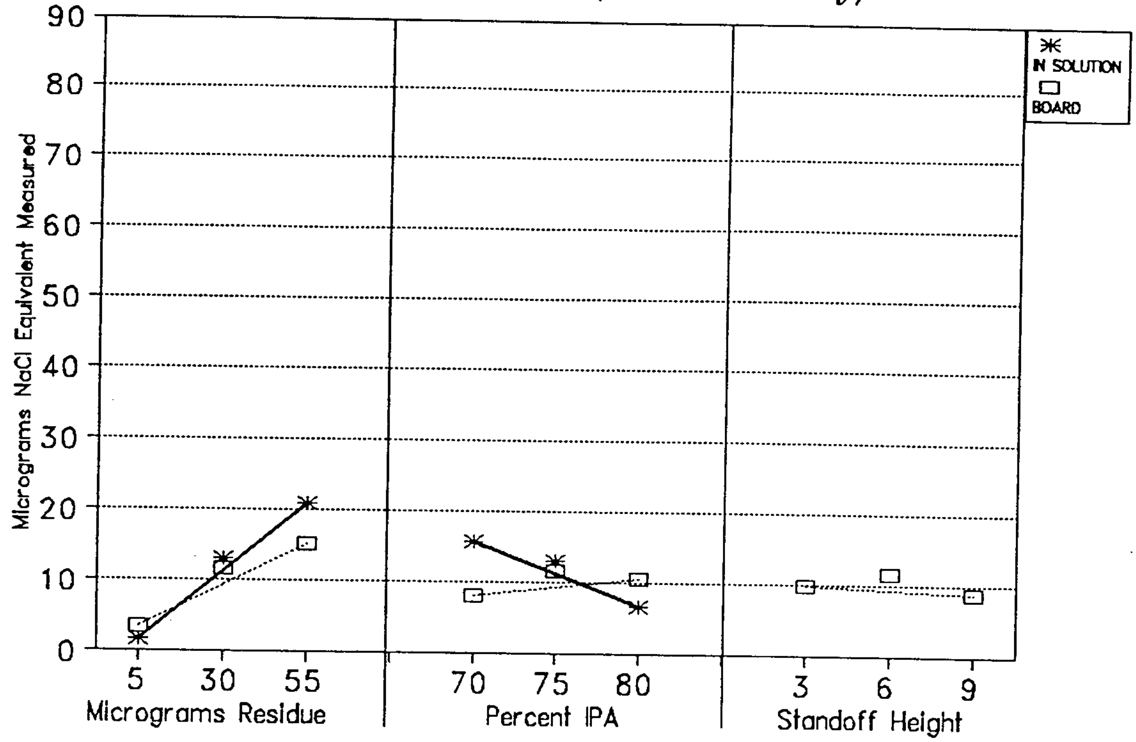
TABLE OF EFFECTS (Board Tests: Total)

	DYNAMIC SYSTEMS				STATIC SYSTEMS				
	Zero Ion	Iono-graph 500M	Iono-graph 500SMD	CM-5 dynamic	Omega-meter 600R	Omega-meter 600SMD	Ionex 2000	Icom 5000	CM-5 static
MEAN	34.01*	32.66*	31.03*	5.68*	22.01*	17.93*	13.14*	18.27*	15.06*
MAIN									
Residue (R)	51.55*	42.86*	38.89*	6.59*	17.82*	17.01*	11.33*	7.33*	13.66*
IPA (I)	-23.88*	-42.32*	-31.83*	-0.61	-27.52*	-14.33*	-14.43*	-4.79*	6.29x
Volume (V)					-1.23	-10.13*	-2.23	3.88	
Channel (C)	2.88	-1.90	-2.79	0.49	-0.37	0.69	0.12	-1.00	-4.49
Heat (H)						6.69*		1.61	
INTERACTION									
R*I	-18.80*	-23.04*	-20.27*	-1.54	-6.37x	-4.13*	-5.68*	-2.46	-3.66
R*V					-2.48	0.07	-0.01	-0.35	
R*C	0.00	-3.50	-0.30	-0.44	-1.09	-3.11x	-0.81	-1.21	4.51
R*H						3.14x		2.72	
I*V					-6.72x	-1.34	0.98	1.78	
I*C	3.38	-6.65	0.06	0.26	-0.03	0.43	1.63	-0.58	-2.31
I*H						0.13		4.85	
V*C					1.56	1.53	-1.54	2.20	
V*H						1.03		-3.12	
C*H						-3.94*		-2.53	
R*I*V					-2.42		1.96		
R*I*C	4.77	-3.11	3.99	-0.31	-2.36		-0.24		6.09x
R*V*C					3.58		0.36		
I*V*C					-4.41		-0.11		
CENTER	53.69*	47.23*	5.84	1.79	9.72x	1.53	8.26*	0.15	1.48

Mean Response = average of all runs (except center points, adjusted for unbalance in design).
Main Effects = average change in response when setting of this factor changed from low to high level.
Interactions = difference in the effect of one factor when level changed in other factor(s).
Notation: R*I is the Residue/IPA interaction.
Center points = difference between the response observed at the center point and the expected value at center based on other test runs (expected value = mean response).
* indicates a factor is statistically significant with > 95% confidence, based on experimental error.
x indicates a factor is statistically significant with 90 - 95% confidence.

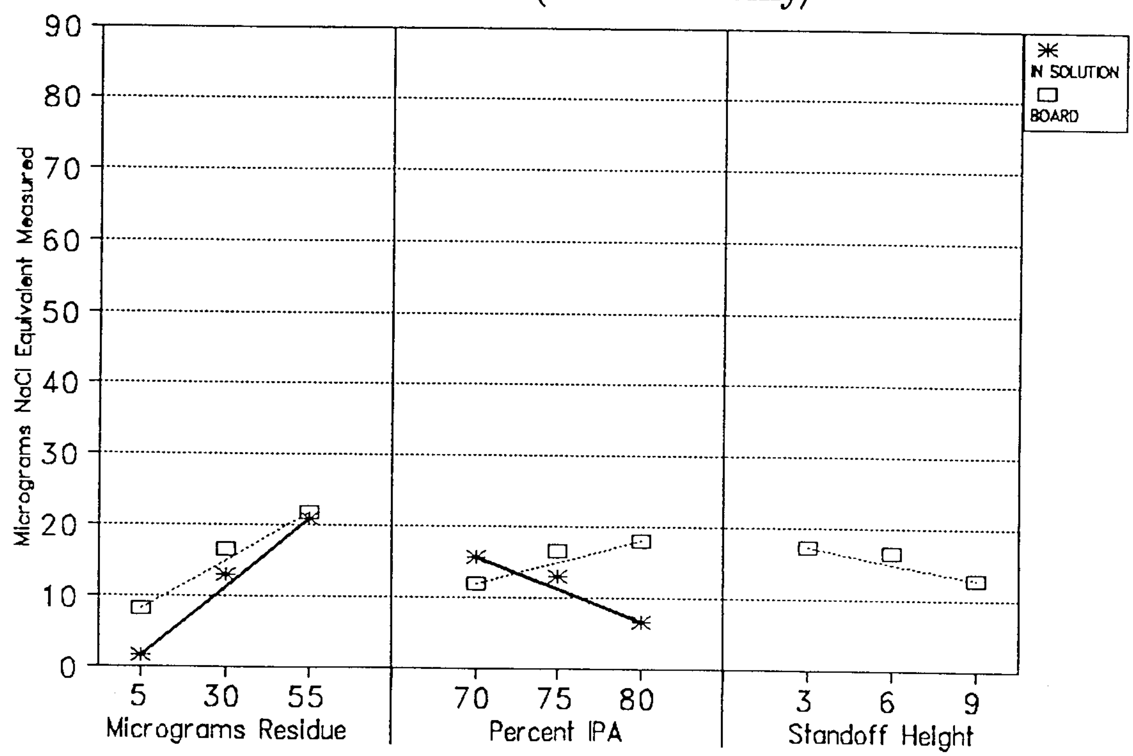
CONTAMINOMETER (static) : Board w/Block

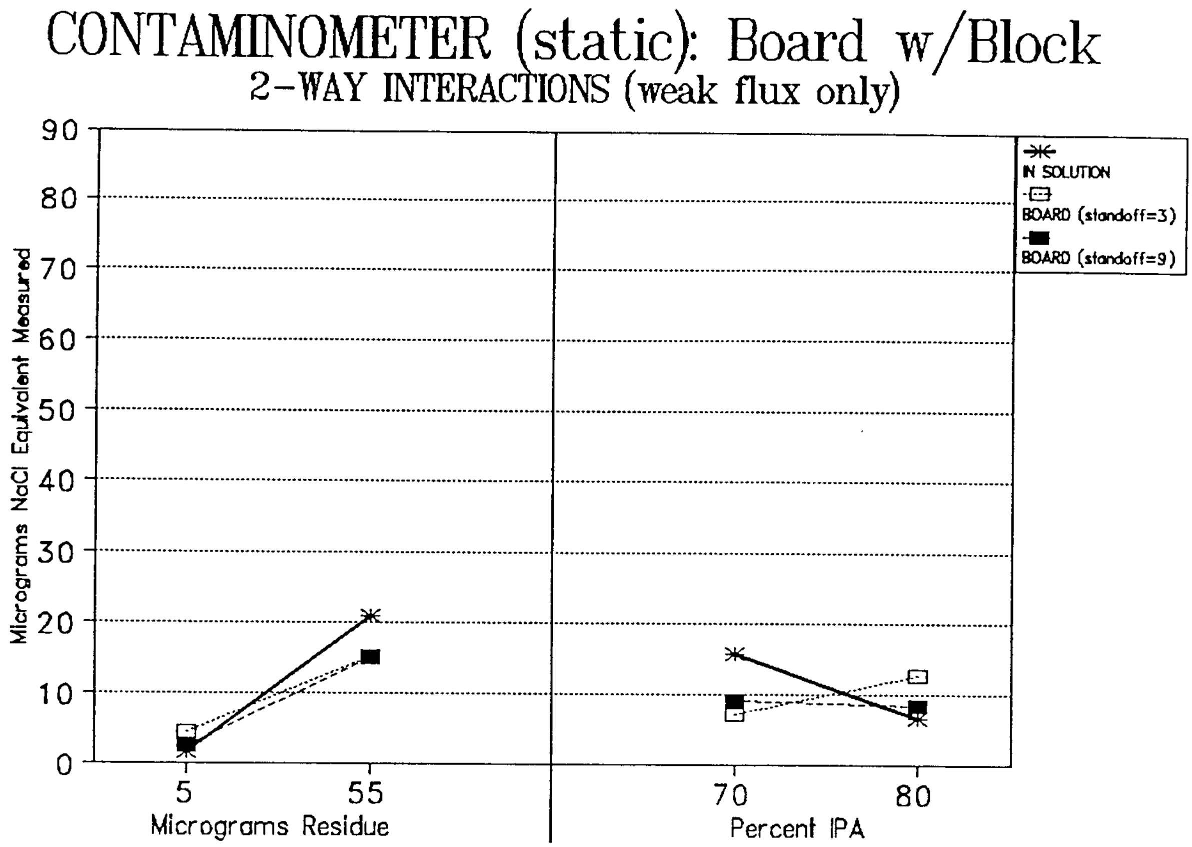
MAIN EFFECTS (weak flux only)

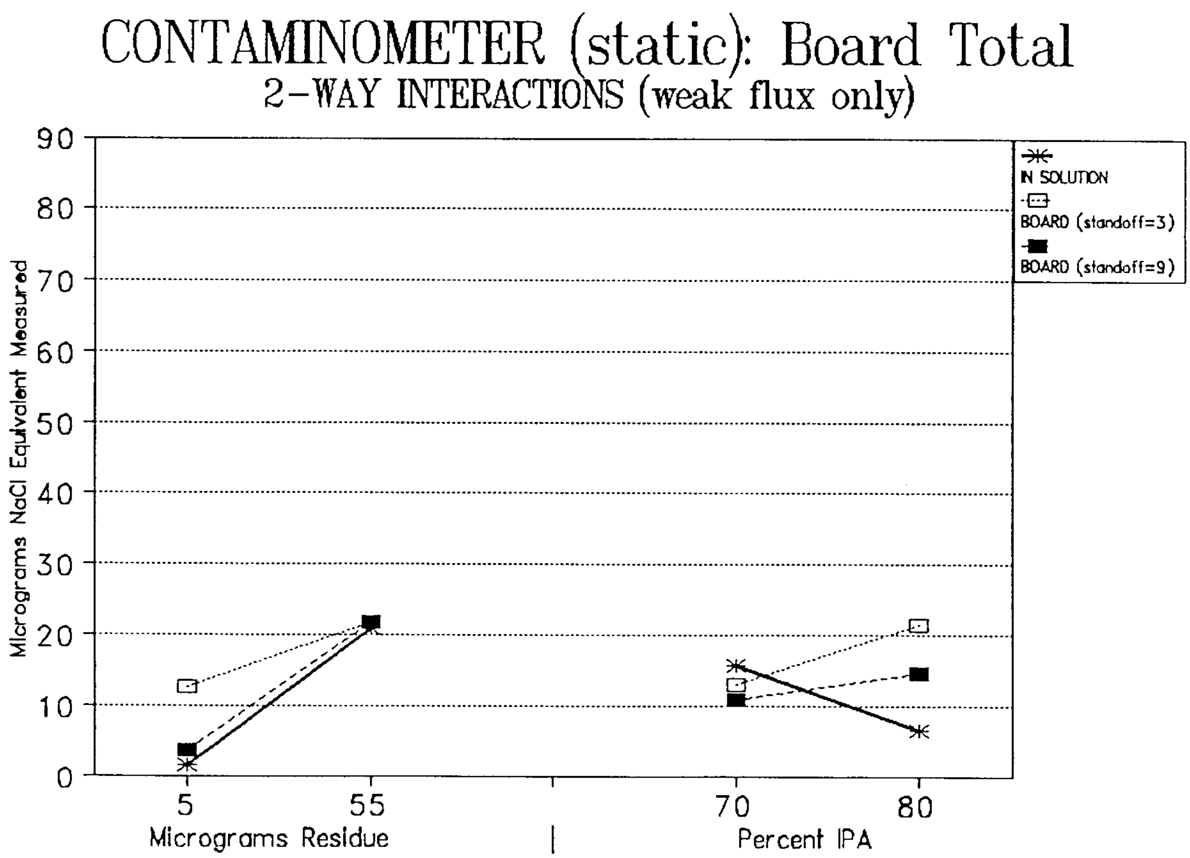


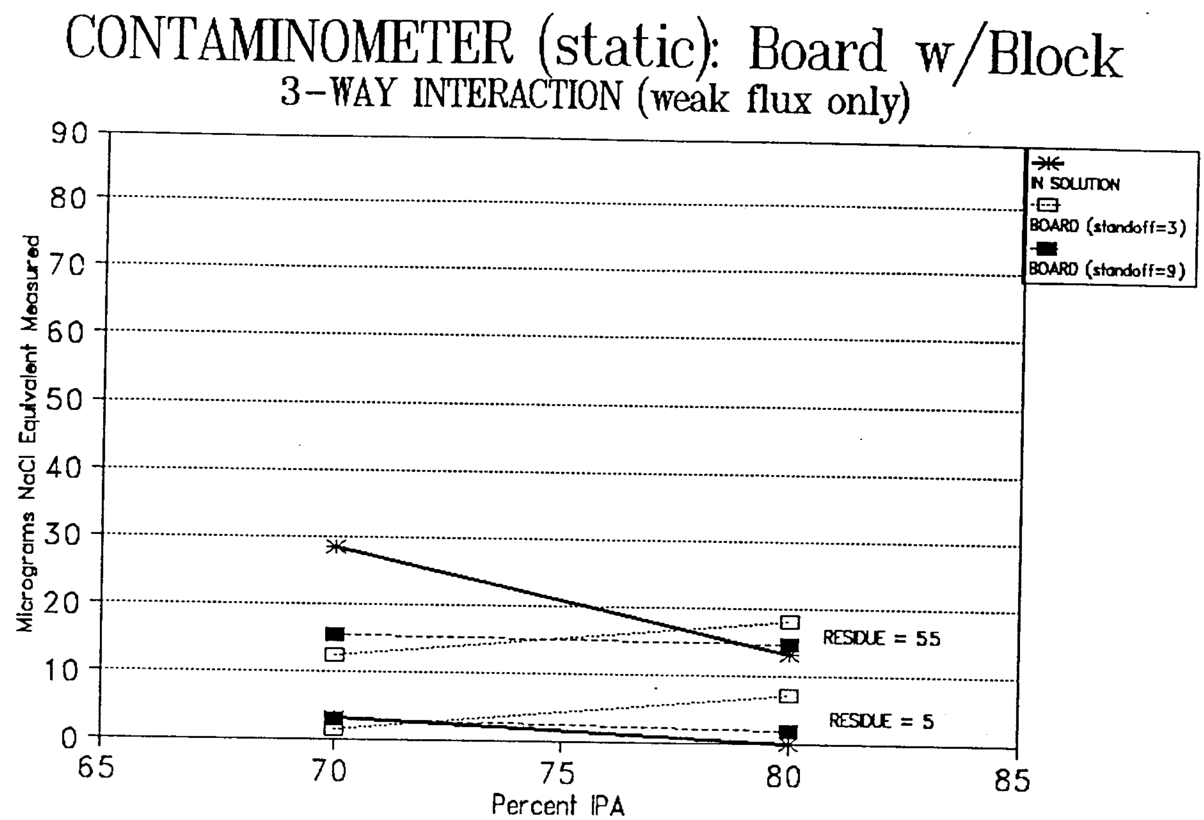
CONTAMINOMETER (static): Board Total

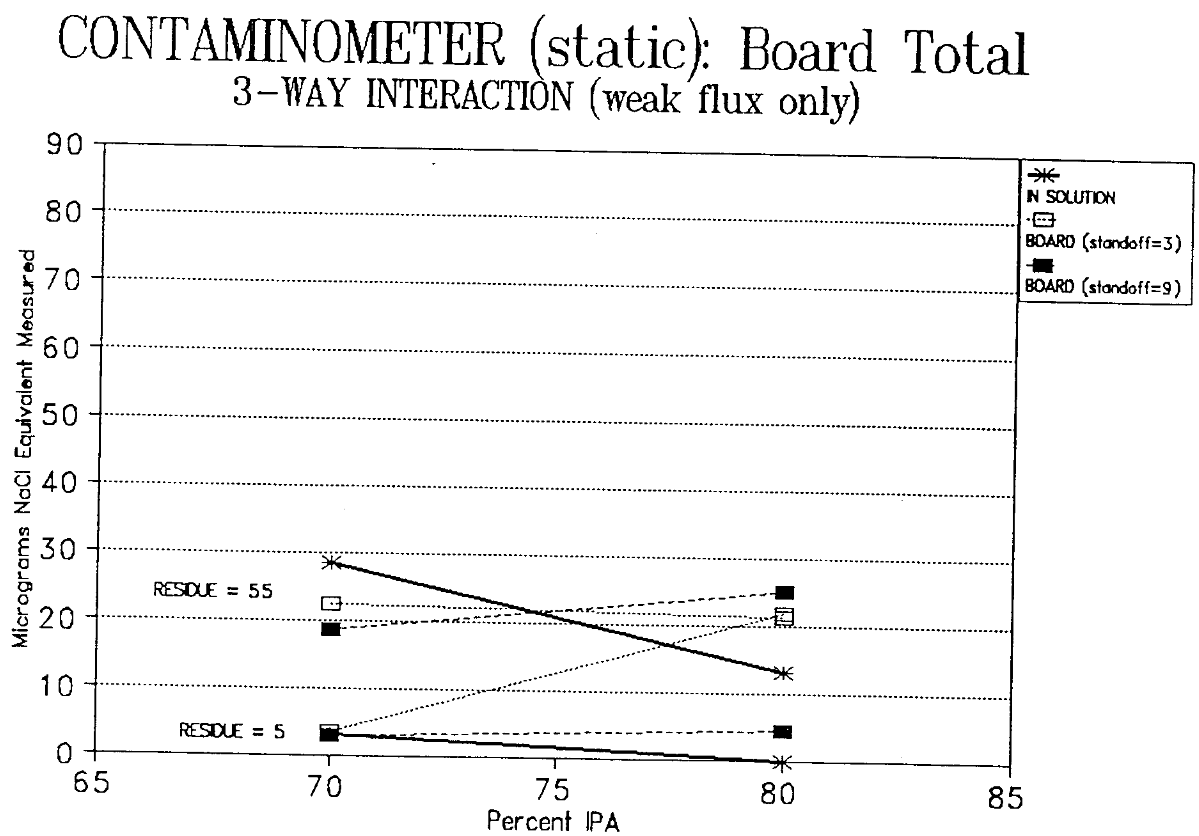
MAIN EFFECTS (weak flux only)




CONTAMINOMETER (static): Board w/Block
2-WAY INTERACTIONS (weak flux only)
Micrograms NaCl Equivalent Measured
0
10
20
30
40
50
60
70
80
90
5
55
Micrograms Residue
70
80
Percent IPA
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)


CONTAMINOMETER (static): Board Total
2-WAY INTERACTIONS (weak flux only)
Micrograms NaCl Equivalent Measured
0
10
20
30
40
50
60
70
80
90
5
55
Micrograms Residue
70
80
Percent IPA
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)


CONTAMINOMETER (static): Board w/Block
3-WAY INTERACTION (weak flux only)
Micrograms NaCl Equivalent Measured
0
10
20
30
40
50
60
70
80
90
65
70
75
80
85
Percent IPA
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)
RESIDUE = 55
RESIDUE = 5


CONTAMINOMETER (static): Board Total
3-WAY INTERACTION (weak flux only)
Micrograms NaCl Equivalent Measured
0
10
20
30
40
50
60
70
80
90
65
70
75
80
85
Percent IPA
IN SOLUTION
BOARD (standoff=3)
BOARD (standoff=9)
RESIDUE = 55
RESIDUE = 5

CONTAMINOMETER CM-5 (static)
IN SOLUTION TEST (weak flux)

Predictor	Coef	Stdev	t-ratio	p	
Constant	11.1663	0.4492	24.86	0.000	*
R	9.6337	0.4492	21.44	0.000	*
I	-4.5563	0.4492	-10.14	0.002	*
R*I	-3.0238	0.4492	-6.73	0.007	*
CTR.PT	1.8937	0.8602	2.20	0.115	

s = 1.037 R-sq = 99.6% R-sq(adj) = 99.1%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	4	839.16	209.79	194.91	0.001
Error	3	3.23	1.08		
Total	7	842.39			

SOURCE	DF	SEQ SS
R	1	679.47
I	1	105.71
R*I	1	48.76
CTR.PT	1	5.22

CONTAMINOMETER CM-5 (static)
BOARD TEST w/BLOCK

Predictor	Coef	Stdev	t-ratio	p	
Constant	9.287	2.162	4.30	0.005	*
R	5.913	2.162	2.74	0.034	*
I	1.188	2.162	0.55	0.603	
C	-0.525	2.162	-0.24	0.816	
R*I	0.063	2.162	0.03	0.978	
R*C	0.425	2.162	0.20	0.851	
I*C	-1.600	2.162	-0.74	0.487	
R*I*C	0.050	2.162	0.02	0.982	
CTR.PT	2.446	4.614	0.53	0.615	

s = 7.060 R-sq = 61.6% R-sq(adj) = 10.5%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	480.34	60.04	1.20	0.422
Error	6	299.04	49.84		
Total	14	779.38			

SOURCE	DF	SEQ SS
R	1	416.54
I	1	20.41
C	1	0.00
R*I	1	0.04
R*C	1	2.00
I*C	1	27.31
R*I*C	1	0.03
CTR.PT	1	14.01

CONTAMINOMETER CM-5 (static)
BOARD TEST TOTAL

Predictor	Coef	Stdev	t-ratio	p	
Constant	15.056	1.351	11.14	0.000	*
R	6.831	1.351	5.06	0.002	*
I	3.144	1.351	2.33	0.059	x
C	-2.244	1.351	-1.66	0.148	
R*I	-1.831	1.351	-1.36	0.224	
R*C	2.256	1.351	1.67	0.146	
I*C	-1.156	1.351	-0.86	0.425	
R*I*C	3.044	1.351	2.25	0.065	x
CTR.PT	1.477	2.884	0.51	0.627	

s = 4.413 R-sq = 89.5% R-sq(adj) = 75.5%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	8	994.06	124.26	6.38	0.018
Error	6	116.86	19.48		
Total	14	1110.92			

SOURCE	DF	SEQ SS
R	1	664.54
I	1	115.61
C	1	41.44
R*I	1	35.77
R*C	1	18.50
I*C	1	14.26
R*I*C	1	98.82
CTR.PT	1	5.11

CONCLUSIONS

Testing performed at the EMPF has shown that as technology advances and PWA surface areas become smaller, surface residues will become increasingly harder to measure accurately.

Specific Observations/Conclusions

- **Residue Quantity.** The most significant factor that influenced the final contamination result was the quantity of residue being measured. This variable was significant for both "in solution" and "test coupon" data regardless of whether the system was static or dynamic. It was interesting to note that static systems and the dynamic systems were grouped separately, but the dynamic systems measured a more significant change going from low to high concentration levels, yet showing a tighter grouping. It can also be noted that the static systems read similar or higher than the dynamics at low concentration levels, but read lower at higher concentrations.

- **Alcohol Concentration.** Perhaps the next most significant variable was that as the IPA concentration was increased from 70% to 80%, the results dropped. This is not surprising, knowing that it is the water that ionizes the contamination, and the alcohol is there merely to dissolve the nonionic (rosin) material to get access to any trapped ionic contamination. The 70% solution contains more water than the 80% solution, thereby giving this solution more ionizing capabilities. This effect was seen in both "in solution" and "test coupon" tests. Again, there is a definite grouping associated with the static verses dynamic systems, but the dynamic systems seem to be most affected by the alcohol change. This is probably due to the fact that the dynamic systems assume an infinite solution volume, thereby continually providing "fresh" solution to ionize contamination residues.

- **Flux Effect.** In comparing weakly ionizable flux to strongly ionizable flux during the "in solution" testing, the dynamic systems showed this variable to be insignificant with the exception of the Ionograph 500SMD. The Ionograph 500SMD and all of the static systems showed that flux type was a significant variable. It was interesting to note that the flux effect on all of the static systems showed a positive effect when the flux type shifted from a weak flux to a strong flux, whereas the dynamic systems showed a slightly negative effect. Though the weakly ionizable and strongly ionizable fluxes were different from each other, the trends that occurred when changing other variables were similar. Once the fluxes were introduced to the test coupons and baked, however, a wide variation in the strongly ionizable flux data began to appear. These fluctuations caused concern as to the statistical validity of the data. The same variations were not detected when using the weakly ionizable flux on the test coupons. Because of these wide variations and the trend similarities to weakly ionizable flux when other variables were altered during "in solution" testing, it was decided by the ICTG not to perform extensive testing on the strongly ionizable flux.

- **Standoff Height.** The standoff height did not have as big of an effect as anticipated for the static systems. Though the standoff height was increased from 3 mils to 9 mils, a similar amount of residue was still being left under the stainless steel plate and no significant trends were noted. Though not significant, the standoff height seemed to affect the dynamic systems more than the static systems, meaning that a larger percent of residue was removed from under the 9 mil standoff than that of the 3 mil standoff. Statistically, the Ionograph 500M was the only system that measured a significant change in residue detected as the standoff height was increased.

- **Temperature Effect.** The temperature of the solvent in all of the systems increased but stabilized during operation, even those without heating elements. Due to pumps moving the solvent and friction in the plumbing, solvent temperatures would typically increase in an unheated system 10 to 15 °F from initial room temperature. This correlates with a study performed at DuPont. Only the Icom 5000 and the Omegameter 600SMD could be run with the heaters in the "on" or "off" position. Both systems showed higher results when the solvent was heated. In addition, the heated systems, when crossed with the solution volume, indicated that the volume variable was more significant.

- **Deadband.** Most of the systems have a region beyond the maximum capability of the resistivity probes known as the deadband. Since each probe has a maximum range, the quantity of ionic residues present above the systems' probe capability will not be measured until the resistivity drops below the upper limit of the probe. For example, if the maximum capability of the probe is 100 megohm-cm, but the resistance exceeds 100 megohm-cm, the display will continue to read 100 megohm-cm. Any ionic residues that drop the resistance to 100 megohm-cm would not be measured. Resistivity, however, is not linear, and the amount of residue it takes to drop the resistivity from 150 megohm-cm to 140 megohm-cm is much less than the amount of residue it takes to drop the resistivity from 50 megohm-cm to 40 megohm-cm. Since there is an area where the ions pass the resistivity probe, but are not detected, the deadband zone should be avoided or false low readings will result. The deadband can be avoided by starting each test at the same point, and not allowing an extended cleaning cycle.

- **Carbon Dioxide Absorption.** Carbon dioxide can dissolve in water to form carbonic acid. This can weakly ionize into H^+ and HCO_3^- ions, which will cause an increase in the overall ionic readings. Extractions which are made for longer times will show higher CO_2 errors, since time allows more CO_2 to be absorbed from the atmosphere. In most instances, the CO_2 contributions will be small, representing only a relatively small error in measurement results. If, however, we are measuring a small sample in a large volume of extracting solution, the effective total micrograms of contamination will give rise to a larger relative error in the reading expressed as $\mu g/in^2$. There did not appear to be any correlation between increased CO_2 absorption and use of sprays. The CO_2 absorption was not detected in the dynamic systems, since they are continually deionizing the solvent and removing the small amount of CO_2 before it has a chance to accumulate to a measurable amount. Further testing, however, would be required to fully characterize the effects of CO_2.

- **Volume effect.** The volume effect was perhaps the most unusual observation made in this study. When the volume was increased from a low level to a higher level during the "in solution" tests, the results also tended to increase. This is consistent with original hypothesis in that the more solution available will provide a greater ionizing capability. In addition, the heated systems (Omegameter 600 SMD and the Icom 5000) indicated that the volume variable seemed more significant. In contrast, however, when the volume was increased during the coupon testing, the ionic results tended to drop. This decrease in ionic measurement readings was consistent on the static and the dynamic systems with the exception of the Icom 5000. There is no explanation for this observance at present.

General Observations

- Throughout the testing, a disagreement, or separation between the "dynamic" and the "static" families of cleanliness test equipment was apparent. The static systems tended to "group" the data that was collected, as did the dynamic systems. However, the groupings were separate in that the contamination levels detected by the dynamic systems were grouped higher, while the static systems tended to group the same level of contamination to a lower resistivity level. Additional testing, not outlined in the original test plan, showed that there were apparent limitations associated with the "static" process that hindered the ability of the solvent to ionize, and thus measure, contamination as an analytical tool.

- Ionic conductivity testing should not be the sole method for evaluating and choosing a process or material. Other methods include ion chromatography, HPLC, surface insulation resistance (SIR), electrochemical migration, and residual rosin analysis.

- Close variable control is required on current ionic conductivity/ resistivity test methods and equipment to maintain consistency. Current ionic conductivity test methods and equipment can be validly used for process control tools. Though there are variables that influence final ionic readings, all of the systems will detect equipment failures, material handling and process errors. Current ionic cleanliness systems will indicate subtle changes to a users existing manufacturing process, when used as a process control tool.

- While they are suitable for use in process control, current ionic conductivity/resistivity test methods and equipment are not accurate analytical tools and should only be used for monitoring relative changes in cleanliness. This is consistent with the development and use of test methods since 1972.

- Pass/fail limits and equivalency factors are not valid applications for current ionic conductivity/resistivity test methods and equipment due to the accuracy and precision problems noted above. However, until a more precise method for analyzing residual contamination is developed, this is the only tool we have and all current contract requirements must be adhered to.

APPENDIX A

DESIGN OF EXPERIMENTS: OVERVIEW

Why Design of Experiments?

The purpose of running any experiment is to better understand how specific factors affect the output of a process or the performance of a product. A successful experiment is one that provides the research team with reliable information: information that may either agree or disagree with their theories about how the process works. Agreement with research theory will improve ability to predict outcomes, and disagreement will lead to revised theories which can be studied in further experimentation.

Some of the advantages of using a statistically designed experiment include:

- dealing with variation (experimental error)
- identifying non-linear and interaction effects
- relative ease of analysis
- efficient experimentation (most information with fewest runs)

Variation is present in all processes to some extent. In any experiment, variation due to uncontrolled factors or due to measurement error can produce misleading results. A well designed experiment will reduce the effect of experimental error. It will also make it possible to determine if the factors being studied have a "significant" effect. Misleading conclusions can also occur when the effect due to a particular factor is non-linear, or if it is dependent on the setting of another factor (called an interaction effect). A statistically designed experiment makes it easier to identify these complex effects.

The most efficient and reliable approach is to use a statistically designed experiment. A well-designed experiment can provide conclusions using rather elementary methods of analysis, while a poorly designed one may not provide useful information, even with the most sophisticated analysis.

The Statistically Designed Experiment

There are several types of designed experiments in common use. Those used in this study are the full factorial and fractional factorial designs. These are used to study many factors concurrently, and to identify which of the factors have a significant effect. Usually, each factor is run at only two

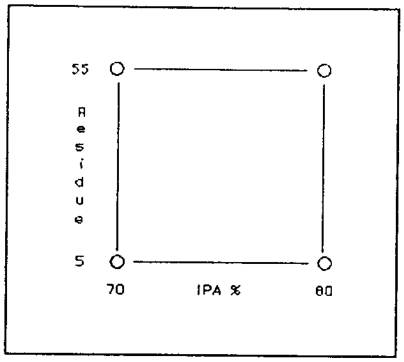


Figure 19 Full Factorial

different "levels" (two different settings). In full factorial designs, all possible combinations are run in the experiment. An easy way to picture it is geometrically: With two factors, the test runs in the experiment would be the four corners of a square (Figure 19). With three factors, the runs would be the eight corners of a cube (Figure 20).

In a fractional factorial design, not all combinations are run in the experiment, but if the right ones are selected they can still provide reliable information about the factors. In the design pictured in Figure 20, either the "*" or "o" corners of the cube would be an example of a fractional factorial design for three factors.

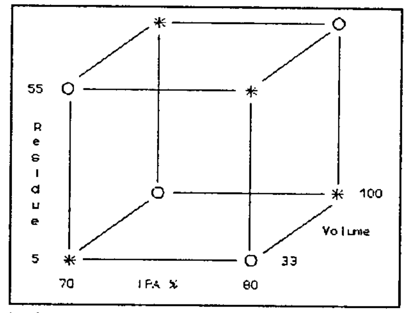


Figure 20 Fractional Factorial

Statistically designed experiments provide advantages in analysis and interpretation because they are "orthogonal". Orthogonal designs are balanced with respect to all factors. This can be seen if the cube is collapsed into any plane or into any line. In the ionic conductivity experiments, the repeated runs added to the end of each experiment cause the design to be unbalanced (usually with respect to IPA), making the analysis less straightforward.

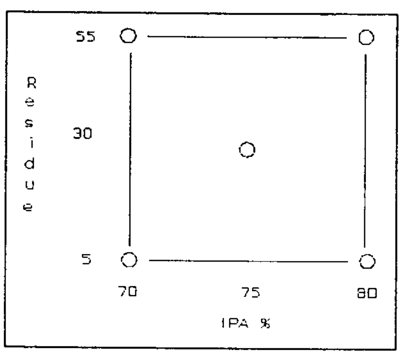


Figure 21 Full Factorial & Center Point

In many experiments, test runs are included at the center point to determine whether there is evidence of a non-linear effect (Figure 21). However, the information gained from a center point will not indicate which factor is responsible for the non-linear effect. Additional test runs would be necessary to verify any theories regarding this. If there is strong suspicion that one particular factor will have a non-linear effect, then the design should be set up to include at least three levels of that factor throughout the design instead of a center point.

Interpreting Results

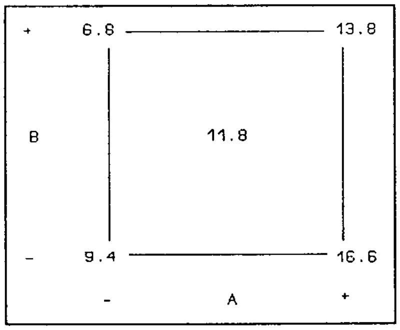


Figure 22
Simple Factorial Example

A simple example of a two factor experiment is shown in Figure 22 and will be used to describe the analysis and interpretation of results. The two factors (A,B) are run at two levels (-,+) and the "-" and "+" signs represent "-1" and "+1", which are standard coded values for the levels of a factorial design. The center point would then be "0". The effects that can be determined in this example are: the main effect of A, the main effect of B, the interaction effect between them (AB), and the center point will be used to test the linearity.

- Main Effects

A main effect is the difference in output when a factor is changed from low level to high level. When the design is balanced, this is the average of all runs at the low level subtracted from the average of all runs at the high level. In the example given in Figure 22, the main effect of A would be:

$$A = (13.8 + 16.6)/2 - (6.8 + 9.4)/2 = 15.2 - 8.1 = 7.1$$
$$B = (6.8 + 13.8)/2 - (9.4 + 16.6)/2 = 10.3 - 13.0 = -2.7$$

Similarly, the main effect of B would be -2.7. The negative effect means that the response (the output) decreases as factor B is changed from low level to high level. Main effects are graphically presented by plotting the average response at each level (see Figure 23). The response at the center point is plotted on the same graph to visually check for curvature (non-linearity). It should fall on or near the center of the line, as in this example, when the effects are linear. In many of the Ionic Conductivity experiments, the center point fell far off the line, indicating a non-linear effect.

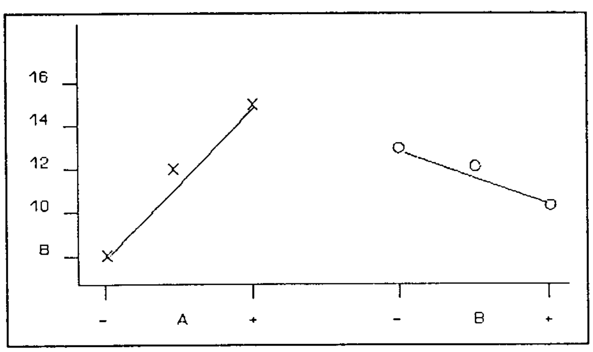


Figure 23 Main Effects Plot

- Interactions

Again, using the example given in Figure 22, the effect of each factor is consistent regardless of the level of the other factor. The effect of factor A is 7.0 when B is at the high level and 7.2 when B is at the low level. Similarly, the effect of B is -2.8 at the high level of A and -2.6 at the low level of A. The effects of these factors are independent. There is no interaction.

When the effect of a factor is dependent on the level of one or more other factors, then an interaction exists. In this case, the effects of these factors cannot be interpreted separately. Consider the example in Figure 24. The effect of factor C is 10.6 when factor D is at the high level, but it is only 2.6 when D is at the low level. Similarly, the effect of D is 3.4 at the high level of C, and it is in the opposite direction (-4.6) when factor C is at the low level. This is called a two-way interaction. The usual notation is C*D or just CD.

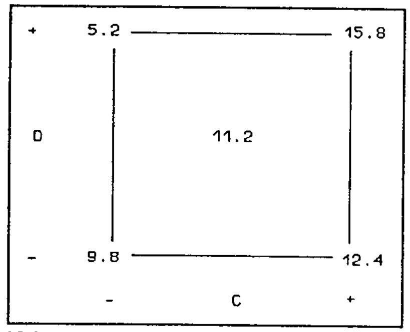


Figure 24
Interaction Example

The interaction effect is calculated by subtracting the effect of factor C at the low level of factor D from the effect of factor C at the high level of factor D and divided by two, which is (10.6 - 2.6)/2 = 4.0. Note that the same value is achieved using the effect of D at the two levels of C (3.4 - {-4.6})/2 = 4.0). Also note that the A*B interaction effect in the other example is only -0.1.

The calculated value for the effect of an interaction is used to determine whether the effect is significant, but it has little intuitive meaning. The best way to understand the effects is with an interaction plot (Figure 25), which is simply graphing the effect of one factor at each level of the other. A difference in slopes is characteristic of an interaction. Parallel or near parallel lines indicate that the factors are independent (no interaction).

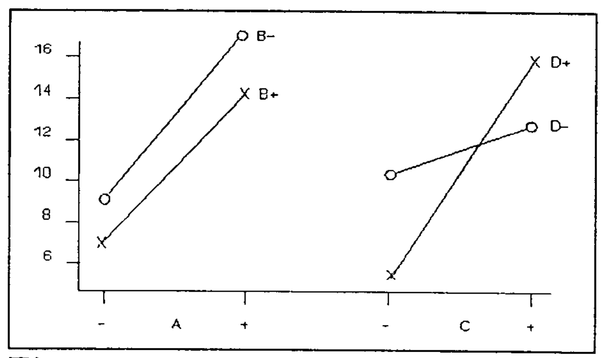


Figure 25 Interaction Plot

- Statistical Analysis

The results of any experiment are going to be affected by the natural variation in the process. Misleading conclusions can be made if this variation, called experimental error, is large relative to the magnitude of the effects. An experimenter who doesn't consider experimental error during the analysis can produce false conclusions and waste a lot of time explaining effects that may not really exist. A well-designed experiment reduces the influence of variation on the results. Statistical analysis of the experimental error determines whether there is enough evidence to conclude an effect does exist. Such an effect is called statistically significant.

There are several statistical tests that determine if an effect is significant. Each of these tests is based on the probability of observing, during the experiment, an effect of that magnitude or greater if the true value of the effect were zero. In other words, what is the probability of observing an effect of that size just by chance, completely due to experimental error? If that probability is low, then the "p-value" should be less than 0.05 (5%). If this is the case, it can also be said that there is 95% confidence that the effect is significant.

Because the ionic conductivity experiments were unbalanced the data was analyzed using a technique called multiple regression. The information of primary importance in the statistical analysis output is contained in the columns listing the "predictor", the coefficient ("coef"), and the p-value ("p"). The predictor column identifies the effect, where R, I, V, C and H are the main effects (coded using the first letter of each factor). The interactions are coded with a "*" between the letters. For example, R*I is the residue*IPA interaction.

The effects are derived from the coefficients calculated by this analysis, but their interpretation is consistent with that covered earlier in this text. The effect for all main effects and interactions is simply equal to twice the value of the coefficient. For the constant and center point ("CTR.PT"), the effect is equal to the coefficient. The "constant" is the mean response of all runs except the center points, adjusted for the unbalance in the design. This is the value that is expected to be observed at the center point, based on the other data. All of the other coefficients are the change in response relative to that constant when the factor is at high or low level. For main effects, the average response at the high level comes from adding level comes from subtracting. For two-way interactions, add the coefficient when both factors are at their high level or low level. Subtract when one is at its high level and the other is at its low level. (Again, the graphs are the easiest way to understand interactions.) For the center point, the coefficient is the difference from where it was expected to be to where it actually was. The constant plus this coefficient is the observed average at the center.

For all of these, statistical significance is determined by a p-value less than 0.05. However, in some cases a p-value between 0.05 and 0.10 was worth noting as marginally significant.

Comments on the Ionic Conductivity Tests and Results

The experiments run on the ionic conductivity test equipment were two level full factorial and fractional factorial designs with center points. These experiments are often called "screening" designs because they are good for capturing the larger (significant) effects like a screen mesh separating gravel from sand and dirt. Their purpose is to identify the factors that the experimenter should focus on in order to better understand or control the process. They are rarely the final step, but they often help light the path that the experimenter wants to follow. It is not unusual to leave an experiment such as this having discovered many new questions.

The analysis of each of these experiments includes a table of effects, graphical representation of the main effects and interactions, and a statistical analysis. The graphs are very useful for understanding the effects, but the reader should focus only on the significant effects and on the general trends seen consistently across different systems. Trying to draw conclusions from insignificant effects or small differences between systems is not wise. (Don't look past the gravel on the screen and try to make conclusions about the dirt!)

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