ELECTROSTATIC CHARGING OF FUEL SYSTEM COMPONENTS

The purpose of this study was to determine if an electrostatic discharge could have been a potential source of the ignition which occurred in the center wing tank of TWA 800 on July 17, 1996.

The study consisted of field trips to become familiar with the structure and components of the center wing tank on a Boeing 747 aircraft and laboratory testing of fuel tank components. The field trips and laboratory studies are listed below and are described in the Attachments which comprise this report.

ATTACHMENT #	TITLE	DATE
1	TRIP REPORT #1, CALVERTON, NY	1/16-17/97
2	TRIP REPORT #2, MARANA, AZ	1/21-22/97
3	SMALL SCALE LABORATORY STUDIES, NRL, WASHINGTON, D.C.	1/30, 2/11,18/97
4	TRIP REPORT #3, WPAFB, OH	2/28/97
5	TRIP REPORT #4, WPAFB, OH	3/3-8/97
6	COMMENTS ON ELECTROSTATIC CHARGING OF INSULATED CHARGE COLLECTORS—PHASE I OF WRIGHT LABORATORY TESTS: 3-8 MARCH 1997	3/3-8/97
7	TRIP REPORT #5, WPAFB, OH	4/8-12/97
8	COMMENTS ON ELECTROSTATIC CHARGING OF INSULATED CHARGE COLLECTORS—PHASE II OF WRIGHT LABORATORY TESTS: 8-12 APRIL 1997	4/8-12/97
9	TRIP REPORT #6, WPAFB, OH	5/7-9/97
10	ELECTROSTATIC CHARGING OF A TEFLON-LINED CLAMP	5/20-9/25/97
11	ANALYSIS OF FUEL SAMPLES FRO OLYMPIC AIRWAYS	6/26-6/27/97

TRIP REPORT #1
CALVERTON, NY

PLACE:	Calverton, NY
DATE:	16-17 January 1997
CONTACTS:	Dr. Bernie Loeb, Director, NTSB Ron Schleede, Ass't. Director, NTSB John Clark, NTSB Jim Cash, NTSB Bob Swaim, NTSB
PURPOSE OF VISIT:	To attend a review on the status of the TWA 800 investigation and to inspect wreckage of aircraft.

The following notes were made during the status review:

1. Two hundred, fifteen (215) out of 230 victims' remains have been recovered. One passenger was exposed to a transient fireball.

2. Four hundred, twenty-two (422) out of 430 seats have been recovered.

3. Observers reported that there were two small explosions that may have been about five seconds apart, followed by a fireball about 15-45 seconds later.

4. Two jettison pumps have been recovered from the center wing tank, but not the scavenge pump. Maintenance records show that when scavenge pumps fail, they die. They do have thermal protection. They are overhauled after 9,000 hours.

5. Concord is the only civil aircraft known to use <u>static dissipator additive</u> at JFK..

6. Twenty-four (24) psi is required to fail fuselages, maybe as little as 18 psi.

7. Over 90% of the wreckage of TWA 800 has been recovered.

An inspection was made of the center wing tank and components recovered from the wreckage of TWA 800. The main focus of this inspection was to see if any insulated charge collectors were present in the tank, or if there was any evidence of static charge mechanisms, such as splash or spray filling. (Insulated charge collectors are metallic components that are not electrically bonded or grounded to the aircraft structure.) No insulated charge collectors or indications of static charging mechanisms were found.

TRIP REPORT #2
MARANA, AZ

PLACE:	Evergreen Air Center, Marana, AZ
DATE:	21-22 January 1997
CONTACTS:	Larry D. Parsell, Evergreen Customer Service Representative Frank Miller, Evergreen Robert Swaim, NTSB Gene York, ALPA Mike Collins, FAA/Seattle Bob Vanderheiden, TWA Ken Craycraft, TWA Rich Parks, Boeing
PURPOSE OF VISIT:	To inspect the center wing tank (CWT) on a TWA 747 (A/C No. 17109) that had just come out of service.

The inspection was in accordance with the NTSB Test Plan (Section D, p.2) of NTSB *Static Sub-Group Systems Investigation,* January 10, 1997. The team report on this visit is given in NTSB *Static Sub-Group of Systems Investigation Airplane Examination*, January 22, 1997.

The only significant item uncovered during the inspection of the CWT was the presence of two potential isolated charge collectors, namely: 1) a cushion clamp on the cross feed manifold; and 2) flexible fuel couplings. It remains to be seen whether these components have sufficiently high resistivity to collect static charge and whether or not sufficient static charge can be placed on these couplings to constitute an ignition hazard.

SMALL SCALE LABORATORY STUDIES
NRL, WASHINGTON, D.C.

Tests were conducted at the Naval Research Laboratory (NRL), Washington, D.C. on January 30, and on February 11 and 18, 1997. The purpose of these tests were to check out and verify the performance of the instrumentation requested by NTSB for electrostatic charging tests to be conducted later at Wright Laboratory. The equipment consisted of:

1. EMCEE Fuel Conductivity Meter;
2. Keithley Electrometer;
3. Keithley Recorder;
4. Electrostatic Voltmeter (0-30 kV range); and
5. Electrostatic Voltmeter (0-5 kV range).

After replacement of batteries in the fuel conductivity meter and minor repairs to the pen system on the recorder, all of the equipment was found to be in good working order. In addition, some preliminary tests were conducted on an insulated charge collector (a three inch automotive hose clamp) to check the voltage build up on the clamp when it was sprayed with fuel using a 50cc syringe. These were followed by tests with an aircraft cushioned clamp as the target. The test set up is shown in *Figure 1.*

Spraying of the hose clamp with 10cc of fuel (Jet A, conductivity = 2.57 pS/m) using a 20 gauge needle produced -2 volts on the clamp. Using a 26 gauge needle, -15 volts were recorded. Substituting a white silicone cushioned aircraft clamp, -55 volts were developed using a 20 gauge needle.

The Adel clamp was installed on a section of tubing that had a flexible fuel tube coupling attached as shown in *Figure 2.* Fuel was sprayed on the clamp bolt: 6.5 volts were obtained with 20 cc of fuel and a 26 gauge needle. The voltage on the clamp did not fall off after spraying was stopped, indicating that the insulation was very good. The capacitance of the aircraft clamp was 70 nF using a capacitance meter.

When fuel was sprayed on the flexible fuel tube coupling no voltage build up was detected, indicating that the O-rings on this coupling are sufficiently conductive to bleed off any charge. The resistance of these O-rings will be checked during a later test program at Wright Laboratory.

Figure 1

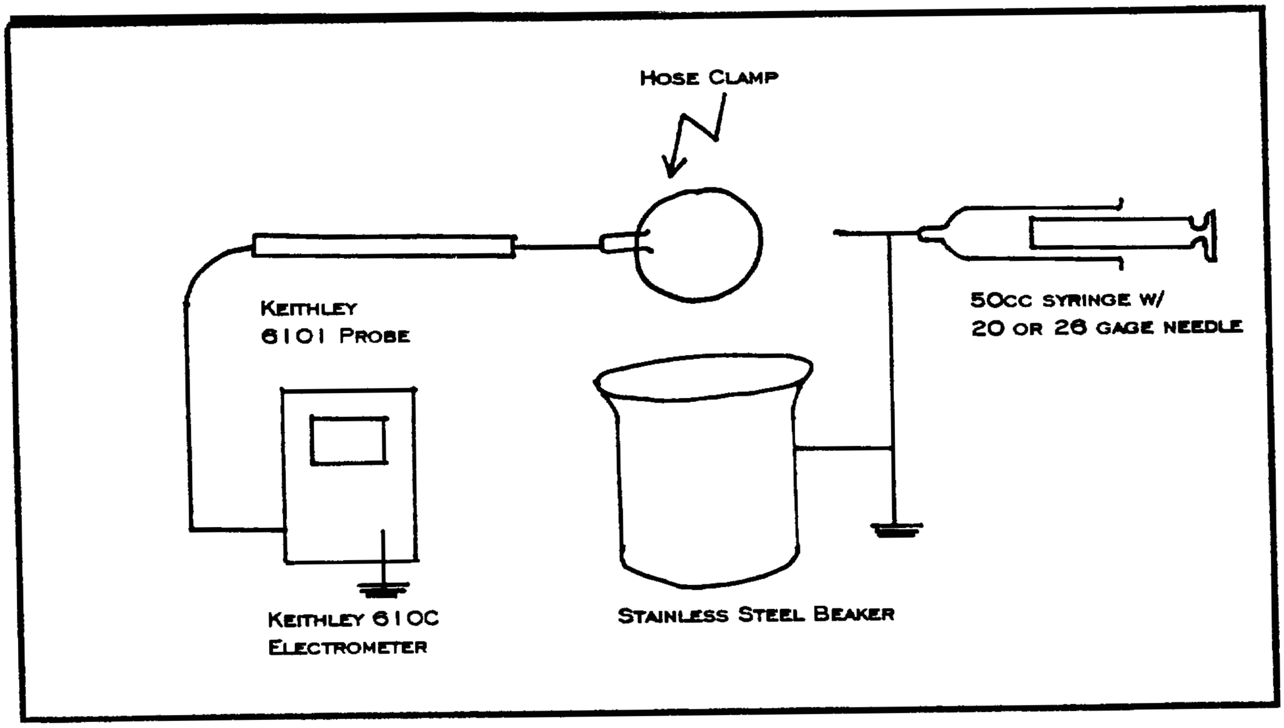
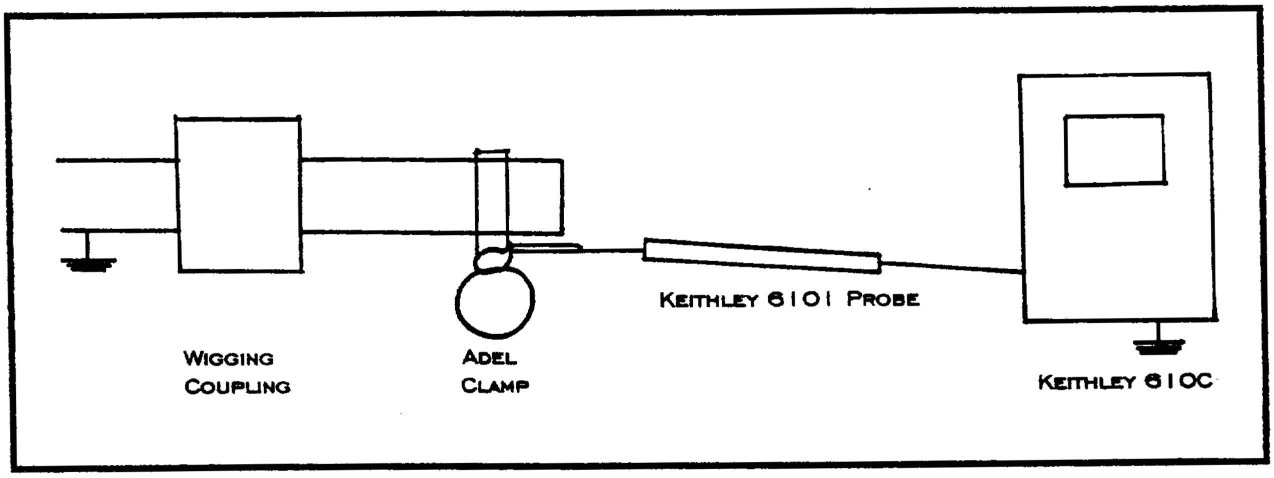


Figure 2



TRIP REPORT #3
WPAFB, OH

PLACE: Wright Laboratory, Building 490, Room 150

DATE: 28 February 1997, 0930

CONTACTS:
Dexter Kalt, UDRI
Steve Gerken, WL/MLSA
Mike Manders, WL/MLSA
Marlin Vangsness, UDRI
Cindy Obringer, WL/POSI
J. Leonard, GEO-CENTERS

PURPOSE OF VISIT: To inspect instrumentation and flowbench to be used in the static charging tests that are scheduled to start March 3, 1997, at Wright Laboratory and to discuss comments on the test plan circulated by Bob Swaim in NTSB letter of February 19, 1997.

The experimental set-up will consist of a fuel tank (55 gallon drum), a pump (not an aircraft pump), a section of tubing to relax charge generated by the pump, a manifold containing a "TEE" for inserting orifices of various sizes to spray charged fuel on the test article (flexible fuel tube coupling or Adel clamp), and a 5" section of tubing downstream of the TEE which will be electrically isolated using Teflon ferrules to permit measurement of streaming current. All tubing will be 1" stainless steel. The test article will be supported by a fixture which will be placed on a scissors jack to vary the distance between the test article and the spray orifice. The manifold and the test article will then be enclosed in a flammable liquid storage locker which will be fitted with a Lexan door to permit videotaping of the test in progress. The storage locker will be purged with N_2 before the test for safety reasons. The test setup is shown in *Figure 1.*

The instrumentation to be provided by Messrs. Gerken and Manders is listed in *Table A*. Dexter Kalt will provide for fuel conductivity and fuel flow and pressure measurements. The spray flow rate for each orifice will be determined by collecting a sample of the spray output over a prescribed time.

Specific concerns raised by Messrs. Gerken and Manders are listed in *Table B*. These concerns were resolved during the discussion of the test plan.

FIGURE 1

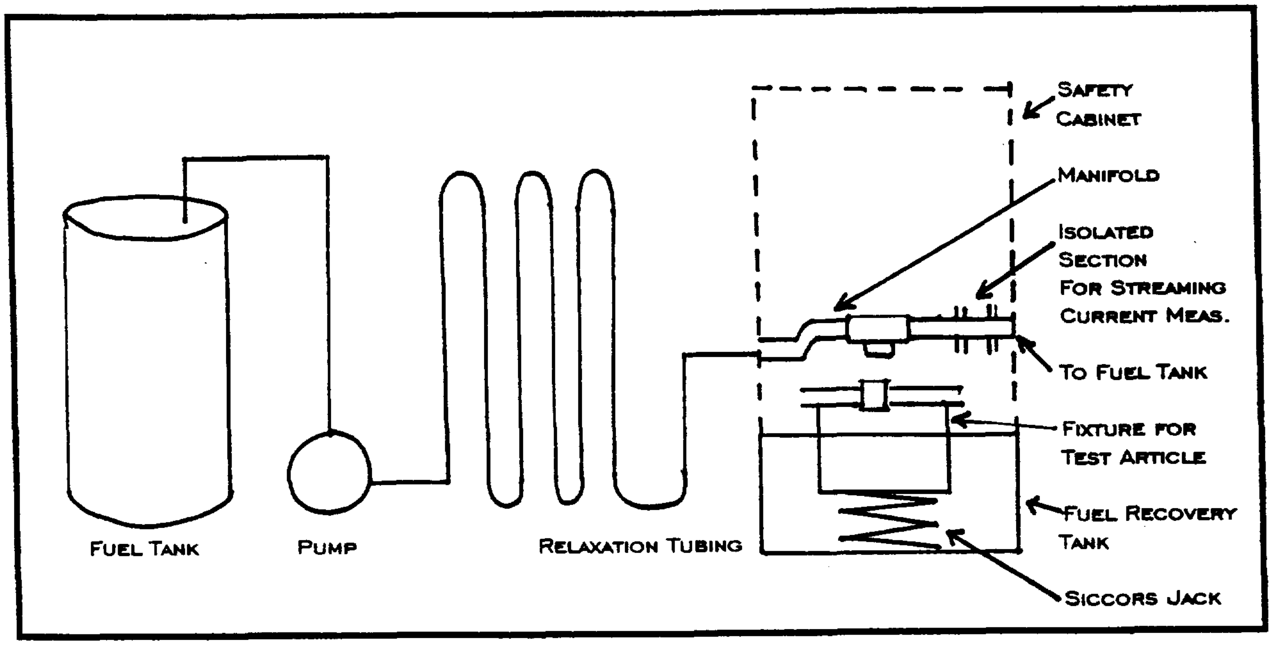


TABLE A

EQUIPMENT LIST TWA 800 ESD TESTING
CAPACITANCE METER & TEST LEADS (HP 4192)
ELECTROSTATIC VOLTMETER/PROBE/PUMP (MONROE MODEL 175)
CHARGE PLATE MONITOR (ION SYSTEMS MODEL 200)
ELECTROMETER/TEST LEADS/ADAPTER (KEITHLEY MODELS 610C & 614)
AIR IONIZER (3M 961)
HUMIDITY CONTROLLER/2 SENSORS (ETS MODEL 512)
FIELD MONITOR (PROSTAT MODEL PFM-711A)
MEGOHMSMETER (BECKMAN MODEL L10A)
TEST LEADS FOR ALL INSTRUMENTS & FINE GAUGE WIRE FOR CONNECTION TO CHARGE PLATE MONITOR & ISOLATED CONDUCTOR

TABLE B

STATIC DISCHARGE POSSIBILITY COMMENTS
CHARGE ACCUMULATION REQUIRES 1 MEGOHM?
AT WHAT VOLTAGE ARE THE RESISTANCES BEING MEASURED?
HOW IS CAPACITANCE BEING MEASURED? TYPE OF METER, FREQUENCY, REAL OR IMAGINARY COMPONENTS?
IS EVERYBODY USING THE SAME METHOD TO DETERMINE CAPACITANCE?
ARE ALL CAPACITANCE MEASUREMENTS REFERENCED TO GROUND?
HOW DOES A 1 MEGOHM COUPLING RESISTANCE IMPACT THE CAPACITANCE MEASUREMENT TECHNIQUE?
CHECK ON 70000V/IN IN OPEN AIR VS. 30-35000V/IN ACROSS A NONCONDUCTIVE SURFACE.
ALL POTENTIAL ENERGY MAY NOT CONVERT TO HEAT ENERGY. SOME OF THE ENERGY MAY TRANSFORM INTO LIGHT, HEAT, ELECTROMAGNETIC—ALTHOUGH MOST MAY BE HEAT.
WHAT WAS CONDUCTIVITY/ANTISTATIC PROPERTY OF FUEL?

Other questions/concerns raised during the discussion of the test plan are as follows:

1. The Teflon-lined Adel clamp seems to be an ideal charge collector based on the high resistivity of the Teflon liner and the close proximity of the exposed metal portion to the tubing (about $^1/_8$" or less). The clamp supplied (UMPCO D26, MS 21919) was somewhat distorted and a replacement was requested.

2. The duration of each test was discussed. Should it be 13 minutes to correspond with the flight time of TWA 800 or until the voltage plateaus? This will be determined on March 3, 1997, when the group meets.

3. Who will run the experiments (NTSB group members or Wright Laboratory personnel)? It was decided that Wright Laboratory personnel would run the tests and collect data. Specifically, Messrs. Gerken and Manders (MOS) will make all measurements on p.4 of Test Plan: (R, C, and breakdown voltage) for all couplings, R and C on test article before each test, measure voltage build up on test article, and streaming current.

4. A "TEE" will be installed in the manifold to support the orifice plate. The diameters of the hole in the orifice plate will correspond to:

   a. A 26 gauge hypodermic needle;
   b. A 20 gauge hypodermic needle; and
   c. A #40 drill, based on Boeing Tests. (Tom Peacock claims to have pinned a 100v Keithley using a #40 hole spray orifice.)

5. A field meter will be used to check the Lexan door after each test and an ionizer used to discharge it, if necessary. If charging of the Lexan door becomes a problem, a copper screen will be placed over it leaving a small area uncovered for videotaping the test in progress.

6. Experiments will be timed using a clock in the field of view of the video camera.

7. The entire test matrix seems rather extensive. It seems doubtful that all of the tests can be accomplished in one week.

8. Testing with one fuel only seems rather risky since the charging tendency of fuels vary widely. Since TWA 800 had been fueled in Athens with 90 pS/m fuel (presumably containing STADIS 450) before it was fueled with 1 pS/m fuel at JFK, it would be desirable to run some tests (worst case scenario) using a fuel containing small amounts of STADIS 450—enough to raise the conductivity to 5, 10, and 20 pS/m.

JOSEPH T. LEONARD, PH.D.
MAY, 1997

TRIP REPORT #4
WPAFB, OH

PLACE:	Wright Laboratory, Dayton, OH
DATE:	3-8 March 1997
CONTACTS:	Robert Swaim, NTSB Cindy Obringer, Wright Laboratory Dexter Kalt, UDRI @ Wright Laboratory Tom Peacock, Boeing Gene York, ALPA Michael Collins, FAA Ken Craycraft, TWA Charles Hale, IAM, TWA
PURPOSE OF VISIT:	To observe electrostatic charging tests on fuel couplings and clamps as conducted at Wright Laboratory by laboratory and University of Dayton Research Institute personnel

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The results of the first phase of testing covering the week of March 3, 1997, are contained in NTSB report of March 7, 1997, *Systems Electrical Sub-Group Field Notes*, prepared by Robert L. Swaim. Specific comments on the Phase I tests are given in Attachment 6.

The results of the Phase I testing were sufficiently encouraging to warrant a second phase. A list of goals for Phase II testing are listed in *Table A*.

TABLE A

GOALS FOR PHASE II STATIC TESTS AT WRIGHT LABORATORY	
1.	OPTIMIZE SPRAY PATTERN TO DELIVER MORE FINE DROPLETS TO THE TARGET, E.G., USE 3 OR 4 SMALL HOLES VS. ONE LARGE HOLE. ALSO, TRY TO DEVELOP A TUBING CRACK SPRAY PATTERN BY MASHING THE END OF A 1/4" OR 3/16" TUBE IN A VISE.
2.	MAKE ONE NOZZLE WITH A VERY SMALL ORIFICE TO GENERATE A FINE, CHARGED MIST. DETERMINE IF CHARGED MIST CAN INDUCE HIGH VOLTAGES ON THE CLAMP.
3.	ADDITIZE THE FUEL WITH STADIS 450 TO ACHIEVE CONDUCTIVITY LEVELS OF 20-30 PS/M AND 100 PS/M. INVESTIGATE THE EFFECT OF HIGHER FUEL CONDUCTIVITY ON CHARGING ONCE THE OPTIMIZED SPRAY PATTERN AND DISTANCE HAVE BEEN DETERMINED.

4. Optimize the distance between spray nozzle and target.

5. Determine if temperature effect on charging, as observed in Phase I testing, is real by repeating tests at room temperature and 100°F with the same nozzle, pressure, and distance.

6. Are there other Teflon-lined clamps in the inventory? The clamps in the photos from the United 727 incident at Minneapolis seemed to have a thicker Teflon lining than the clamps used in the Phase I testing. If so, then these clamps should be included in the Phase II tests.

7. When optimized test conditions have been determined, tests should be conducted on a 1 ¾" or 2" Wiggins coupling with Viton O-rings.

8. Charge decay measurements should be taken for at least five minutes after the spray has been turned off to determine how fast charge is being lost from the coupling or clamps, particularly with higher conductivity fuels.

9. Once optimized charging conditions have been determined, isolate nozzle and make streaming current measurements at the nozzle. Care should be taken to assure fuel does not flow over Teflon insulation on nozzle to preclude charging of the fuel by Teflon.

10. Determine charging characteristics of a spray emanating from a split Viton O-ring on a Wiggins coupling.

11. After all charging tests are completed, determine the breakdown voltages for the Teflon-lined clamp(s) and Wiggins couplings in a 'as installed' condition, i.e., mounted on tube.

COMMENTS ON ELECTROSTATIC CHARGING OF INSULATED CHARGE COLLECTORS—PHASE I OF WRIGHT LABORATORY TESTS: 3-8 MARCH 1997*

INTRODUCTION

The purpose of these tests was to examine conditions required to produce an electrostatic discharge under conditions similar to a Boeing 747 center wing fuel tank. For a discharge to occur, the following conditions would have to be met:

1. Fuel would have to become charged, electrostatically, by being sprayed through a small orifice (i.e., a pin hole leak in a pressurized fuel line).

2. The fuel would have to impinge on an isolated charge collector (i.e., a metallic component in the fuel tank that was not electrically bonded or grounded to the aircraft structure).

If sufficient charge accumulates on the isolated component, then a spark can occur to some nearby grounded component. If the spark has enough energy, and if the fuel vapors in the tank are in the flammable range, an ignition will occur.

Investigators have identified two components in the center wing tank of a 747 aircraft—namely, a clamp and a coupling—that were not electrically bonded to the aircraft structure and hence may have been isolated charge collectors. The tests at Wright Laboratory were designed to see if either of these components could acquire sufficient electrostatic charge to produce an incendiary spark. For this purpose, fuel was sprayed from a pressurized fuel line using a variety of orifices to simulate different types of fuel leaks (e.g., a straight stream, a fine spray, or an atomized mist) onto the two types of components, namely a teflon-lined clamp and a Wiggins coupling. The voltage build up on the components was measured during spraying as an indication of charge accumulation.

Another potential mechanism for producing a spark discharge in the tank would be the accumulation of charge on the surface of fuel being sprayed into the tank, and a subsequent discharge from the fuel surface to the fuel inlet device located in the rear of the center wing tank. The possibility of charge accumulation on the fuel surface was also examined during the Phase II testing at Wright Laboratory.

*The data contained in this report are based on visual observation of the video monitors showing the test instrumentation while the tests were in progress. They were taken to provide a more timely assessment of the test program since it was recognized that the official report of these tests would not be available for several months after the tests were completed. Hence, the data in this report do not constitute the official record of these tests. The official record is contained in the following report: Obringer, C., Gerken, S.C., Manders, M.J., Kalt, D.H. and Vangsness, "Electrostatic Charge Generation from Turbine Fuels", Wright Laboratory Report, 15 October 1997.

Objective

The objective was to examine electrostatic charging characteristics of fuel sprayed from various sized orifices onto electrically isolated targets. The targets were the following insulated charge collectors found in the center wing tank (CWT) of a 747 aircraft (N17109) at Evergreen Air Center, Marana, AZ:

1. Teflon-lined clamp (Fig. 1); and

2. Wiggins couplings (Fig. 2).

A silicone-lined clamp was also tested. The clamp was obtained from a mechanic at Evergreen who was about to install it in the CWT of TWA B-747, N17109.

EXPERIMENTAL SET-UP

The experimental set-up is shown in *Figure 3*, which was taken from the Group Notes of the Phase I testing. Fuel was sprayed on the test article (clamp or coupling) from an orifice and the voltage build up on the test articles measured by an electrostatic field meter. Streaming current in the fuel flowing through the pipe was measured by connecting a Keithley electrometer to an electrically isolated section in the pipe upstream of the orifice.

Fuel used in these tests was Jet A fuel from JFK, which was supplied in two 55 gallon drums. Drum #1 had a conductivity of 5 pS/m at 64°F and Drum #2 had a conductivity of 6 pS/m at 64°F.

RESULTS AND DISCUSSION

The results of the Phase I tests, which were conducted at Wright Laboratory March 3-8, 1997, are summarized in *Table A*.

In the first series of tests, Runs 1-4, fuel was sprayed on a Teflon-lined clamp using a 0.04" diameter orifice. The voltage build up on the clamp was rather low (-71 to -101V) with the maximum value being attained at the intermediate pressure of 25psig. The fuel conductivity was 6 pS/m and the temperature of the fuel was 69°F during these runs. Using the various Wiggins couplings as targets (Runs 5, 6, 7 and 9) resulted in no voltage build up.

It appears that voltage build up on the target is determined by the resistance of the target to ground, as shown in *Table B*. Clearly, the resistance has to be greater than 10^{12} ohms for any

TABLE A
SUMMARY OF THE DATA FOR PHASE I SPRAY CHARGING TESTS

RUN	FUEL PRESS, PSIG	FUEL SPRAY DISTANCE, IN.	ORIFICE SIZE, IN.	VOLTAGE MAX. V	STREAMING CURRENT, X10-9	FUEL SPRAY TIME, MIN.	SPRAY RATE, ML/SEC.	FUEL TEMP.	FUEL CONDUCTIVITY, PS/M
I - TEFLON-LINED CLAMP, UMPCO, DG 26, MS21919, $R = >10^{12}$ ~, C = 44PF									
1	15	1.75	0.04R*	-85	-0.2	~8	6.0	69°F	6 @ 72°F
2	15	1.75	0.04R*	-71	-0.1	~10		69°F	6 @ 72°F
3	42	1.75	0.04R*	-86	-0.07~	~13	10.9	69°F	6 @ 72°F
4	25	2.00	0.04R*	-101	-0.12	~14	8.3	69°F	6 @ 72°F
II - WIGGINS COUPLING FROM CONTINENTAL (T_{11}/T_{12}) $R = 10^6$, C = 3.6 nF									
5	25	1.75	0.04R*	0	-0.23	6	8.3	87°F	10 @ 69°F
6	42	1.75	0.04R*	0	-0.15	5	10.9	83°F	10 @ 69°F
III - WIGGINS COUPLING FROM CONTINENTAL (T_1/T_8) {$R = 1.1 \times 10^7$, C = 10.8 nF / $R = 1.2 \times 10^7$, C = 10.8 nF}									
7	42	1.75	0.04	0	-0.13	6	10.9	85°F	10 @ 69°F
IV - ADEL CLAMP, WH 29 (SILICONE LINER) ON 1 7/8" PIPE, $R = 1.4 \times 10^{10}$, C = 73 pF									
8	42	1.75	0.04	-10	-0.17	5	10.9	84°F	10 @ 69°F
V - WIGGINS COUPLING, REASSEMBLED T_7/T_8, O-RINGS CHANGED, R WENT FROM 10^7 TO 10^9, COUPLING WAS MANIPULATED TO CENTER O-RINGS, $R = 1.49 \times 10^9$, $C = 0.416 \times 10^9$									
9	42	1.75	0.03	2	-0.16	5	31	83°F	17 @ 68°F
VI - TEFLON CLAMP, $R > 10^{12}\ \Omega$, C = 91 pF									
10	25	2.0	0.04R	-213	-.29 TO -.30	15	8	76°F	9 @ 7°F

ELECTROSATIC CHARGING OF FUEL
SYSTEM COMPONENTS

JOSEPH T. LEONARD, PH.D.
MAY, 1997

RUN	FUEL PRESS, PSIG	FUEL SPRAY DISTANCE, IN.	ORIFICE SIZE, IN.	VOLTAGE MAX. V	STREAMING CURRENT, X10-9	FUEL SPRAY TIME, MIN.	SPRAY RATE, ML/SEC.	FUEL TEMP.	FUEL CONDUCTIVITY, PS/M
11	42	2.0	0.04R	-279	-.22 TO -.29	17	11	86°F	9 @ 70°F
12	15	1.75	-0.04R	-228	-.43 TO -.55	15	6	93°F	9 @ 70°F
13	15	2.0	SLoT	-349	-.22 TO -.5	13		91°F	9 @ 70°F
14	42	2.0	SLoT	-521	-.28 TO -.36	12		93°F	9 @ 70°F
15	42	5½	SLoT	-541@ 5 MIN	-.33 TO -.38	5		95°F	9 @ 70°F
COMMENT:	RAN OUT OF FUEL. FUEL TEMP. REACHED 95°F. FUEL FROM DRUM #2 PUT INTO TANK. FUEL TEMP. = 64°, K = 5								
16	42	5½	SLoT	-168	-.02 TO -.03	4.6		65°F	5 @ 64°F
COMMENT:	RUN STOPPED AFTER 4'40". TEMP. OF NEW FUEL WAS 64° VS. 95° FOR RUN 15								
17	42	5½	0.070	-345	N/A, LEAD FELL INTO FUEL	15		65-92°F	5 @ 64°F
18	42	5½	0.070	-507	-.01 TO -.02	16		86-91°F	5 @ 64°F
19	REPEAT OF RUN 18 ON THE NEXT DAY								
19	42	5½	0.070	-570	-.09 TO -.12	16		105-108°F	9-10 @ 86°F
20	42	8	0.070	-658	-.11 TO -.14	15		107-105°F	9-10 @ 86°F
WIGGINS COUPLING ON 1" TUBE WITH VITON O-RINGS, R = 1.2 X 10^{11}, C = 131pF									
21	42	8	0.070	14	-0.09	3		97°	9-10 @ 86°F

*R = RAGGED HOLE

TABLE B
EFFECT OF RESISTANCE ON VOLTAGE BUILD UP

RUNS	TARGET	V	R	RC TIME, SEC.
5 & 6	WIGGINS COUPLING FROM CONTINENTAL (T_{11}/T_{12})	0	1×10^{8}	0.36
7	WIGGINS COUPLING FROM CONTINENTAL (T_7/T_8)	0	1×10^{7}	0.11
8	CLAMP, SILICONE LINED, WH29	10	1.4×10^{10}	1.0
9	WIGGINS COUPLING (T_7/T_8) W/ DIFFERENT O-RINGS	2	1.4×10^{9}	0.6
20	CLAMP, TEFLON-LINED DG 26	658	$R > 10^{12}$	N.D.
21	WIGGINS COUPLING W/ VITON O-RINGS	15	1.2×10^{12}	15.7

N.D. = THE RC TIME FOR THIS CLAMP CANNOT BE DETERMINED UNTIL A MORE ACCURATE VALUE FOR ITS RESISTANCE IS DETERMINED.

appreciable voltage build up to occur with this spray charging mechanism. As the RC times indicate, when the resistance is less than 10^{10}, most of the charge dissipates in one second or less. (The RC time is the time required for the voltage on the clamp to decrease to 36.8% of its original value.) When Viton O-rings were fitted on a Wiggins coupling in Run 21, the resistance was improved to 1.2×10^{11} and there was some improvement in the voltage build up, i.e., to 15 volts. However, the RC time for this coupling was 15.7 seconds and, as can be seen in *Figure 4*, the charge decay was quite rapid. Although, only two data points were taken the RC time determined from this curve (19 seconds) is in fair agreement with the calculated value of 15.7 seconds.

When the resistance to ground is greater than 10^{12}, e.g. with the Teflon-lined clamp, the charge decays at a very slow rate as shown by the dta in *Figure 5*. Some improvement in voltage buildup was obtained in the second round of tests (Runs 10-12), especially when a slot opening was used in place of the 0.04 inch orifice (Runs 13-15). A comparison in the charge buildup with the slot vs. the 0.04 inch orifice can be seen in *Figure 6*. Both runs were made at the same pressure (15 psig), but the nozzle to target distance was increased slightly (from 1.75 to 2 inches) in going from the nozzle to the slot. This slight increase in distance would not account for the difference in voltage buildup with the slot. The effect of increasing the distance from the target can be seen in *Figure 7* for the slot, and again in *Figure 8* for the 0.07 inch nozzle.

The maximum voltage buildup was obtained with the Teflon-lined clamp using a 0.07 inch orifice at a distance of 8 inches (Run 20). However, the performance of the slot nozzle at a distance of 5 ½ inches (Run 15) was actually better in terms of the rate of voltage buildup than the 0.07 nozzle (*Figure 9*). Unfortunately, Run 15 ended before stabilizing due to fuel exhaustion.

The maximum voltage buildup on the Teflon-lined clamp using the slot was -541V. This was obtained when the fuel temperature was above 90°F. It was not determined whether the higher charging was due to the effect of the temperature on the spray characteristics or on the fuel conductivity. In Run 15, the fuel conductivity was 10 pS/m and the temperature was 95°F. When new fuel was substituted in Run 16 (fuel conductivity was 5 pS/m and the temperature was 64°), much lower charging was obtained. In Runs 19 and 20 where the highest voltage buildup was obtained i.e., -658V using the 0.07 inch orifice, the temperature of the fuel was about 105° and the conductivity was about 10 pS/m. This question about the effect of temperature on charging could be resolved by running tests at a lower temperature, e.g., 65°F, using a fuel with a conductivity of 10 pS/m.

Using the experimentally determined capacitance of the Teflon-lined clamp of 44 pf, the voltage required to produce a spark from this clamp having the minimum ignition energy for hydrocarbon vapors of 0.26 mJ (1) would be:

$$E = \tfrac{1}{2} CV^2$$
$$V = \sqrt{\frac{2E}{C}} = \sqrt{\frac{2(2.6 \times 10^{-4}}{44 \times 10^{-12}}}$$
$$V = 3438 \text{ V}$$

(It was subsequently determined by Wright Laboratory personnel that the breakdown voltage for this clamp at a gap of 0.033 inches was 2920-3550V, which is in the range necessary to produce a spark with the minimum ignition energy. See Phase II, Static Charge Generation Test Plan, D.H. Kalt, revised 7 April 97.) The maximum voltage of 658V obtained in these tests is about 1/5 that required to produce a spark with the minimum ignition energy.

References

(1) Lewis, B and von Elbe, G., "Combustion, Flames and Explosions of Gases", 2nd Edition, Academic Press, New York, 1961, p. 334.

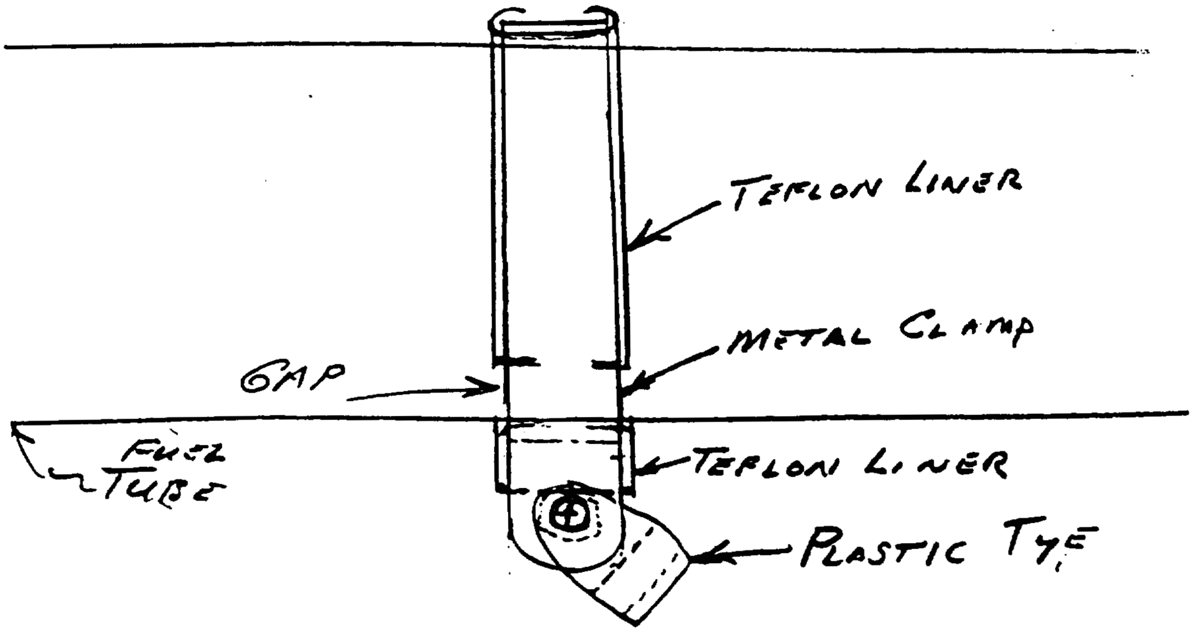


Fig. 1 - Teflon-Lined Clamp (DG26, UMPCO, MS21919)

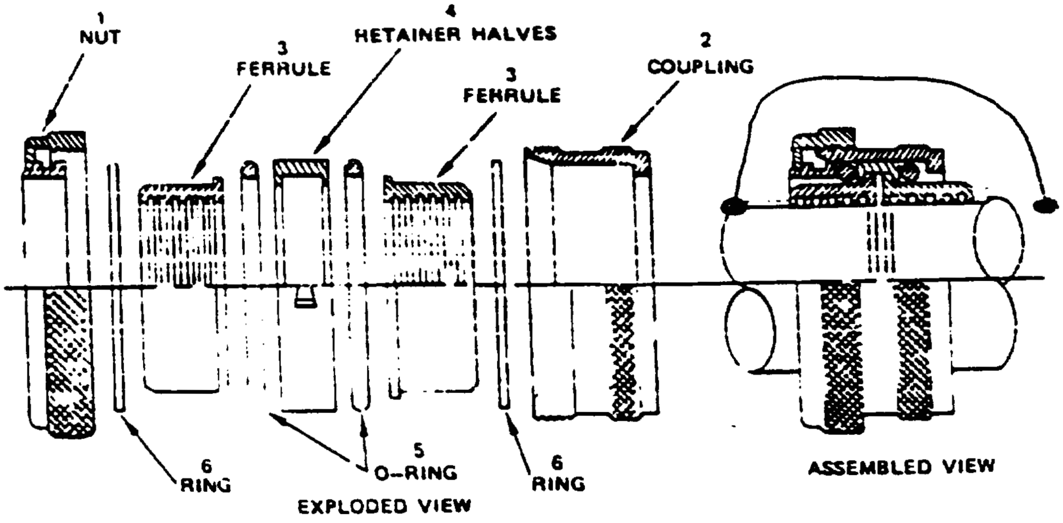
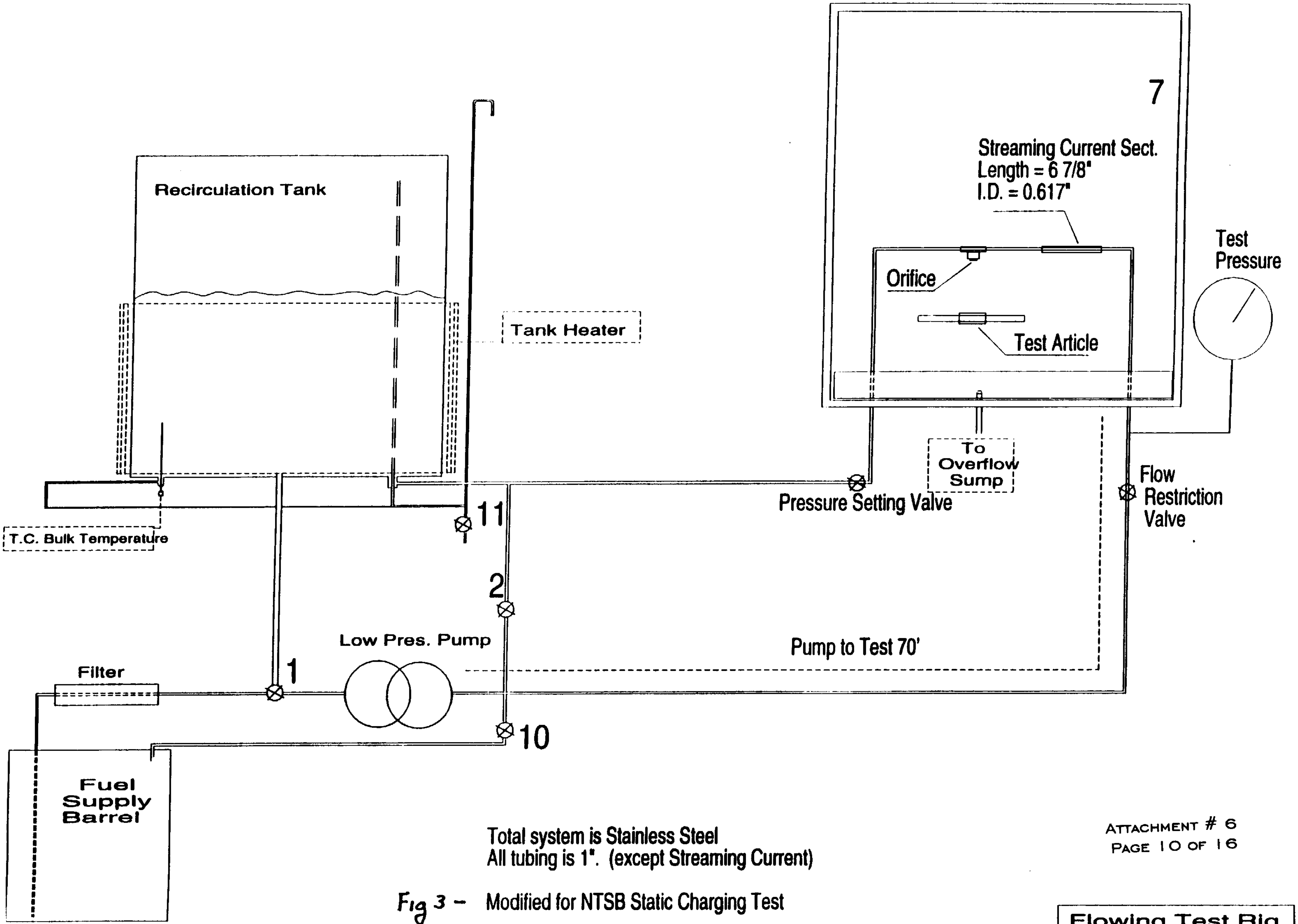


Fig. 2 - Wiggins Flexible Fuel Tube Coupling



Total system is Stainless Steel
All tubing is 1". (except Streaming Current)

Fig 3 – Modified for NTSB Static Charging Test

ATTACHMENT # 6
PAGE 10 OF 16

Flowing Test Rig
M. Vangsness, UD
6 - 2 - 95
Mod 2-28-97

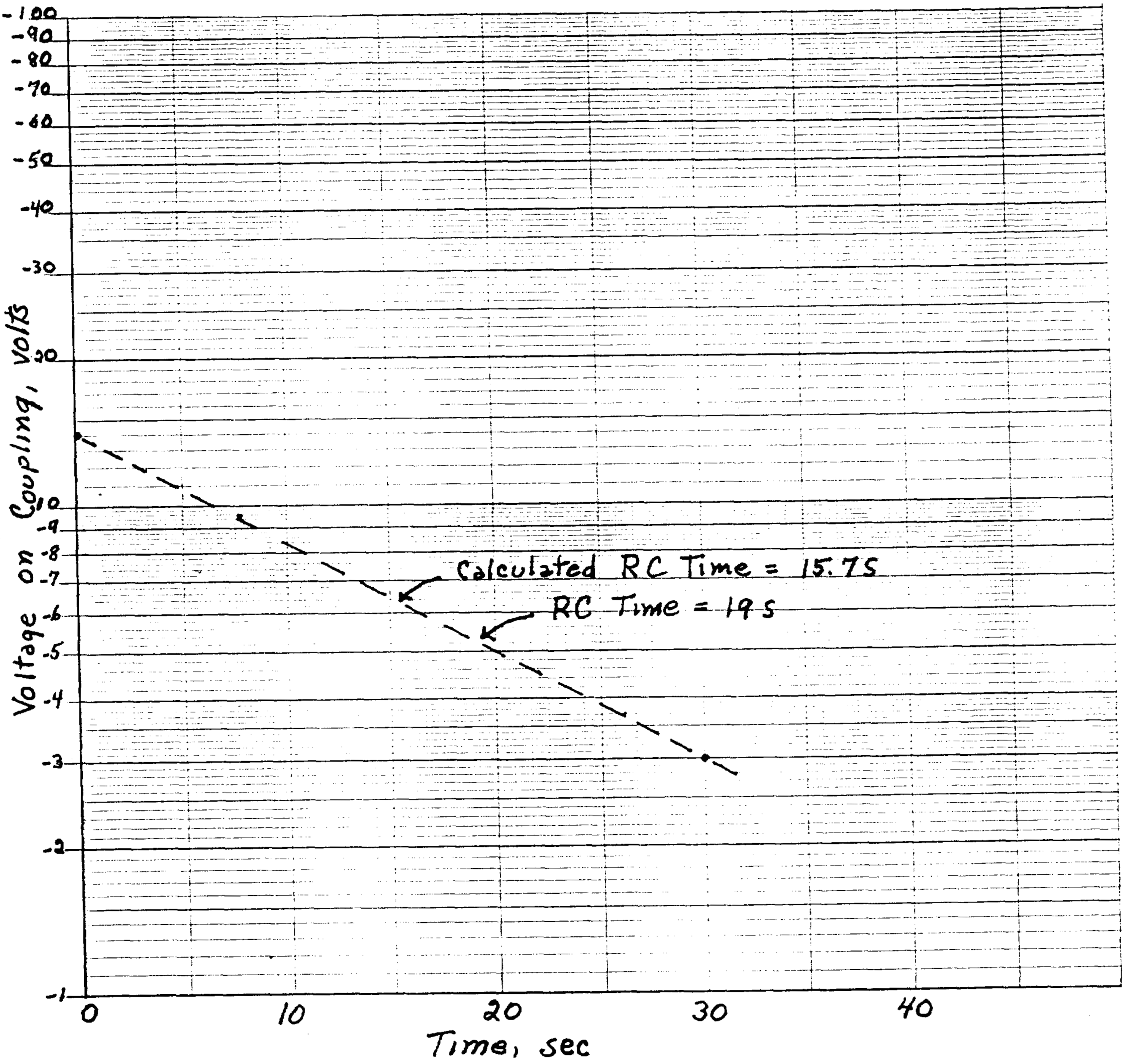


Fig. 4 - Decay of charge on Wiggins Coupling

Figure 5 - Decay of Charge on Teflon Lined Clamp

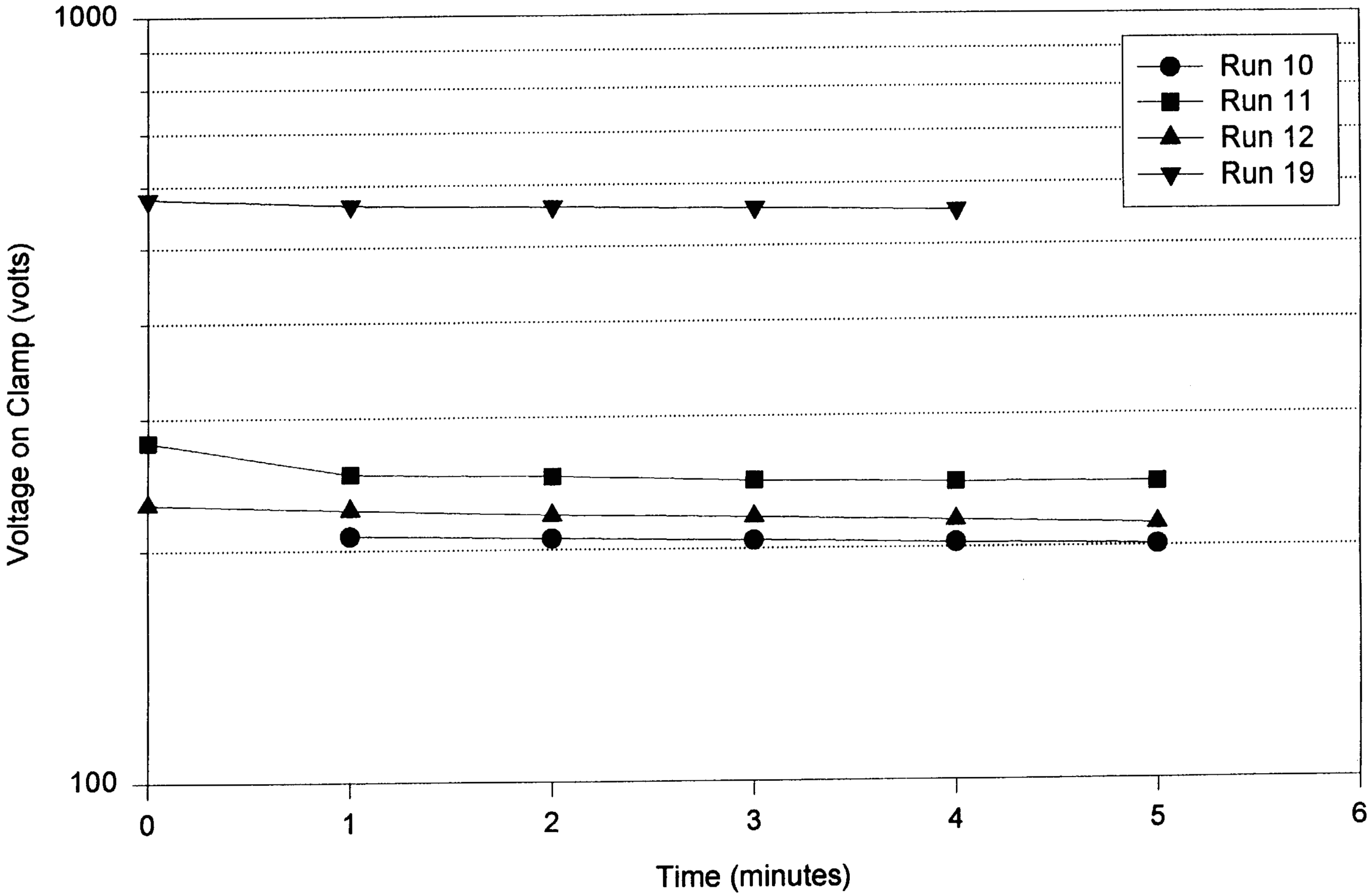


Figure 6 - Comparison of Voltage Build Up on Clamp Using the Orifice and the Slot

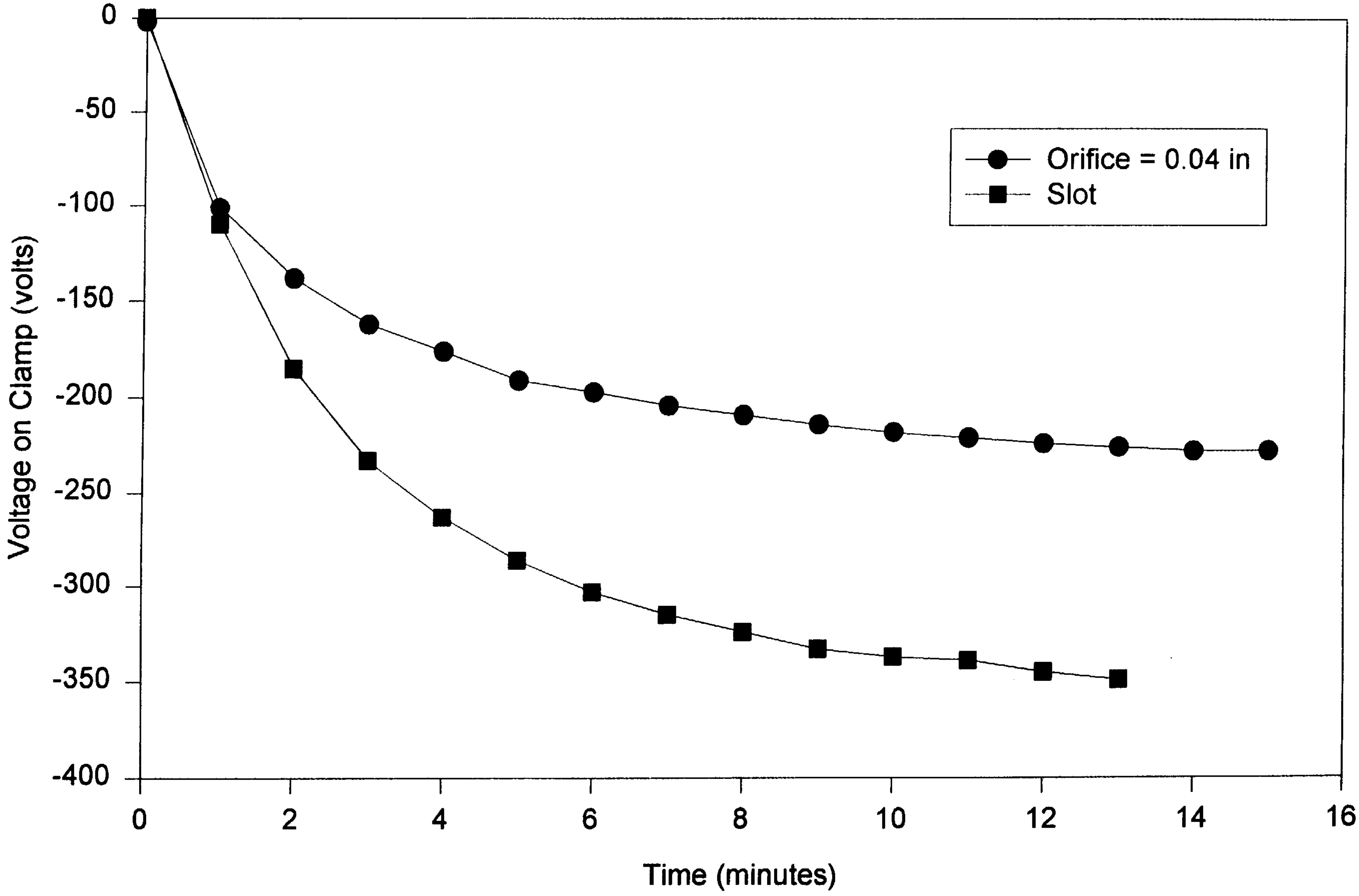


Figure 7 - Effect of Distance from Slot to Clamp on Voltage Build Up

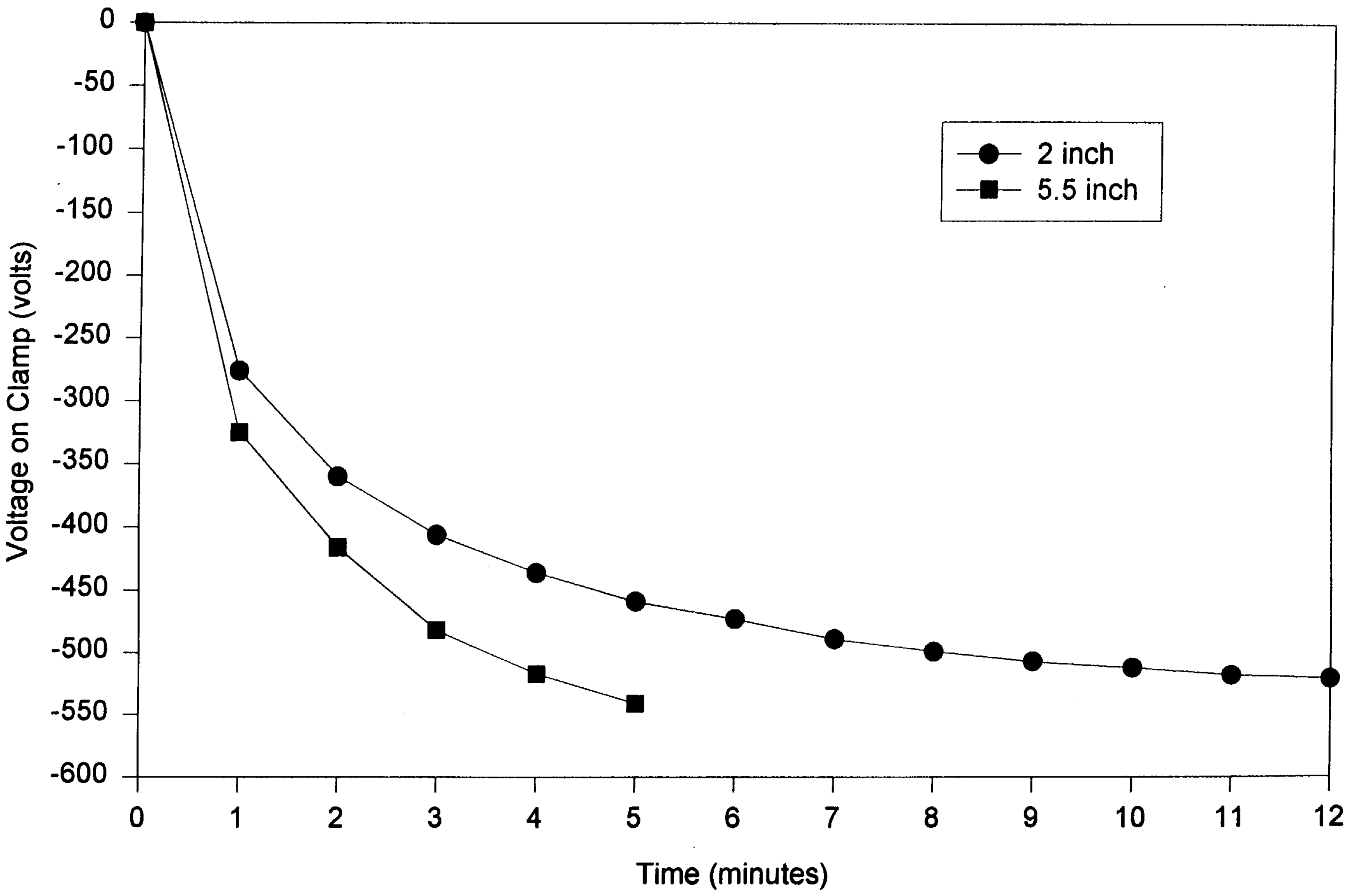


Figure 8 - **Effect of Distance from Nozzle to Clamp on Voltage Build Up**

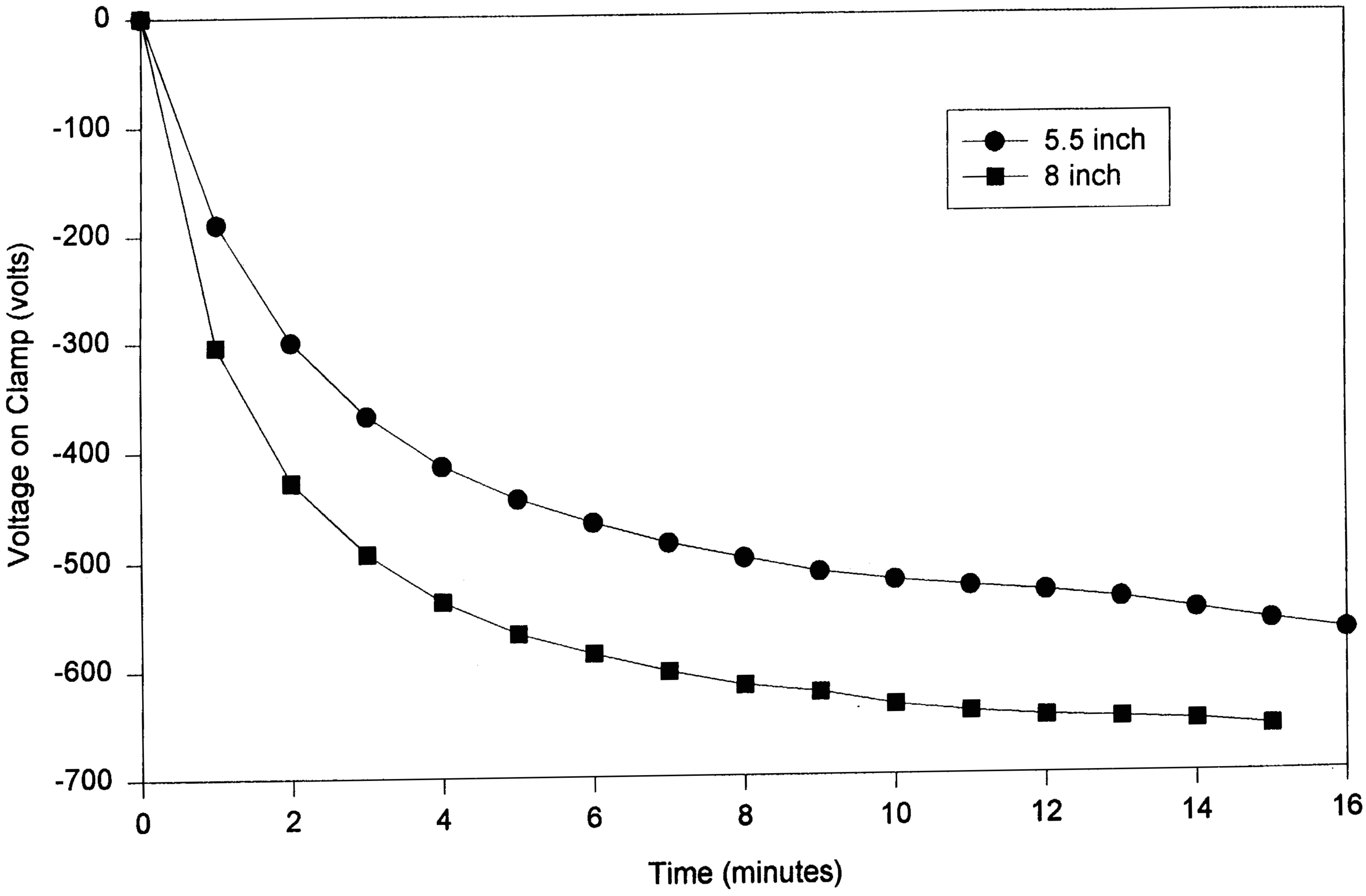
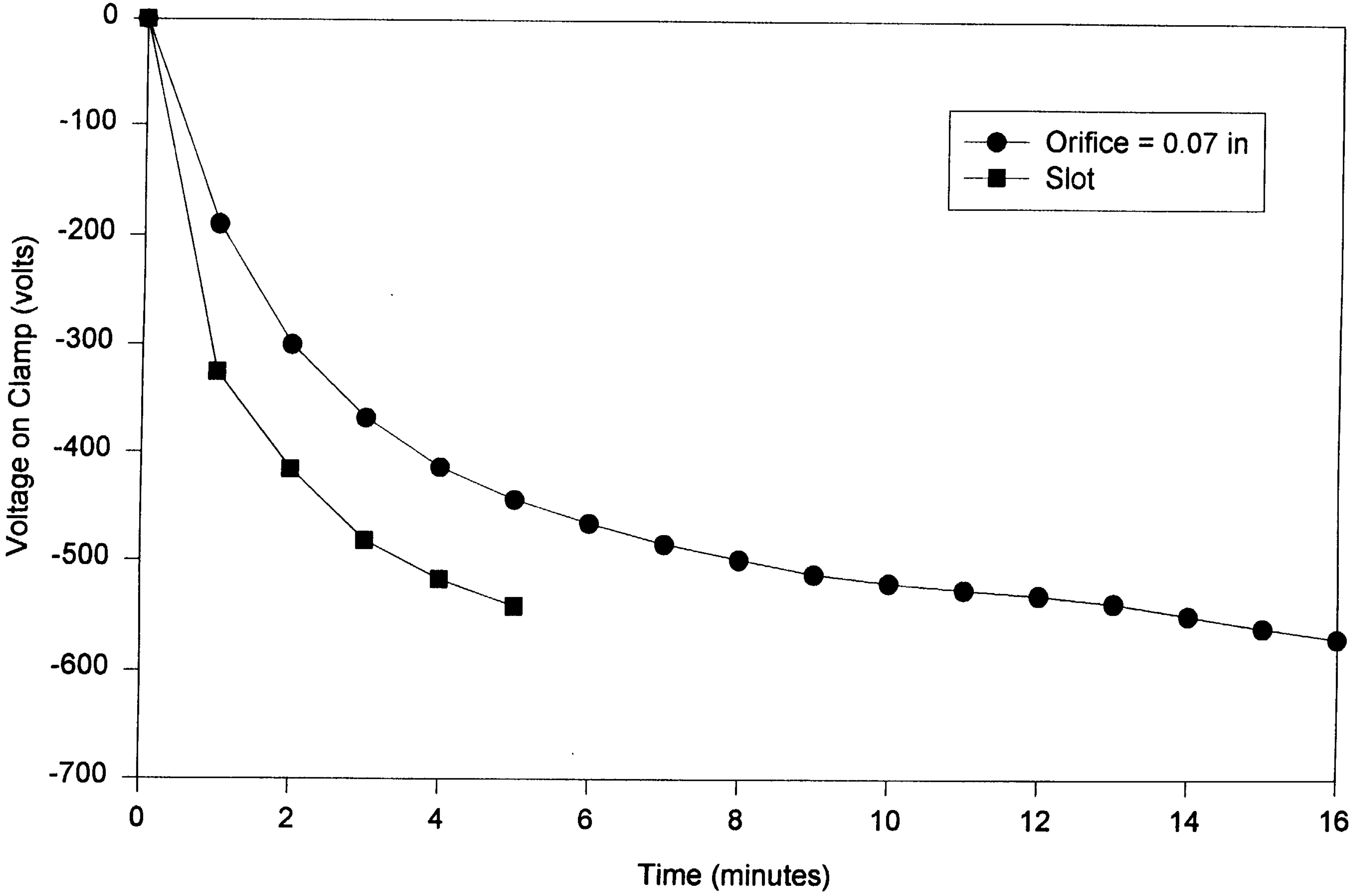


Figure 9 - Comparison of Voltage Build Up on Clamp for Slot vs. Orifice at the Same Distance



TRIP REPORT #5
WPAFB, OH

PLACE:	Wright Laboratory, Dayton, OH
DATE:	April 8-12, 1997
CONTACTS:	Cindy Obringer, Wright Laboratory Dexter Kalt, UDRI @ Wright Laboratory Robert Swaim, NTSB Tom Peacock, Boeing Gene York, ALPA Lee Johnson, ALPA Charles Hale, IAM, TWA
PURPOSE OF VISIT:	To observe the second phase of electrostatic charging tests.

A preliminary report on the Phase II tests is give in Attachment 8.

COMMENTS ON ELECTROSTATIC CHARGING OF INSULATED CHARGE COLLECTORS—PHASE II OF WRIGHT LABORATORY TESTS: 8-12 APRIL 1997*

INTRODUCTION

The Phase I tests demonstrated that it was possible to buildup a potential of -658 volts on a Teflon-lined clamp by spraying the clamp with Jet A fuel using a 0.07 inch orifice. Although this voltage represented a considerable improvement over the initial results obtained in Phase I (-71 to -101 volts), it did not approach the calculated 3,438 volts required to produce a spark having the minimum ignition energy of 0.26 mJ with this clamp. In addition, the test did not produce significant voltage buildup on Wiggins couplings by spray charging. Hence, additional work was performed to examine more effective spray charging techniques.

OBJECTIVE

The objective was to examine the effects of target angle, spray distance, fuel temperature, and conductivity on the spray charging process. For this purpose, a standard target (an 8" x 11" aluminum plate, coated on one side with Boeing BMS 10-20 epoxy-chromate primer—as used in the B-747 fuel tank) was employed. Also in this phase, the possibility of producing a spark discharge by spraying fuel into the tank was investigated.

EXPERIMENTAL PROCEDURE

The experimental set up is shown in *Figure 1*. In the first series of tests (Runs 1-4), the target plate was not used. Rather, the fuel was sprayed directly in the tank using a 5-hole, 0.07 inch diameter equivalent orifice and the voltage build up on the fuel surface was measured using an Ionized Environment-Electrostatic Locator, Model ACL 400, manufactured by ACL, Incorporated. A second field meter was located high in the compartment to detect any charge on the fuel mist.

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* THE DATA CONTAINED IN THIS REPORT ARE BASED ON VISUAL OBSERVATION OF THE VIDEO MONITORS SHOWING THE TEST INSTRUMENTATION WHILE THE TESTS WRE IN PROGRESS. THEY WERE TAKEN TO PROVIDE A MORE TIMELY ASSESSMENT OF THE TEST PROGRAM SINCE IT WAS RECOGNIZED THAT THE OFFICIAL REPORT OF THESE TESTS WOULD NOT BE AVAILABLE FOR SEVERAL MONTHS AFTER THE TESTS WERE COMPLETED. HENCE, THE DATA IN THIS REPORT DO NOT CONSTITUTE THE OFFICIAL RECORD OF THESE TESTS. THE OFFICIAL RECORD IS CONTAINED IN THE FOLLOWING REPORT: OBRINGER, C., GERKEN, S.C., MANDERS, M.J., KALT, D.H. AND VANGSNESS, "ELECTROSTATIC CHARGE GENERATION FROM TURBINE FUELS", WRIGHT LABORATORY REPORT , 15 OCTOBER 1997.

In Runs 5-20, the target plate was installed in the test chamber and the current from the plate to ground was measured using a Keithley Model 614 Electrometer as the fuel was sprayed on the plate. Both the 5-hole orifice and the slot orifice were used in these tests. Factors examined included:

a) the effect of the primer coating;
b) the angle of the plate with respect to the spray;
c) temperature of the fuel;
d) the effect of the distance between the spray orifice and the target plate; and
e) the effect of fuel conductivity.

RESULTS AND DISCUSSION

The results of these tests may be summarized as follows:

Runs 1-4: Fuel was sprayed into the tank and the voltage on the fuel surface was measured. The results of these tests are summarized in *Table A*. No appreciable voltage was detected on fuel surface in this series of tests. It is possible that the static detector may not have been sensitive enough for this type of fuel charging since at least a low voltage on the fuel surface would have been expected. Repeating these tests with a Monroe Electrostatic Field Meter that is appropriately shielded from the fuel spray may yield different results.

TABLE A
EFFECT OF SPRAYING FUEL DIRECTLY INTO TANK
(NO SCREEN)

RUNS	ORIFICE	TARGET	FUEL PRESS, PSIG	SPRAY FUEL CONDUCTIVITY PS/M	FUEL TEMP	VOLTAGE ON SURFACE
1	5-HOLE, 0.07IN DIAMETER EQUIVALENT	FUEL PAN	25	4@ 72°F	74°F	0
2	SLOT NOZZLE	FUEL PAN	25	4@ 72°F	91°F	0
3	SLOT NOZZLE	FUEL PAN	25	4@ 72°F	89°F	0
SPRAYING LOW CONDUCTIVITY FUEL ON SURFACE OF AN INTERMEDIATE CONDUCTIVITY FUEL (K=30@ 72°F)						
4	5-HOLE, 0.07IN DIAMETER EQUIVALENT	FUEL PAN	25	4@ 72°F	89°F	0

Runs 5-9: Fuel was sprayed alternately on the primer coated and bare sides of the target plate, with and without a screen. The results of these tests are summarized in *Table B*. The screen more than doubles the charging current (compare Runs 5 and 6), but there doesn't appear to be any significant difference in charging current between the primer coated and the bare metal target surface (compare Runs 7 & 8 with 9).

Run 10: Fuel was sprayed on the plate as it was rotated from 0 to 90° with respect to the spray direction. The results of these tests are given in *Table B*. The data for the current off the plate are as recorded by the author rather than the range of values reported in the Group Notes (1). The charging current appears to fall off above 60°, but below 60°, the charging current is not dependent on the plate angle.

Run 11: Fuel was sprayed on plate at a fixed angle of 30° while the temperature of the fuel was increased from 60 to 120°F (no screen). The results of these tests are given in *Table B* and are plotted in *Figure 2*. As can be seen from the figure, the charging current increased with increasing temperature. This is as would be expected since the conductivity of the fuel increases with increasing temperature and the charging tendency of the fuel is known to increase with increasing conductivity.

TABLE B

CHARGING CURRENTS DEVELOPED AS FUEL WAS SPRAYED ON ELECTRICALLY ISOLATED PLATE USING 5-HOLE ORIFICE

RUN	ORIFICE	SIDE SPRAYED	TARGET ANGLE, DEGREES	FUEL PRESS, PSIG	FUEL CONDUCTIVITY, PS/M @72°	FUEL TEMP. °F	CURRENT OFF PLATE, NA**	REMARKS
EFFECT OF PRIMER COATING ON PLATE CHARGING					2	90	-0.28~	NO SCREEN
5	5-HOLE, .07 DIA	COATED*	45	25	2	100	-0.65~	SCREEN ADDED
6	5-HOLE, .07 DIA	COATED	45	25	2	100	-0.50 ~	SCREEN ADDED
7	5-HOLE, .07 DIA	COATED	45	25	2	100	-0.50~	REPEAT OF RUN 7
8	5-HOLE, .07 DIA	COATED	45	25	2	102	-0.60~	REPEAT TO CHECK GROUND
9	5-HOLE, .07 DIA	COATED	45	25				
CHANGING ANGLE OF PLATE WITH RESPECT TO SPRAY					<10	100	-0.96 MAX	SCREEN 24" FM ORIFICE
10	5-HOLE, .07 DIA	COATED	15	25	<10	100	-0.96 MAX	SCREEN 24" FM ORIFICE
	5-HOLE, .07 DIA	COATED	30	25	<10	100	-0.96 MAX	SCREEN 24" FM ORIFICE
	5-HOLE, .07 DIA	COATED	45	25	<10	100	-0.86 MAX	SCREEN 24" FM ORIFICE
	5-HOLE, .07 DIA	COATED	60	25	<10	100	-0.84 MAX	SCREEN 24" FM ORIFICE
	5-HOLE, .07 DIA	COATED	PARALLEL	25				
EFFECT OF TEMPERATURE ON CHARGING AT FIXED ANGLE. DISTANCE = 24 INCHES					5	60	-.176~	NO SCREEN
11	5-HOLE, .07 DIA	COATED	30	25	5	65	-194~	NO SCREEN
	5-HOLE, .07 DIA	COATED	30	25	5	70	-.212~	NO SCREEN
	5-HOLE, .07 DIA	COATED	30	25	5	75	-.230~	NO SCREEN
	5-HOLE, .07 DIA	COATED	30	25	5	80	-.240~	NO SCREEN
	5-HOLE, .07 DIA	COATED	30	25	5	85	-.290~	NO SCREEN
	5-HOLE, .07 DIA	COATED	30	25	5	90	-.310~	NO SCREEN
	5-HOLE, .07 DIA	COATED	30	25	5	95	-.340~	NO SCREEN
	5-HOLE, .07 DIA	COATED	30	25	5	100	-.367~	NO SCREEN
	5-HOLE, .07 DIA	COATED	30	25	5	105	-.380~	NO SCREEN
	5-HOLE, .07 DIA	COATED	30	25	5	110	-.440~	NO SCREEN
	5-HOLE, .07 DIA	COATED	30	25				
CHANGING DISTANCE TO 18 INCHES					>10@72°F	122	-.368	NO SCREEN
12	5-HOLE, .07 DIA	COATED	30	25	>10@72°F	122	-.345	NO SCREEN
	5-HOLE, .07 DIA	COATED	45	25	>10@72°F	122	-.414	NO SCREEN
	5-HOLE, .07 DIA	COATED	60	25				

RUN	ORIFICE	SIDE SPRAYED	TARGET ANGLE, DEGREES	FUEL PRESS, PSIG	FUEL CONDUCTIVITY, PS/M @72°	FUEL TEMP, °F	CURRENT OFF PLATE, NA**	REMARKS
CHANGING DISTANCE TO 12 INCHES								
13	5-HOLE, .07 DIA	COATED	15	25	>10@72°F	122	.300	NO SCREEN
REPEAT OF RUN 13								
14	5-HOLE, .07 DIA	COATED	30	25	>10@72°F	115	-.350~	NO SCREEN
	5-HOLE, .07 DIA	COATED	FLAT	25	>10@72°F	115	-.280	NO SCREEN
	5-HOLE, .07 DIA	COATED	45	25	>10@72°F	115	-.255	NO SCREEN
	5-HOLE, .07 DIA	COATED	15	25	>10@72°F	115	-.360	NO SCREEN
	5-HOLE, .07 DIA	COATED	60	25	>10@72°F	115	-.230	NO SCREEN
CHANGING DISTANCE TO 6 INCHES								
15	5-HOLE, .07 DIA	COATED	FLAT	25	5@72°F	111-114	-.310	NO SCREEN
	5-HOLE, .07 DIA	COATED	15	25	5@72°F	111-114	-.350	NO SCREEN
	5-HOLE, .07 DIA	COATED	30	25	5@72°F	111-114	.310	NO SCREEN
	5-HOLE, .07 DIA	COATED	45	25	5@72°F	111-114	.280	NO SCREEN
	5-HOLE, .07 DIA	COATED	60	25	5@72°F	111-114	.240	NO SCREEN

* PLATE WAS COATED ON THE TOP SIDE WITH BOEING BMS 10-20 EPOXY-CHROMATE PRIMER

** DATA FROM JTL NOTES

Runs 12-15: Fuel was sprayed on the target at distances of 6 to 18 inches to see the effect of the spray distance on the charging current. The results of these tests are given in *Table B* and are plotted in *Figure 3.* No significant differences in charging current were obtained as the distance was decreased from 18 to 6 inches; except at a target angle of 60° where the charging current was appreciably higher.

Run 16: The spray nozzle was changed from the 5-hole to the straight slot and the effect of the screen on the charging current was observed for various plate angles using the neat (un-additized fuel). The results of these tests are given in *Table C* and are plotted in *Figure 4*. As with the 5-hole orifice in Runs 5 and 6, the slot produced about twice as much charge when the screen was used as when it wasn't used.

Run 17: The current from the tank to ground was measured instead of the current from the plate since the tank collects more of the charged spray than the plate. The fuel conductivity was increased to 32 pS/m for this test by adding Stadis 450 and the fuel temperature was 118°F. The results of these tests are given in *Table C*. As in previous runs, the use of a screen more than doubled the current and the maximum currents observed (7.3 nA with the screen and 2.6-3.0 nA without the screen) were the highest values seen thus far. It was also noted that the sign of the charging current changed from minus to plus due, undoubtedly, to the presence of Stadis 450 in the fuel.

TABLE C

CHARGING CURRENTS DEVELOPED AS FUEL WAS SPRAYED ON ELECTRICALLY ISOLATED PLATE USING A SLOT ORIFICE

RUN	ORIFICE	SIDE SPRAYED	TARGET ANGLE, DEGREES	FUEL PRESS, PSIG	FUEL CONDUCTIVITY, PS/M @72°	FUEL TEMP. °F	CURRENT OFF PLATE NA**	REMARKS
16	SLOTTED NOZZLE W/INTERNAL MESH	COATED	FLAT	25	5@ 72°F	104	-0.62	NO SCREEN
	SLOTTED NOZZLE	COATED	30	25	5@ 72°F	104	-0.53	NO SCREEN
	SLOTTED NOZZLE	COATED	45	25	5@ 72°F	104	-0.45	NO SCREEN
	SLOTTED NOZZLE	COATED	30	25	5@ 72°F	104	-1.39	SCREEN ADDED
	SLOTTED NOZZLE	COATED	45	25	5@ 72°F	104	-1.36	SCREEN ADDED
INCREASED FUEL CONDUCTIVITY TO 32 PS/M								
17	SLOT	COATED	30	25	32 @ 72°F	105		TANK TO GROUND CURRENT W/SCREEN 7.3NA TANK TO GROUND CURRENT W/O SCREEN 4.2 NA
MEASURING TANK CURRENT AND VOLTAGE ON PLATE								
18	SLOT	COATED	30	25	32 @ 72°F	106		TANK TO GROUND CURRENT W/SCREEN =2.5NA VOLTAGE ON PLATE= 1,080
INSTRUMENTED TARGET PLATE								
19	SLOT	COATED	FLAT	25	32 @ 72°F	106	2.9	WITH SCREEN
	SLOT	COATED	30	25	32 @ 72°F	106	5.9	WITH SCREEN
	SLOT	COATED	45	25	32 @ 72°F	106	6.1	WITH SCREEN
	SLOT	COATED	15	25	32 @ 72°F	106	2.5	WITH SCREEN
	SLOT	COATED	60	25	32 @ 72°F	106	6.9	WITH SCREEN
	SLOT	COATED	FLAT	25	32 @ 72°F	106	1.0	NO SCREEN
	SLOT	COATED	30	25	32 @ 72°F	106	2.8	NO SCREEN
	SLOT	COATED	45	25	32 @ 72°F	106	3.4	NO SCREEN
	SLOT	COATED	15	25	32 @ 72°F	106	1.5	NO SCREEN
	SLOT	COATED	60	25	32 @ 72°F	106	3.7	NO SCREEN
FUEL CONDUCTIVITY INCREASED TO 94 PS/M @ 72°F								
20	SLOT	COATED	30	25	94 @72°F	116	9±3	NO SCREEN
	SLOT	COATED	30	25	94 @72°F	116	11±3	SCREEN

Run 18: This Run was essentially a repeat of Run 17, except that the voltage on the plate was also measured at the same time as the tank current to ground. The results of these tests are given in *Table C*. The maximum current from the tank in this test was 2.5nA using the screen, which is considerably less than the value of 7.3 nA obtained in Run 17. The voltage on the plate was 1,080 volts.

Run 19: Using the same fuel as in Runs 17 and 18 (32 pS/m @ 72°), the effects of target angle and use of a screen were determined. The results of these tests are given in *Table C* and are plotted in *Figure 5*. As in previous Runs, the use of the screen nearly doubled the charging current. Note that the sign of the current changed to positive due to the presence of Stadis 450. Also, there appeared to be a pronounced increase in charging current with increasing target angle. This was not found with the lower conductivity fuel in Run 16 (*See, Figure 4*). Also, the magnitudes of the currents in Run 19 were considerably higher due to the presence of Stadis 450.

Run 20: In this Run, the fuel conductivity was increased to 94 pS/m at 72°F and the charging current measured with and without a screen. Although the charging currents were higher in this Run than in any of the previous Runs, the currents were very unstable. They do tend to confirm that charging current continues to increase with increasing fuel conductivity (*See, Table D*).

TABLE D
EFFECT OF CONDUCTIVITY ON CHARGING CURRENT
USING THE SLOT ORIFICE AND A TARGET ANGLE OF 30°

RUN	FUEL CONDUCTIVITY, PS/M @ 72°F	CURRENT OFF PLATE, NA	REMARKS
16	5	-.62	NO SCREEN
	5	-1.39	WITH SCREEN
19	32	2.8	NO SCREEN
	32	5.9	WITH SCREEN
20	94	9±3	NO SCREEN
	94	11±3	WITH SCREEN

OBSERVATIONS

The results of these tests may be summarized as follows:

1. The charging current increases with temperature over the range of 60 to 110°F.
2. The use of a screen doubles the charging current.
3. At a given temperature, increasing the fuel conductivity by the addition of Stadis 450 increases the charging current.
4. With low conductivity fuel, the angle of the target had no significant effect on the charging current. However, with fuel containing Stadis 450, there was a pronounced increase in charging current with target angle.
5. The maximum voltage on the plate was 1080V.

REFERENCE

(1) Robert Swaim, *Static Sub-Group of Systems Investigation*, April 11, 1997, National Transporation Safety Board.

Fig. 1 - Apparatus for Plate Charging Measurements

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of DAYTON
RESEARCH
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Measurement Configuration

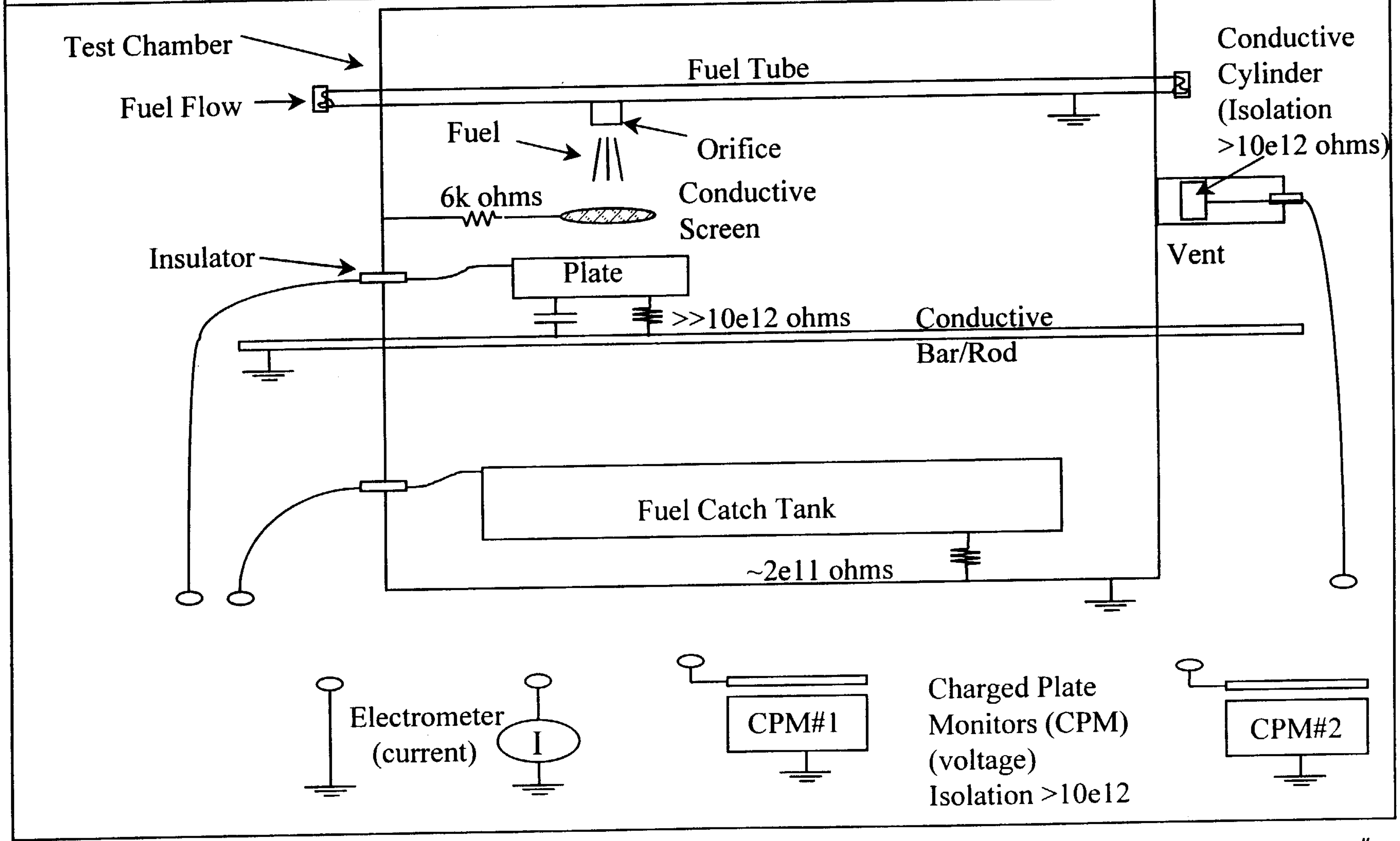


Fig. 2 - Effect of Fuel Temperature on Plate Current (Run 11)

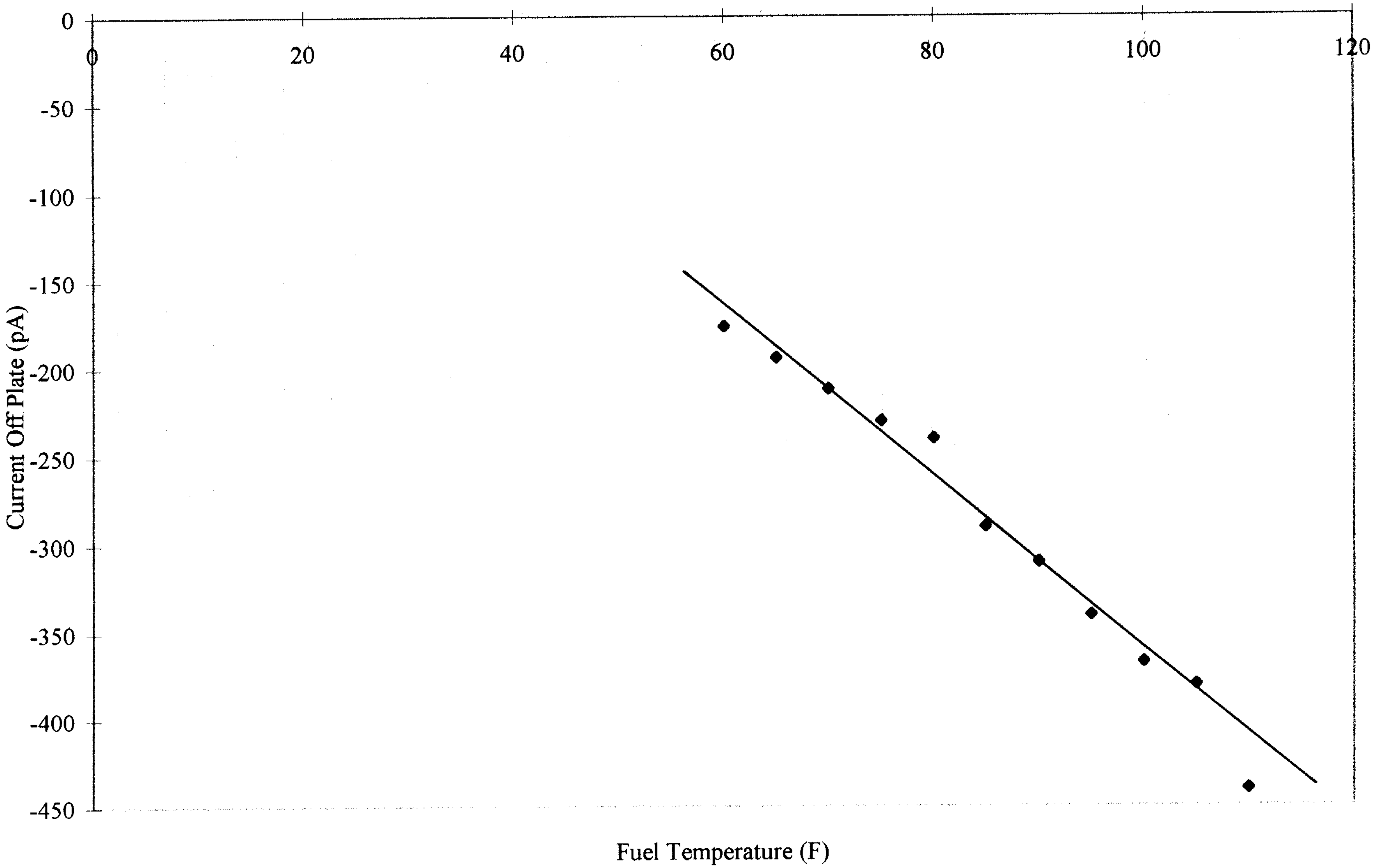


Fig. 3 - Effect of Distance on Charging of Plate at Various Angles Using 5-Hole Orifice (0.07 in. Diam) - Runs 12-15

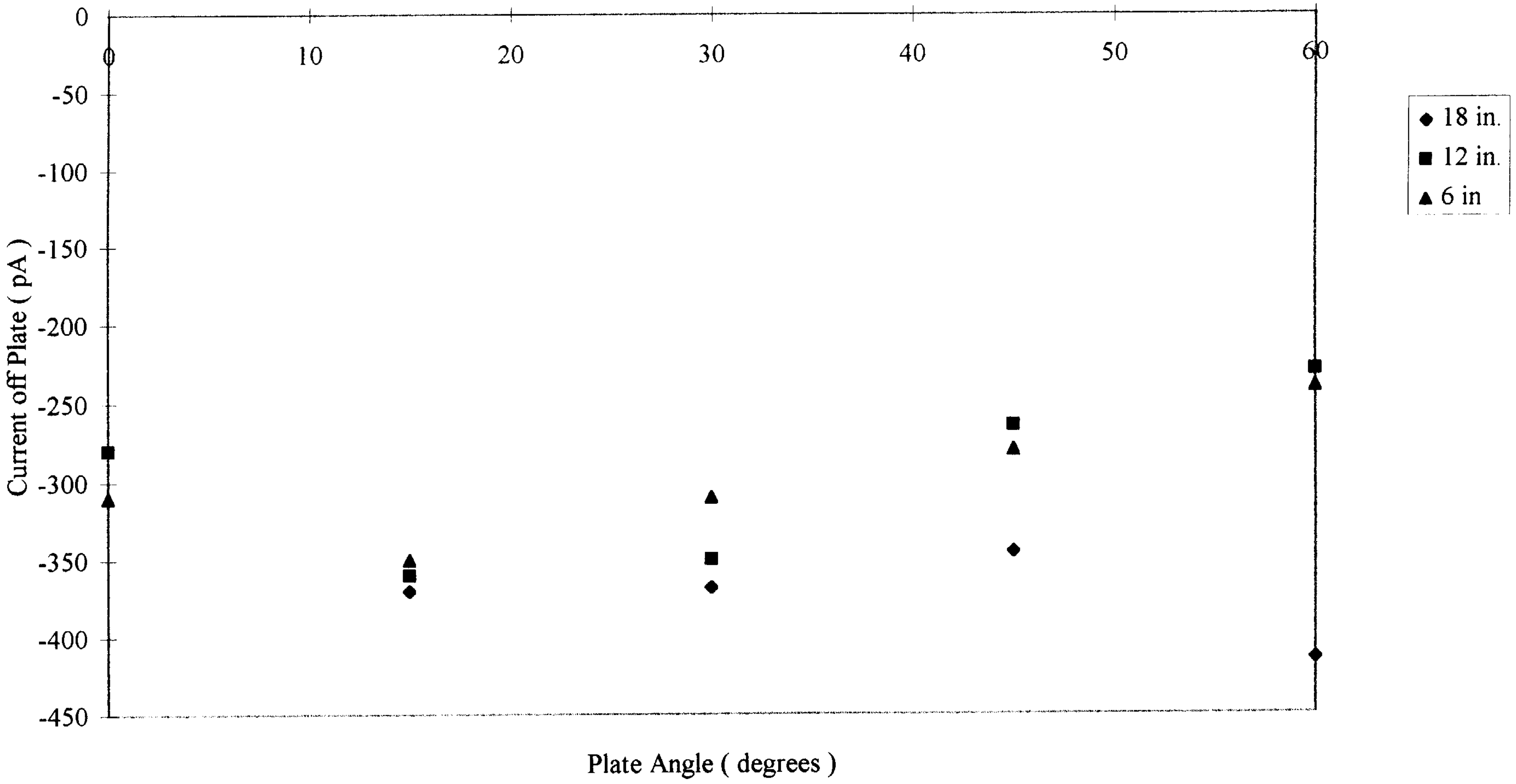


Fig. 4 - Effect of Screen on Plate Current at Various Angles Using Slot and Neat Fuel (Run 16)

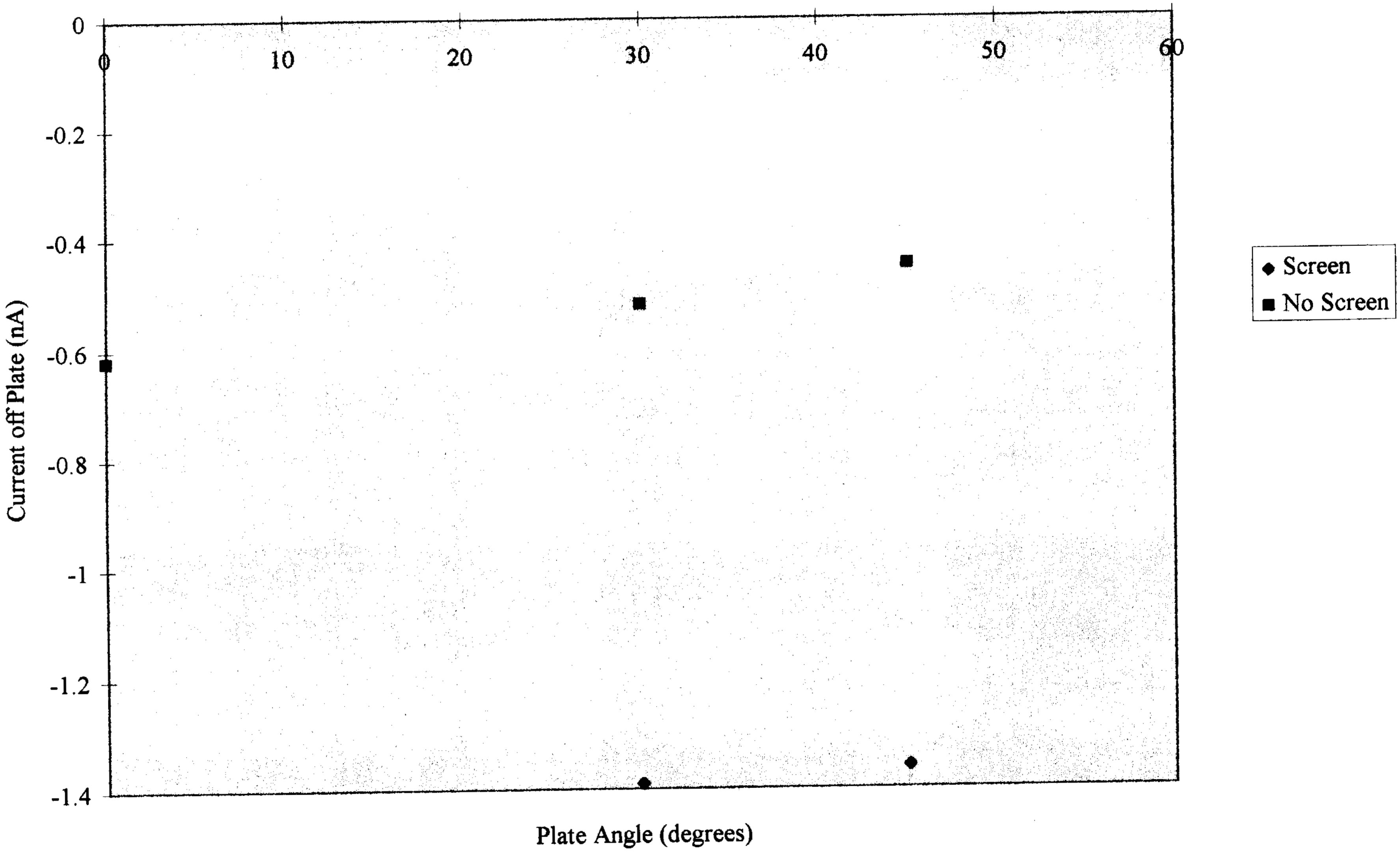
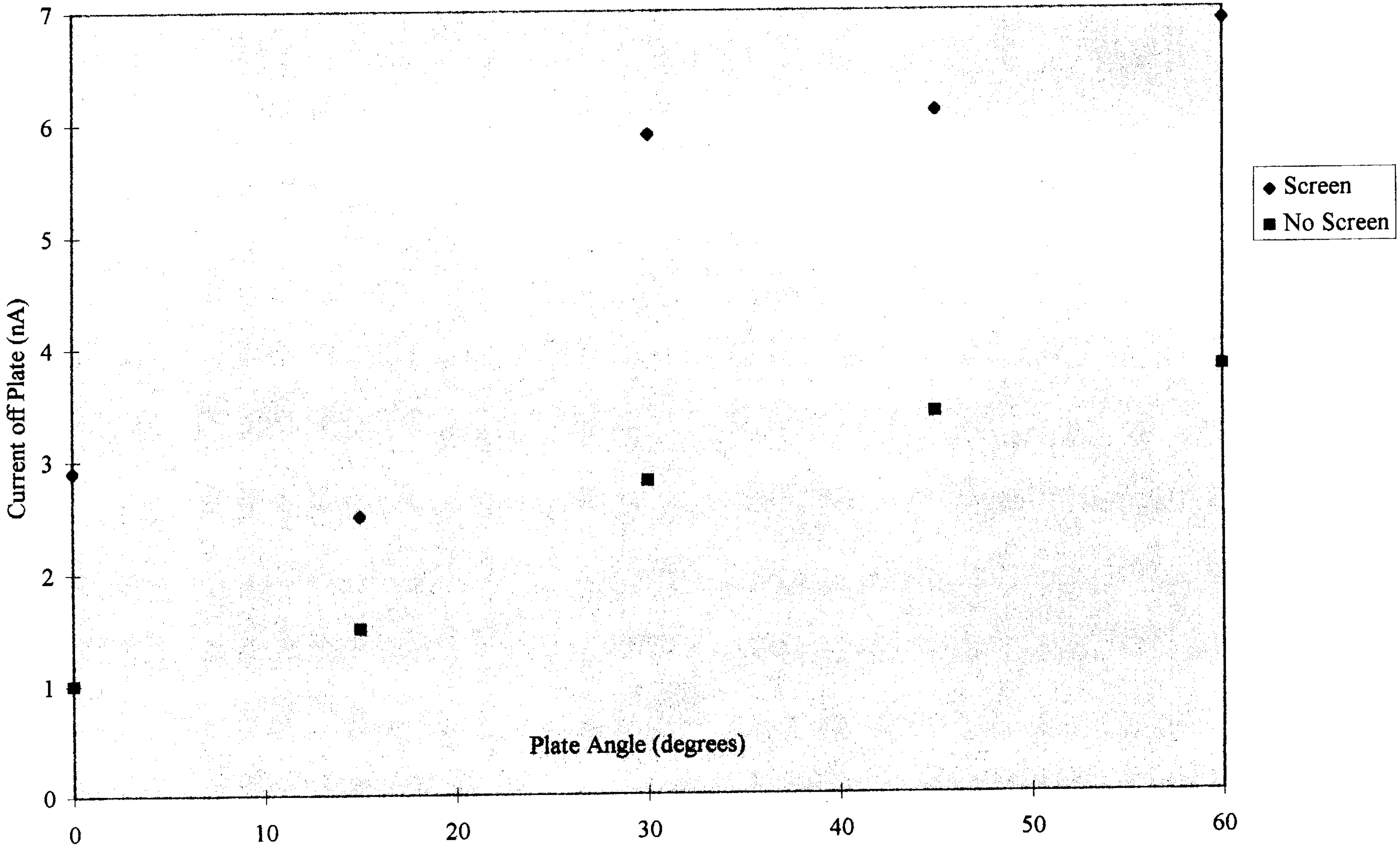


Fig. 5 - Effect of Screen on Plate Current at Various Angles for Fuel Containing Stadis 450 (Run 19)



TRIP REPORT #6
WPAFB, OH

PLACE: Wright Laboratory, Dayton, OH

DATE: May 7-9, 1997

CONTACTS:
Robert Swaim, NTSB
Cindy Obringer, Wright Laboratory
Dexter Kalt, UDRI @ Wright Laboratory
Steve Gerkin, Wright Laboratory/MLSA
Mike Manders, Wright Laboratory/MLSA
Marlin Vangsness, UDRI

PURPOSE OF VISIT: To conduct spray charging tests.

The tests planned for this series are shown in *Enclosure 1* of this attachment.. This plan was developed at a meeting held at Wright Laboratory on April 30, 1997. The experimental setup is shown in *Enclosure 2*.

Prior to conducting the spray charging tests, the T_7/T_8 Wiggins Coupling was assembled using Viton o-rings, split rings and retainer. A series of capacitance and resistance measurements were made as follows:

Configuration of Wiggins Coupling	Resistance,ohms @10V
Tubing pulled to extend both tubes	2×10^{11}
Tubing pushed together but not touching	8×10^{11}
Tubing pushed together real hard	5×10^{11}
Tubing cocked	3.5×10^{11}

The capacitance values were:

	Capacitance, pF
Female side of coupling to tube	190
Male side of coupling to tube	196

When voltage was increased in steps from 10 to 100 to 500 to 1000 volts, it was not possible to obtain a resistance reading above 500V due to internal sparking. When the split rings were removed, a reading of 6 x 10^{10} ohms was obtained at 1,000V. The breakdown voltage was 5,790V on the male side of the coupling and 3,780V on the female side (obtained by maneuvering the tube). It was possible to see the sparks at the opening of the Wiggins coupling.

It was possible to assemble the Wiggins coupling with the retainer installed, but not with the split rings, and get a resistance reading of 4 x 10" ohms at 1,000V. This condition required manipulation of the tubing and several attempts. The breakdown voltage was 1,270V and the capacitance 56 pF for this configuration. The energy of this spark discharge (0.045 mJ) is far below the minimum ignition energy for hydrocarbon vapors (0.25 mJ (1)). If care is not taken in aligning the tubes, it is not possible to get a resistance reading at 1,000V (R @ 100V = 4 x 10"). When the voltage was increased to 1,000V, breakdown occurred in the coupling.

The Wiggins coupling (T_7/T_8) was reassembled using Teflon o-rings, split rings, and retainer. Breakdown occurred between 500-1000V, regardless of the effort to manipulate this coupling to prevent sparking.

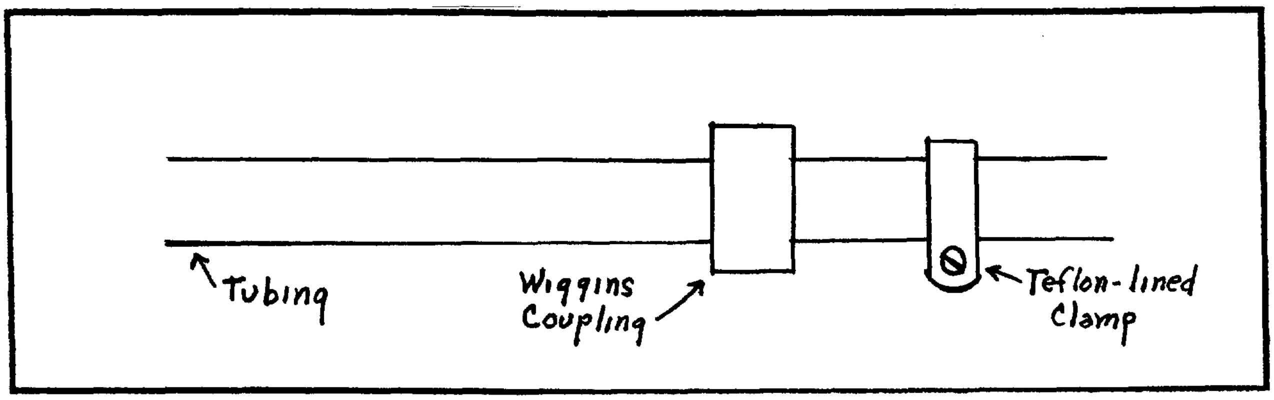
The Teflon-lined clamp was mounted on the tubing and the breakdown voltage was 3,600V when the voltage was applied to the clamp and the tube grounded. When the voltage was applied to the tube, the breakdown voltage was 3,200V. Based on the measured capacitance for this clamp of 40 pF, the corresponding spark energies are 0.26 mJ at 3600V and 0.20 mJ at 3200V. The energies are equal to or just below the mininum ignition energy of 0.26 mJ for hydrocarbon vapors (1). The gap of the clamp was readjusted to produce a breakdown voltage of 4300V which corresponds to a spark energy of 0.37 mJ. This is above the minimum ignition energy of 0.26 mJ.

The Wiggins coupling and the Teflon-lined clamp were then assembled on the same piece of tubing as shown in *Figure 1.*

It was decided to use a straight tube, rather than the bent tube shown in *Enclosure 2*, for the spray charging tests.

In the first spray charging tests (Run 1), fuel having a conductivity of 50 pS/m @ 84° was sprayed on the exposed tube. The Wiggins coupling had Viton o-rings and no split rings or retainer. The voltage slowly built up to 117V, but fell off rapidly. It was noted that the high conductivity fuel had wetted all surfaces in the cabinet that were supporting the tube. The wetted surfaces were continuous between the tube and the grounded cabinet. (The tube was resting on a Lucite support and held down with plastic ties).

FIGURE 1



After the test, a voltage was applied to the charged plate of the monitor to check for leakage. The voltage diminished from 725 to 695V in 60 seconds, indicating a high leakage rate through fuel wetted supports.

In the second run, fuel was sprayed on the Teflon-lined clamp. A continuous coat of fuel was seen covering the clamp and Lucite support. (The Lucite support was covered by an aluminum foil tent to deflect the spray.) The voltage climbed to 33V after 9 minutes of spraying. After the spray was turned off, the voltage fell rapidly indicating a high leakage rate.

References

(1) Lewis, B. and von Elbe, G., "Combustion, Flames and Explosions of Gases", 2nd Edition, Academic Press, New York, 1961, p. 334.

Phase III

TEST CONFIGURATIONS

I. PIPE 1 3/4" TUBE / 45° ANGLE
- A. FUEL CONDUCTIVE
  - 1. LOW CU / OR LESS
  - 2. 30 CU / 3305 / STATUS 450
- B. DISTANCE 1. 24" w/wo TARGET 16" (DEFLECTOR PLATE)
- C. TEMPERATURE 95°
- D. ORIFICE(S) 1. 1.5 HOLE 2. SLOT
- E. "O"-RINGS:
  - 1. TEFLON
  - 2. FLUOROCARBON

MEASUREMENTS

- A. FUEL RESISTANCE
- B. I - TUBE (CURRENT)
- C. V - Tube (VOLTAGE)
- D. V - Outer Shell (VOLTAGE)
- E. BREAKDOWN Voltage Wiggans (5 Position)
  - 1. TEFLON
  - 2. FLUOROCARBON
- F. CAPAC. (5 Positions)
  - 1. TEFLON
  - 2. FLUOROCARBON

II. PIPE CLAMP (TEFLON) 1 3/4"

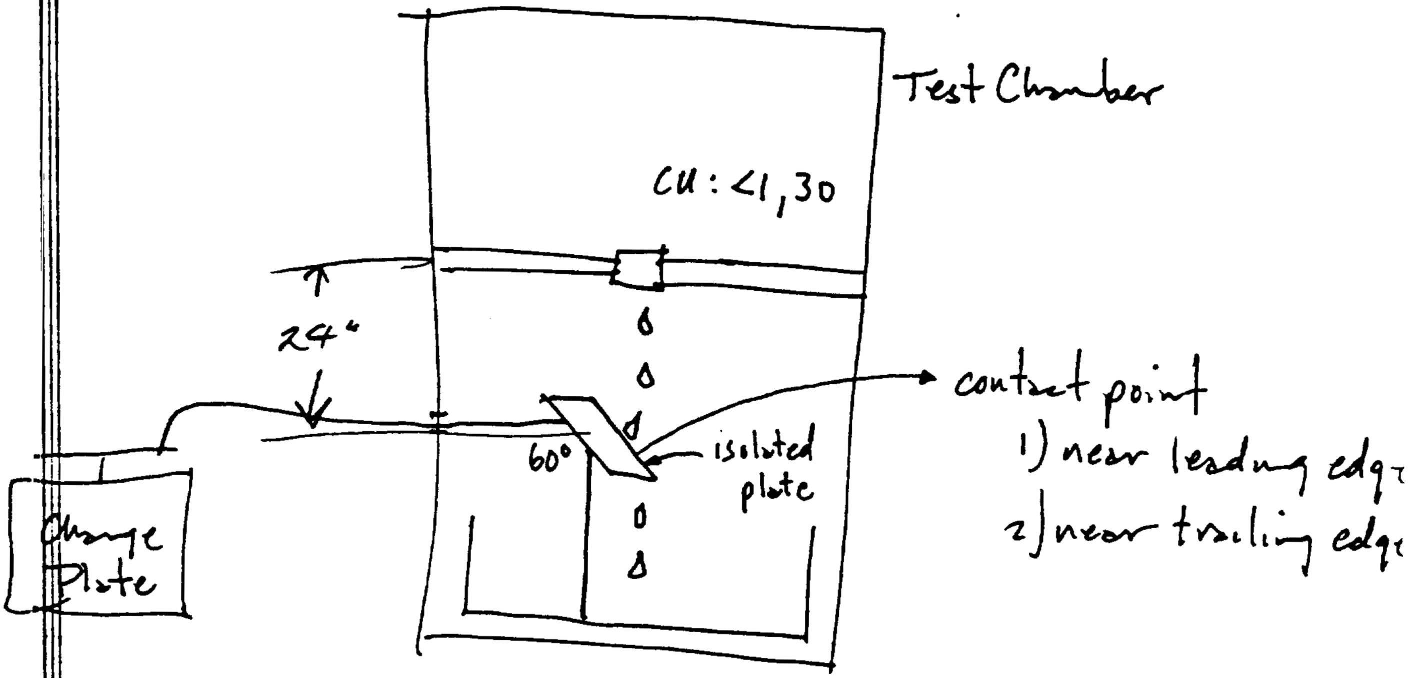
If break down obtained, increase gap to find when gap stops

1. 30 Cu Fuel
2. SCREEN EXT.
3. 24" Dist.
4. 115°F
5. SLOT
6. 0.010" Gap TEFLON tube

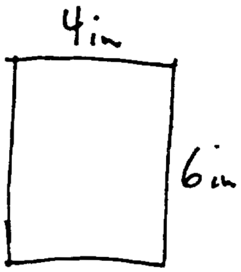
MEASUREMENTS

- A. BREAKDOWN V.
- B. Voltage (out meter)
- ~~C. CURRENT~~
- C. CAPACITANCE

III Steves Drip Test



isolated plate :



Enclosure 2

ELECTROSTATIC CHARGING TEST
SETUP
PROPOSED
(UDRI/WL-MLSA/POSF)
30 APR 97

PREVIOUSLY RPT'D

WORST CASE

TEST CONDITIONS

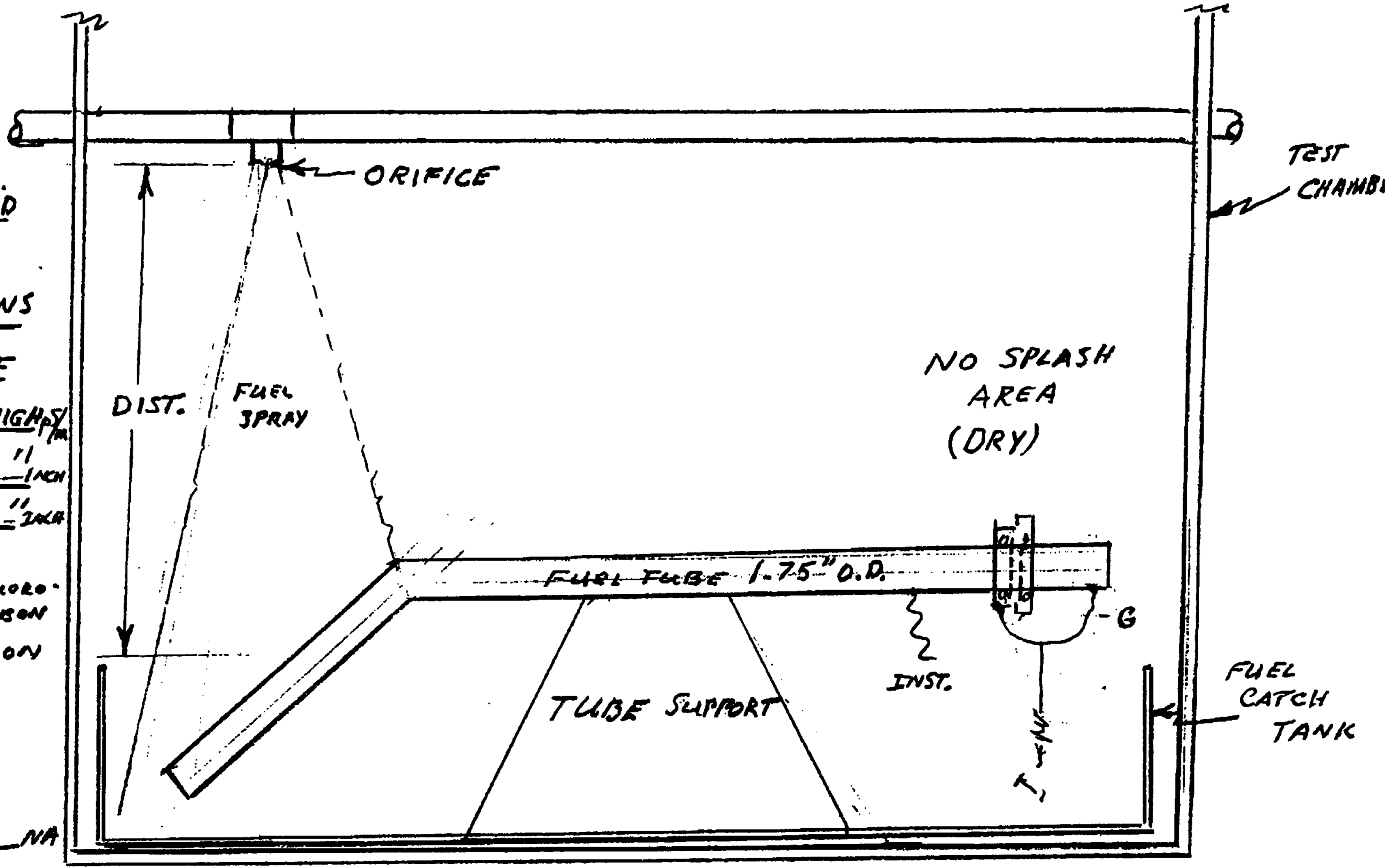
FUEL TEMP. - 90-100°F

FUEL Cu - LOW/HIGH PPM

ORIFICE - ______" INCH

DISTANCE - ______" INCH

WIGGINS "O" RING MAT'L - Fluoro-
a) CARBON
b) TEFLON



MEASUREMENTS
1) CURRENT ______ NA
2) VOLTAGE ______ VOLTS
3) CAPACITANCE ______ pF
4) RESISTANCE ______ Ω

ELECTROSTATIC CHARGING OF A TEFLON-LINED CLAMP

Background - In previous testing at Wright Laboratory, the highest voltage obtained by spraying fuel on a teflon-lined clamp was 658 volts. Based on the capacitance of this clamp of 44 pf, the voltage required to produce a 0.26 mJ spark would be 3438 V. This is more than 5 times the highest voltage obtained so far with this clamp. It was decided that additional laboratory tests would be needed to determine the maximum voltage that could be obtained on this clamp by spraying with charged fuel before proceeding with more full scale tests at Wright Laboratory.

Objective - The objective of these laboratory tests was to determine the maximum voltage that can be produced by impinging electrostatically charged fuel on a teflon-lined clamp.

Approach - In order to achieve the above objective various means of increasing the electrostatic charge on Jet A fuels were evaluated including the use of additives and filters. The additives included the only currently approved static dissipator additive for jet fuels, namely, Stadis 450, and Gulf 178, a corrosion inhibitor for jet fuels which is no longer produced. It was found in previous studies (1) that Gulf 178 is a prolific generator of static charge in jet fuels.

The filters chosen included the same coarse fiberglass medium as used in an aircraft fuel filter coalescers and a separator paper known as Type 10. This separator paper was identified in previous studies as a prolific generator of static charge in fuels (1) and was cited as a contributing factor in two aircraft fueling incidents involving 727 aircraft. The teflon-lined clamp was from the fuel tank of a 747 aircraft. It had a capacitance of 50 pF when mounted on a grounded tube and measured with a portable capacitance meter.

Procedure - An apparatus that was previously used in fuel charging studies (2) was modified for these tests. The apparatus, which is shown in Fig. 1, consisted of a fuel reservoir, an electrically-isolated filter, a stand for supporting the teflon-lined clamp which was mounted on a grounded tube, and a receiving tank. The filter holder was connected to a Keithley 610C electrometer for measuring the filter current. The teflon-lined clamp was connected to an electrostatic voltmeter to measure voltage buildup as the charged fuel passed over the center (connecting bolt) of the clamp. A Monroe Electrostatic Fieldmeter, Model 225K, was also used to measure the voltage on the clamp. The probe of the Monroe meter was positioned 1 cm above the clamp so the meter would read directly in volts. In most tests, 500 ml of fuel was used, but in some cases, the fuel quantity was increased to 1000 or 1500 ml.

In the first five tests, the filter cell from the Water Separometer (Fig. 1) was used with a coarse fiberglass filter medium. For Tests 6-26, the fiberglass medium was replaced by a one inch diameter, Type 10 filter disk. In all the subsequent tests, a Swinny filter holder containing a ½ inch diameter, Type 10 filter was used.

Results and Discussion - The results of the testing with the coarse fiberglass filter are summarized in Table 1 and Figs. 2 and 3. Since the maximum value obtained with the fiberglass filter was only 100 V, no further testing was done with this filter.

For Tests 6-26, a Type 10 filter disk (diameter = 1 inch) was placed in the coalescer cell and a Viton o-ring was placed on top of the paper filter to compensate for the difference in thickness between the fiberglass and paper filters. The results of these tests are summarized in Table 2.

TABLE 1

CHARGING OF TEFLON-LINED CLAMP USING FIBERGLASS FILTER					
Test	**Fuel**	**Fuel Conductivity pS/m**	**Fuel Quantity, ml**	**Maximum Voltage on Clamp, V**	**Remarks**
1	Jet A (NRL 95-11)	2.74	1000	+20 to -8	Background Test - No filter used.
2	"	"	"	-28	" " "
3	"	"	"	+100	Keithley electrometer went off scale at 100V.
4	"	"	"	+100	" " "
5	"	"	"	+95	Electrostatic voltmeter was used in place of Keithley.

Using the neat (un-additized) fuels (Tests 6-10) the maximum voltage obtained was 2860 V using only 500 ml of fuel. Based on the shape of the curve for Test 7 (Fig. 4), it appears that a higher value might have been achieved if additional fuel was used. The two preceding tests with the same fuel (Tests 6C and 6D) produced lower voltages which is common with this type of filter. This is because the filter is not completely homogeneous and the area where the fuel passes through the filter represents only a small part of the entire filter. Based on the voltage decay curve (Fig. 5), most of the charge placed on the clamp by the flowing fuel remained on the clamp during Test 7.

TABLE 2
CHARGING OF TEFLON-LINED CLAMP USING TYPE 10 PAPER IN COALESCER CELL

Test	Fuel	Fuel Conductivity, pS/m	Fuel Quantity, ml	Voltage on Clamp, V	Filter Current x 10^{-10} A	Flow Rate ml/min
6A	(NRL 95-11)	2.74	500	Off scale > 100 V	---	---
6B	"	"	"	Off scale > 500 V	---	---
6C	"	"	"	1300	---	29.4**
6D	"	"	"	2100	-6	23.8**
7	"	"	"	2860	-6	19.2**
8	"	"	"	2580	-6	20.8**
9	(NRL 95-7)	0.67	500	1310	-3.3	30.3*
10	"	0.67	500	1430	-3.6	21.7*
11	Sample E (Jet A + Stadis 450)	8.50	500	800	-7.9	71.4*
12	"	8.50	500	900	-6.5	
13	Sample D (Jet A + Stadis 450)	14.5	500	1900	-5.5	26.3
14	"	14.5	500	1300	-4.1	29.4
15	Sample C (Jet A + Stadis 450)	30.9	500	1830	1.18	71.4
16	Sample C (Jet A + Stadis 450)	30.9	500	1430	1.1	68.4

TABLE 2
CHARGING OF TEFLON-LINED CLAMP USING TYPE 10 PAPER IN COALESCER CELL

Test	Fuel	Fuel Conductivity, pS/m	Fuel Quantity, ml	Voltage on Clamp, V	Filter Current x 10^{-10} A	Flow Rate ml/min
17	"	30.9	1000	1970	1.1	72.5
18	Sample B (Jet A + Stadis 450)	60.5	500	950	-4.5	59.5*
19	Sample B (Jet A + Stadis 450)	60.5	1000	1320	-7.0	60.6*
Effect of Using an Interrupted Fuel Flow Instead of Straight Stream						
20	Sample B (Jet A + Stadis 450)	60.5	1200	3350	-1.2	19.8**
21	Sample C (Jet A + Stadis 450)	37.9	1000	1100	-0.46	42.5*
22	"		1000	1880	-0.55	37.0**
23	(NRL 95-7)	2.71	500	200	-0.22	29.4*
24	(NRL 95-118)	4.74	500	300	-0.83	17.2*
25A	(NRL 95-118)	4.74	500	800	-0.33	Run stopped
25B	(NRL 95-118)	"	500	500	-0.55	Run stopped
26	(NRL 95-118)	"	"	500	-0.9	99.2*

*** Straight Stream**
****Interrupted Flow**

A series of fuel samples with conductivities in the range of 10-90 pS/m was prepared using Stadis 450 Enhanced in Jet A (NRL 95-7). The charging tendencies of these samples are given in Table 2.

With the fuel samples containing Stadis 450 (Tests 11-22) the only way that a significant voltage on the clamp could be achieved was by allowing the fuel to drip on the clamp in a fast, interrupted stream. The interruption of the stream prevented current losses through the stream to the filter and the grounded tank. By use of the interrupted stream technique, a maximum voltage of 3350 volts was obtained in Test 20 using a fuel with a conductivity of 60.5 pS/m. It took 60 minutes to achieve this voltage (Fig. 6).

In subsequent testing with neat fuels (Tests 23-26), no significant charging was obtained. It was therefore decided to try a different type of filter holder, viz., the Swinny filter holder. The Swinny filter holder exposes considerably more filter area to the fuel than the coalescer cell. The results of the tests with the Swinny filter holder are given in Table 3.

Despite the additional filter area, no significant voltages were obtained with neat fuels (Tests 27 and 28) or with fuels containing Stadis 450 (Tests 29-34). Even when interrupted flow was attempted with Sample B (Test 34), a lower voltage was obtained (1530V) than was obtained with this sample in the coalescer cell (Test 20).

The results obtained using Gulf 178 (Tests 39-48) are summarized in Table 4 and plotted in Figs. 7-10. At 100 ppm, Gulf 178 had little effect on either conductivity or voltage on the clamp - compare Test 28 with Test 39. However, substantial increases in both conductivity and voltage on the clamp were obtained at the 333 ppm level (voltage on the clamp was 2510 to 3000 V in Tests 40 and 41) and at the 1000 ppm level, up to 4870 V in Test 43B. In fact, the curves

TABLE 3
CHARGING OF TEFLON-LINED CLAMP USING TYPE 10 PAPER IN SWINNY FILTER HOLDER

Test	Fuel	Fuel Conductivity, pS/m	Fuel Quantity, ml	Voltage on Clamp, V	Filter Current x 10^{-10} A	Flow Rate, ml/min
		Charging by Neat Fuels				
27	(NRL 95-118)	3.50	500	500	-3.9	45.0
28	(NRL 95-7)	0.93	500	0	-1.0	37.9
		Charging by Fuels Containing Stadis 450				
29	Sample E (Jet A + Stadis 450)	10.15	500	400	-2.4	40.0
30	Sample E (Jet A + Stadis 450)	10.15	500	700	-3.3	43.5
31	Sample C (Jet A + Stadis 450)	30.2	500	1050	-4.0	38.5
32	Sample B (Jet A + Stadis 450)	57.3	500	1340	-6.6	37.0
33	Sample B (Jet A + Stadis 450)	57.3	1000	1510	-8.5	38.2
34	Sample B (Jet A + Stadis 450)	57.3	1000	1530	Variable	Interrupted flow
		Effect of Adding Gulf 178				
39	(NRL 95-7 + 100 ppm Gulf 178)	2.96	500	600	-8.0	38.8
40	(NRL 95-7 + 333 ppm Gulf 178)	10.48	500	2510	-14.8	42.0
41	(NRL 95-7 + 333 ppm Gulf 178)	10.89	1500	3000	-14.6	39.5

TABLE 3
CHARGING OF TEFLON-LINED CLAMP USING TYPE 10 PAPER IN SWINNY FILTER HOLDER

Test	Fuel	Fuel Conductivity, pS/m	Fuel Quantity, ml	Voltage on Clamp, V	Filter Current x 10^{-10} A	Flow Rate, ml/min
42	(NRL 95-7 + 1000 ppm Gulf 178)	28.2	500	4670	-53.5	N.D.*
43A	(NRL 95-7 + 1000 ppm Gulf 178)	28.2	500	4800	N.D.*	N.D.
43B	(NRL 95-7 + 1000 ppm Gulf 178)	28.2	500	4870	-53	N.D.
44	(NRL 95-7 + 1000 ppm Gulf 178)	26.0	500	4570	-42	N.D.
45	(NRL 95-7 + 1000 ppm Gulf 178)	26.0	1000	3600	-27	40.6
47	(NRL 95-7 + 1000 ppm Gulf 178)	26.0	500	4200	-41	40.0
48	(NRL 95-7 + 1000 ppm Gulf 178)	26.0	500	4450	-36	39.7

***Not Determined**

for 100 ppm and 333 ppm Gulf 178 (Figs. 7 and 8) indicate that the maximum potentials had been reached at those levels, whereas the curves for the 1000 ppm level (Figs. 9 and 10) suggest that higher potentials, perhaps 5000 V, might be attainable. This, despite the fact that the voltage decay curves indicate that at the 1000 ppm, substantial voltage was being lost due to the higher conductivity (K = 28.2 pS/m) of the fuel as compared with the 333 ppm level (K = 10.55 pS/m) - see Fig. 11. Note also in Figs. 9 and 10 that the high voltages were obtained in less than 4 minutes with fuel containing 1000 ppm Gulf 178.

Two samples of neat Jet A, NRL 95-11B and 95-7, were shaken with water and allowed to settle for 1 hour. Also, samples containing Gulf 178 and Stadis 450 were shaken with water and allowed to settle for as long as 48 hours. As shown in Table 4, no significant changes in fuel conductivity were observed even after 48 hours of exposure to water, except for the sample containing 1000 ppm Gulf 178. This sample showed an increase in conductivity from 29.7 to 80.1 after saturation with water. None of the samples containing Stadis 450 showed an increase in conductivity.

However, all samples showed an increase in charging tendency after exposure to water, as indicated by the increase in the voltage on the clamp as shown in Table 4. This is particularly true of Jet A + 1000 ppm Gulf 178. In one test in which the electrostatic voltmeter was replaced by a spark gap (Fig. 12), the voltage on clamp exceed 4700 volts three times and sparks were observed in the spark gap on all three occasions when using Jet A + 1000 ppm Gulf 178 saturated with water (Fig. 13).

These results are consistent with an earlier study in which it was found the water generally had no significant effect on fuel conductivity, but increased the charging tendency by as much as a factor of 23, depending on the additives or impurities in the fuel (3).

TABLE 4

EFFECT OF WATER ON FUEL CONDUCTIVITY AND VOLTAGE ON CLAMP

Sample	Conductivity, pS/m		Voltage on Clamp	
	Before saturation with water	After saturation with water	Before saturation with water	After saturation with water
Jet A (NRL 95-7)	0.93	0.80*	0	400*
“		1.16**	0	700**
Jet A (NRL 95-118)	3.50	3.64*	500	1220*
“		3.25**	500	1400**
Jet A (NRL 95-7) + 333 ppm Gulf 178	11.75	13.18	2280	2920*
“			2280	4970***
“		12.75	2280	4100***
Jet A (NRL 95-7) + 1000 ppm Gulf 178	29.7	80.1	4900	5500*
“				6500*(a)
“				5000*(a)
Sample B (Jet A + Stadis 450)	56.3	50.5	1100	1520***
Sample C (Jet A + Stadis 450)	28.8	28.7	790	1350***
Sample C (Jet A + Stadis 450)			790	1400*

* 1 hour after saturation with water

** 48 hours after saturation with water

*** 24 hours after saturation with water

(a) In this run 5000 V was achieved in 4 minutes using only 148 ml of fuel.

TABLE 5: TESTS USING A SPARK GAP AND FLAMMABLE FUEL/AIR MIXTURE

Test	Fuel Sample	Test Conditions	Voltage on Clamp, V	Average Filter Current x 10^{-10} A	Flow Rate, ml/min	Flammable Liquid	Remarks
55	1		5000	36.5	41.0	n-heptane	No spark
56	“	Spark gap = 2 mm	5500	45.5	37.0	n-heptane	No spark
57	“	New filter	5500	45.5	52.0	n-heptane	No spark
58	“	Spark gap decreased	5500	41.5	37.0	n-octane	3 sparks, no ignition
59	“	New filter	4700	30.0	38.0	n-heptane	No spark
66	“	New filter	5400*	31.0		n-heptane	3 sparks, no ignition
67	“	Same filter as Test 66	4300	30.0	39.5	n-heptane	2 sparks, no ignition
68	“	Spark gap increased	4500	23.0	39.5	n-heptane	No spark
69	“	New filter	3850	22.0	42.0	n-heptane	No spark
70	“	New filter	5800	75.0	75.0	n-octane	1 spark, no ignition
71	1	Fuel shaken ½ hour before test	3100	58.0	38.5	n-heptane	No spark

TABLE 5: TESTS USING A SPARK GAP AND FLAMMABLE FUEL/AIR MIXTURE

Test	Fuel Sample	Test Conditions	Voltage on Clamp, V	Average Filter Current x 10^{-10} A	Flow Rate, ml/min	Flammable Liquid	Remarks
72	"	New filter	3900	74.0	47.6	n-heptane	No spark
73	"	New filter	4600	51.0	37.0	n-heptane	7 sparks, no ignition
74	"	Same filter as Test 73	4000	52.0	N.D.	n-hexane	No spark
75	"	New filter	5400	42.0	N.D.	n-hexane	1 spark, no ignition
76	"	Fuel shaken 1 hour before test	5700	61.0	37.8	n-hexane	1 spark, no ignition
84**	"	Electrodes lowered to 1 cm above fuel surface	4000	66.0	37.3	n-heptane	No spark
85**	"	Repeat of Test 84	3300	56.0	41.7	n-heptane	No spark
86**	2	New filter	5500	71.0	47.6	n-heptane	No spark
87**	"	Spark gap set at 2 cm	5700	70.0	40.0	n-heptane	1 spark, no ignition
88**	2	New filter	3900	59.0	37.1	N-octane	No spark
89**	"	New filter	3700	47.0	40.8	n-hexane	No spark

TABLE 5: TESTS USING A SPARK GAP AND FLAMMABLE FUEL/AIR MIXTURE

Test	Fuel Sample	Test Conditions	Voltage on Clamp, V	Average Filter Current x 10^{-10}	Flow Rate, ml/min	Flammable Liquid	Remarks
90**	3	New filter	3000	33.0	28.0	n-hexane	No spark
91**	4	New filter	4200	54.0	36.4	n-hexane	No spark
92**	4	Fuel allowed to settle 1 hr	3600	48.0	40.3	n-hexane	No spark
93	5	New sample of fuel	5600	66	47.6	n-octane	4 sparks, no ignition
94	"	Repeat of Test 93	4600	45	43.5	n-heptane	1 spark, no ignition
95	"	Repeat of Test 93 using new filter	3200	33	40.0	n-heptane	4 sparks, no ignition
96	6	New sample of fuel	4100	55	63.7	n-heptane	No spark
97	6	Repeat of Test 96 using new filter	3400	33	41.7	n-heptane	No spark
98	1		4700	81	76.9	n-heptane	No spark
99	"	Repeat of Test 98	4000	37	36.2	n-heptane	No spark
100	5	Sample shaken and allowed to settle 1 hour	6200	101	62.5	n-heptane	No spark

TABLE 5: TESTS USING A SPARK GAP AND FLAMMABLE FUEL/AIR MIXTURE

Test	Fuel Sample	Test Conditions	Voltage on Clamp, V	Average Filter Current x 10^{-10} A	Flow Rate, ml/min	Flammable Liquid	Remarks
101	"	Spark gap decreased	4800	81	62.5	n-heptane	1 spark, no ignition
102	1	Sample shaken and allowed to settle 1 hour	5800	62	41.7	n-heptane	1 spark, no ignition
103	"	Repeat of Test 102 with new filter	3100	30	39.5	n-heptane	No spark
104	"	Repeat of Test 103	5000	58	40.0	n-hexane	No spark
105	"	Repeat of Test 104 with new filter	3400	36	39.4	n-hexane	No spark
106	2	New filter	5000	56	34.9	n-hexane	No spark
107	2	Sample shaken with 10 ml of water and allowed to settle for one hour	5500	62	40.3	n-hexane	No spark
108	"	Sample shaken with 10 ml of water and allowed to settle for one hour	5400	58	39.2	n-hexane	No spark

*** Fuel used in charging apparatus was Jet A (NRL 95-7) + 1000 ppm Gulf 178, saturated with water.**

**** Electrodes were lowered to 1 cm above liquid in beaker for these runs. In prior runs, the electrodes were 5 cm above the liquid.**

Since high voltages were obtained with Jet A NRL 95-7 + 1000 ppm Gulf 178, saturated with water, a number of tests were conducted to see if a spark could be produced which could ignite a flammable fuel/air mixture. For this purpose, the electrostatic voltmeter was replaced by a spark gap which was placed in a beaker containing vapors of n-heptane or, in some cases, n-octane or n-hexane (see Fig. 12). The results of these tests are summarized in Table 5. Visible spark discharges were observed in a number of tests with all three fuels, but no ignitions, despite the fact that the spark gap was increased to produce higher breakdown voltages. In one run (Test 73) a total of 7 spark discharges were observed at 4600 V, but no ignitions were obtained. The maximum voltage obtained with a spark discharge was 5800 V. This corresponds to an energy of 0.84 mJ, using a value of 50 pF for the capacitance of the clamp. Despite the fact this energy is more than 3 times the minimum ignition energy (MIE)for hydrocarbon vapors, no ignitions were obtained. There are two possible explanations for the failure to get ignitions:

(1) The entire capacitance of the clamp may not have been discharged in the spark. The data in Fig. 13 suggest that since the voltage recovered so rapidly after the spark occurred, that there may have been some charge on the teflon (produced by the flowing fuel) that did not take part in the discharge.

(2) The fuel/air mixture in the gap was not right. As shown by Fig. 14, which is taken from Lewis and von Elbe (3), ignitions occur at the minimum value of approximately 0.26 mJ with heptane when the fraction of stoichiometric percentage of heptane in air is 1.8. If the mixture is leaner or richer than 1.8, more energy is required for ignition. Changing the fuel in the beaker to n-hexane or n-octane did not result in any ignitions.

The plot of the voltage on the clamp vs the average filter current (Fig. 15) suggests a relationship between the two, as expected. However, a linear relationship was not found due to voltage losses caused by the high conductivity fuels. The data in Fig. 15 indicate that currents in excess of 2 nA are required to produce voltages on the clamp above 3500 V which are required for sparks above the MIE.

The effect of another contaminant, namely diesel fuel, on the charging tendency of Jet A was also briefly examined. This was because jet fuel going to JFK International Airport is transported in multi-product pipelines where it could encounter trace amounts of impurities from other fuels such as diesel fuel. When jet fuel arrives at JFK, it is clay-filtered to remove contaminants. But it is possible that some contaminants may pass through the clay filters and enhance the electrostatic charging tendency of jet fuel.

The conductivity and charging tendency of a sample of diesel fuel (NRL 93-33) were measured. Then a series of samples representing various dilutions of the diesel fuel in Jet A fuel from JFK were prepared and the conductivities and charging tendencies of these samples were also determined. The results of these tests are shown in Table 6. Diesel fuel (93-33) obviously contains a static dissipator additive since its conductivity is so high (641 pS/m). The high conductivity also permitted the charge to dissipate rapidly as indicated by the low voltage on the clamp and the low charging current. When the JFK fuel was contaminated with various amounts of diesel fuel (Tests 110-112), the resulting voltages on the clamp and the filter currents were not much greater than the corresponding values for the JFK fuel by itself (Test 113). Hence, it doesn't appear that trace amounts of the contaminants in this diesel fuel have any significant effect on the charging tendency of jet fuel. However, the diesel fuel definitely increased the conductivity of the jet fuel, even at a dilution of 1:500.

Limited testing was also done using petroleum sulfonates since earlier studies (1) had shown that these materials enhance the electrostatic charging tendency of jet fuels. The petroleum sulfonates that were found to be most effective in the earlier study were no longer commercially available. But two sulfonates were located, namely, Petronate L (Witco Corp.) and

TABLE 7
EFFECT OF SULFONATES ON CONDUCTIVITY AND CHARGING TENDENCY OF JET FUEL USING TYPE 10 PAPER

Sample	Conductivity pS/m	Voltage on Clamp, V	Filter Current, x 10^{-10} A
Jet A (97-46)	5.19	382	-4.0
Jet A + 1 ppm Sodium Dioctyl Sulfosuccinate	12.23	1200	-7.0
Jet A + 1 ppm Petronate L	1.96	140	-2.3
Jet A + 10 ppm Sodium Dioctyl Sulfosuccinate	141	4400	-39
Jet A + 100 ppm Petronate L	293	1050	-7.6

A final series of tests were run in which the fuel was sprayed from an insecticide-type sprayer (Chapin Stainless Steel Sprayer, Model 3614) onto the teflon-lined clamp. The apparatus was similar to Fig. 1 except that the fuel was sprayed on the center (connecting bolt) of the teflon-lined clamp rather than streaming out of the filter. The fuels included the fuel that produced the maximum voltage on the teflon-lined clamp when using the Type 10 paper to charge the fuel, namely, Jet A + 1000 ppm Gulf 178 saturated with water and Jet A containing Stadis 450. The results of these tests are summarized in Table 8. It is apparent from these data that the sprayer was not as efficient a static charge generator as the Type 10 paper. Hence, no further testing was performed with the sprayer.

TABLE 8
COMPARISON OF FUEL CHARGING TESTS USING AN INSECTICIDE-TYPE SPRAYER VS. TYPE 10 PAPER

Fuel	Conductivity, pS/m	Voltage on Clamp	
		Sprayer	Type 10 Paper
Jet A (97-46)	1.7	120	382
Jet A + 1000 ppm Gulf 178, sat'd with water	80.1	390	5500
Jet A + 1000 ppm Gulf 178, sat'd with water (Repeat)	80.1	290	5500
Jet A + Stadis 450, sat'd with water (Sample C)	28.7	20	1400
Jet A + 10 ppm Sodium Dioctyl Sulfosuccinate	141	200	4400
Jet A + 100 ppm Petronate L	293	0	1050

Summary and Conclusions - The maximum voltages that it was possible to develop on the teflon-lined clamp using Type 10 paper to charge the fuels were as follows:

(1) Jet A fuel with no additives - 2860 V

(2) Jet A fuel containing Stadis 450 - 3350 V (using the interrupted stream technique)

(3) Jet A fuel containing Gulf 178 - 4870 V

(4) Jet A fuel containing Gulf 178, saturated with H_2O - 6200 V

Although two of these values are below the 3458 V required to produce a spark having the minimum ignition energy for hydrocarbon vapors, there is no reason to assume that these are the maximum attainable values. For example, it is possible that a higher charging Jet A fuel without additives could be found. Likewise, it is possible that a more prolific fuel additive or impurity than Gulf 178 exists.

In those tests where a spark gap was connected to the teflon-lined clamp and the spark gap was placed in a beaker containing a flammable fuel/air mixture, sparks were obtained at voltages up to 5800 V, but no ignitions. Even though the energies of these sparks were more than 3 times the calculated MIE, ignition did not occur, possibly because the fuel/air mixture was not correct or because the entire capacitance of the clamp was not discharged because the teflon-lining retained some of the charge.

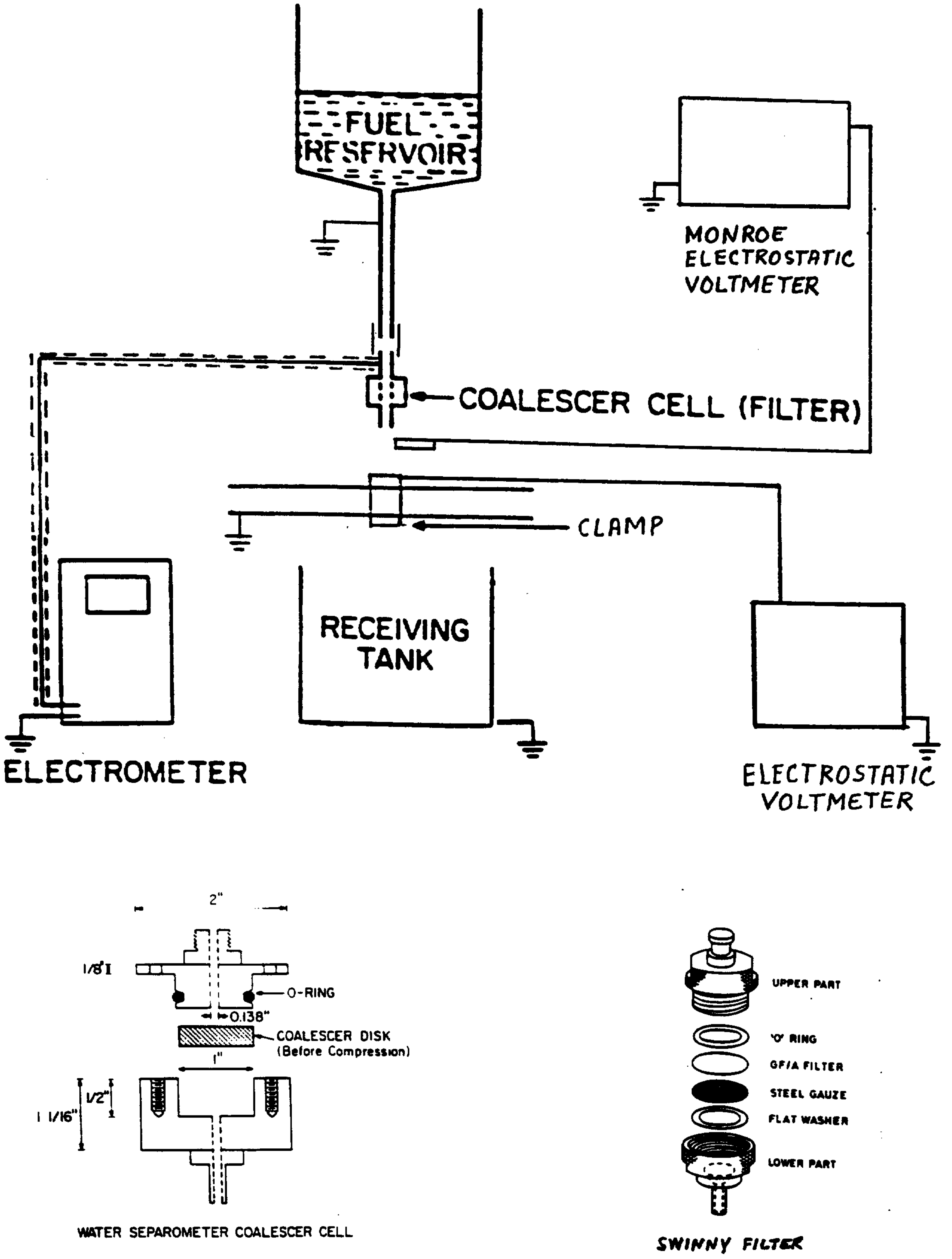
All of these results were obtained using Type 10 separator paper to charge the fuel. When an insecticide-type sprayer was used to charge the fuel and to produce a more realistic fuel leak scenario, much lower voltages were obtained.

REFERENCES

1. Leonard, J.T. and Bogardus, H.F., "Pro-static Agents in Jet Fuels", NRL Report 8021, August 16, 1976.

2. Leonard, J.T. and Carhart, H.W., "Effect of Navy Special Fuel Oil on the Charging Tendency of Jet Fuel", NRL Report 6953, November 20, 1969.

3. Lewis, B. and von Elbe, G., "Combustion, Flames and Explosions of Gases", Academic Press, New York, 1961, p. 334.



WATER SEPAROMETER COALESCER CELL

SWINNY FILTER

Fig. 1 - Fuel Charging Apparatus and Filter Holders

Fig. 2 - Voltage Buildup on Clamp Using Fiberglass Filter in Separometer Cell (Test 4)

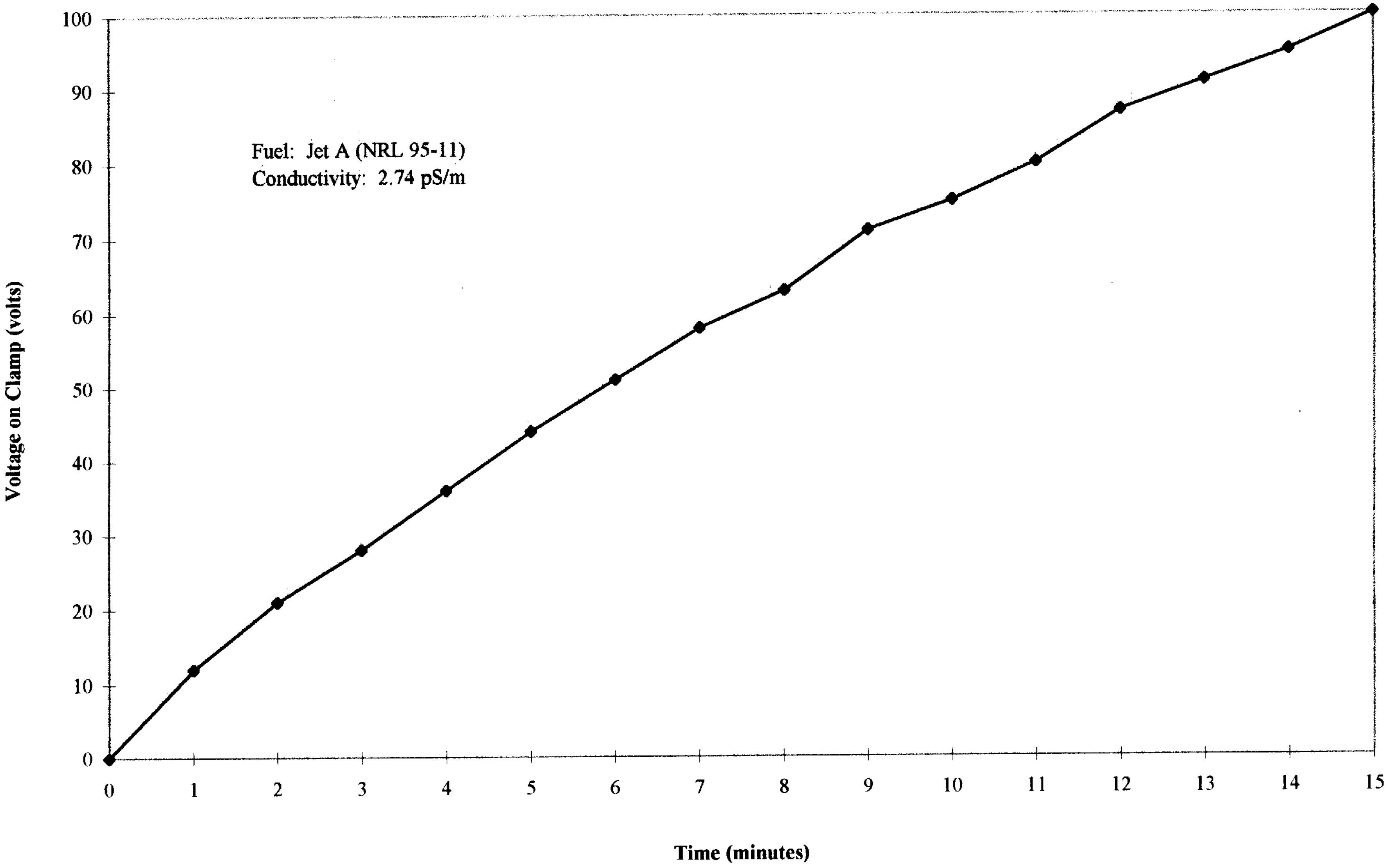


Fig. 3 - Voltage Buildup on Clamp Using Fiberglass Filter in Separometer Cell (Test 5)

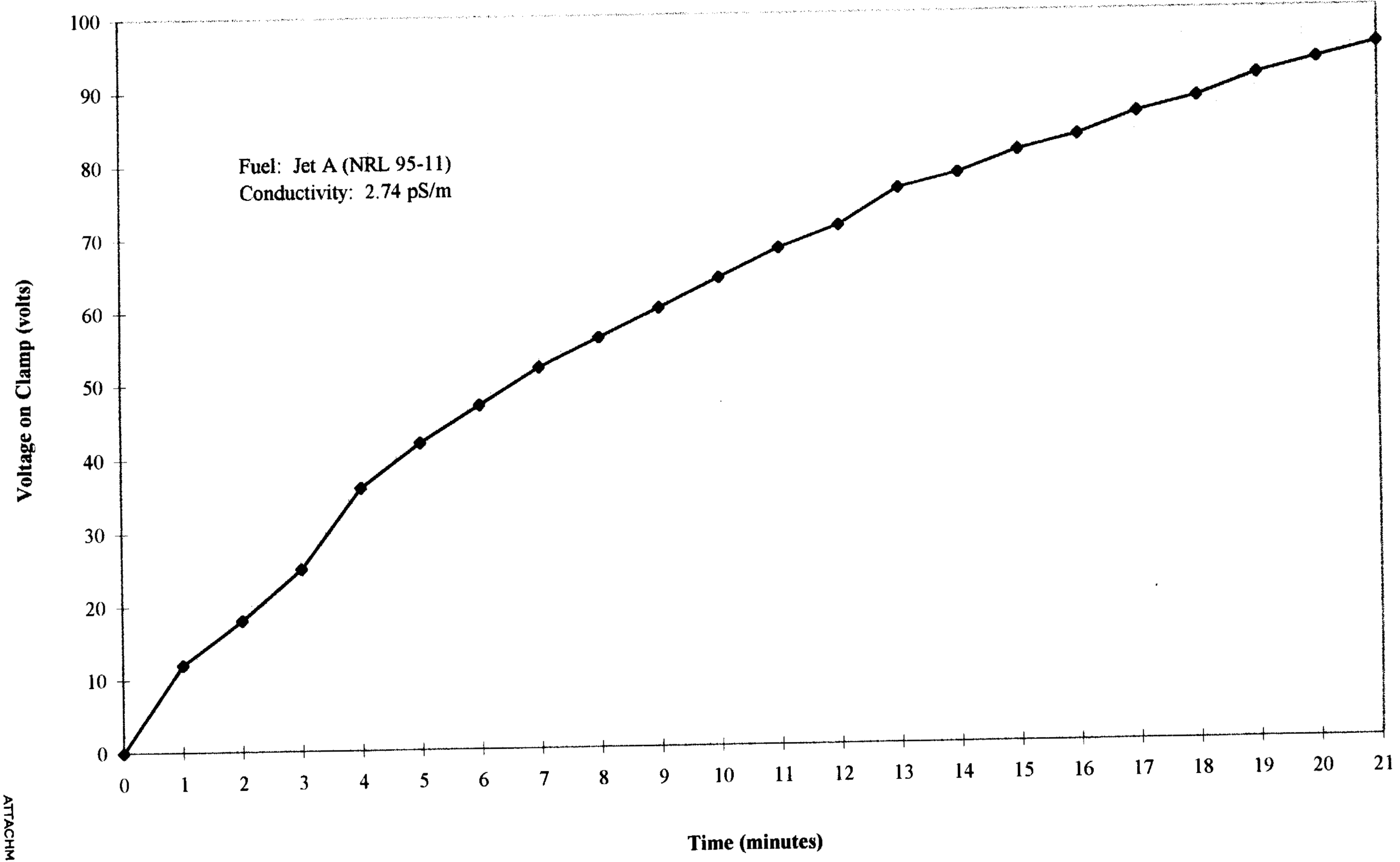


Fig. 4 - Voltage Buildup on Clamp Using Type 10 Paper in Separometer Cell (Tests 6 and 7)

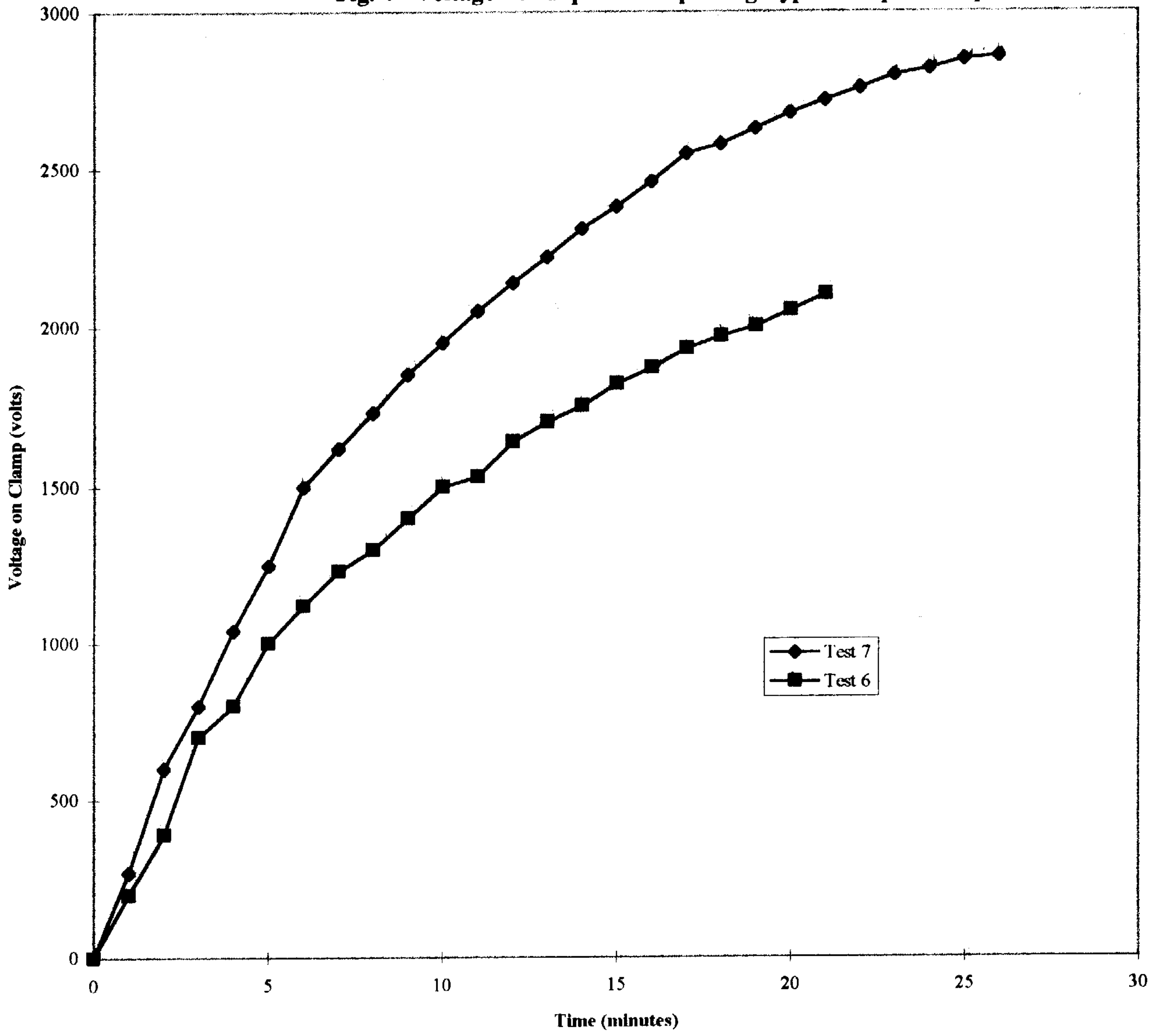


Fig. 5 - Voltage Decay on Clamp (Test 7)

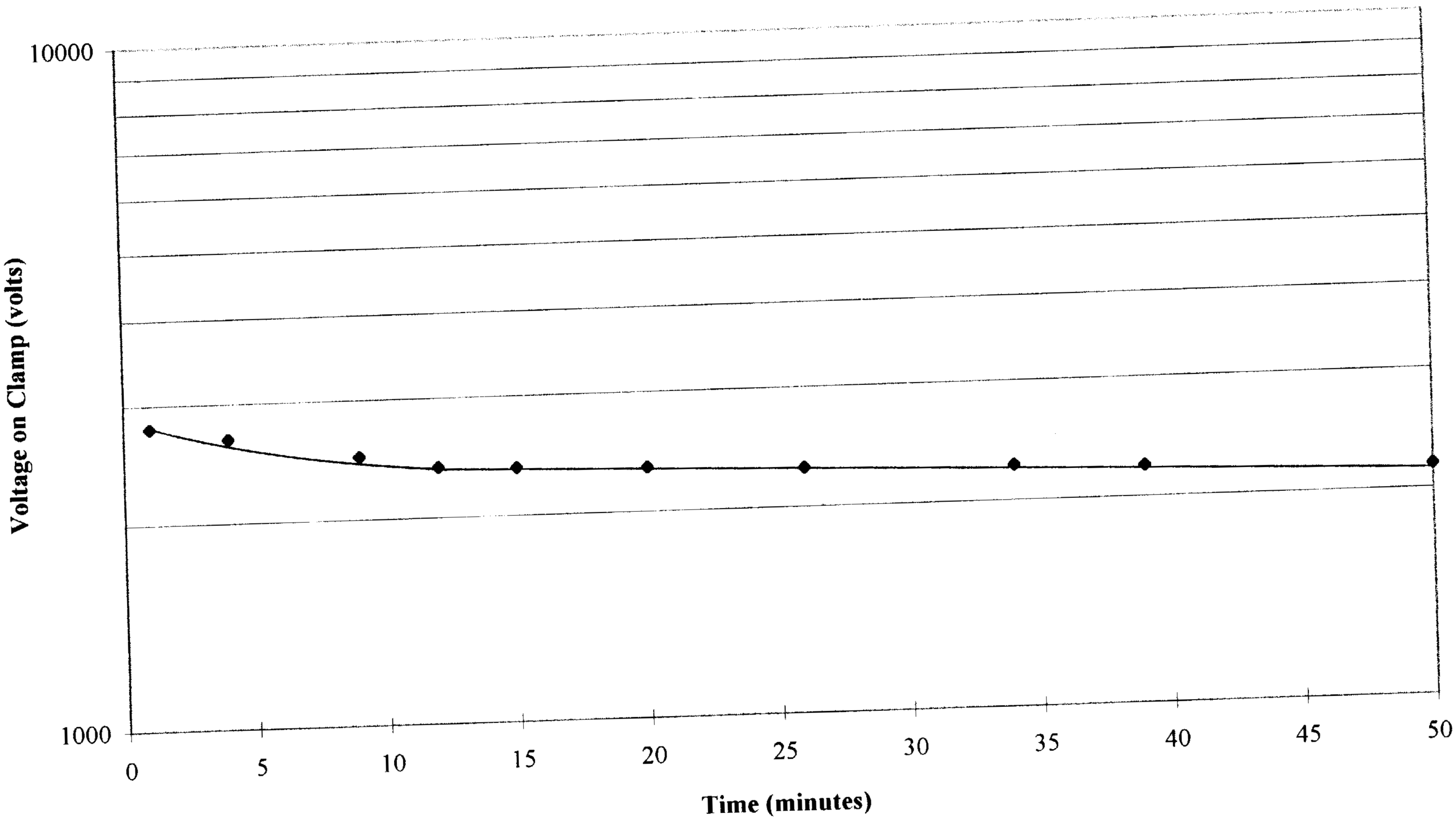


Fig. 6 - Voltage Buildup on Clamp Using Interrupted Stream Technique (Test 20)

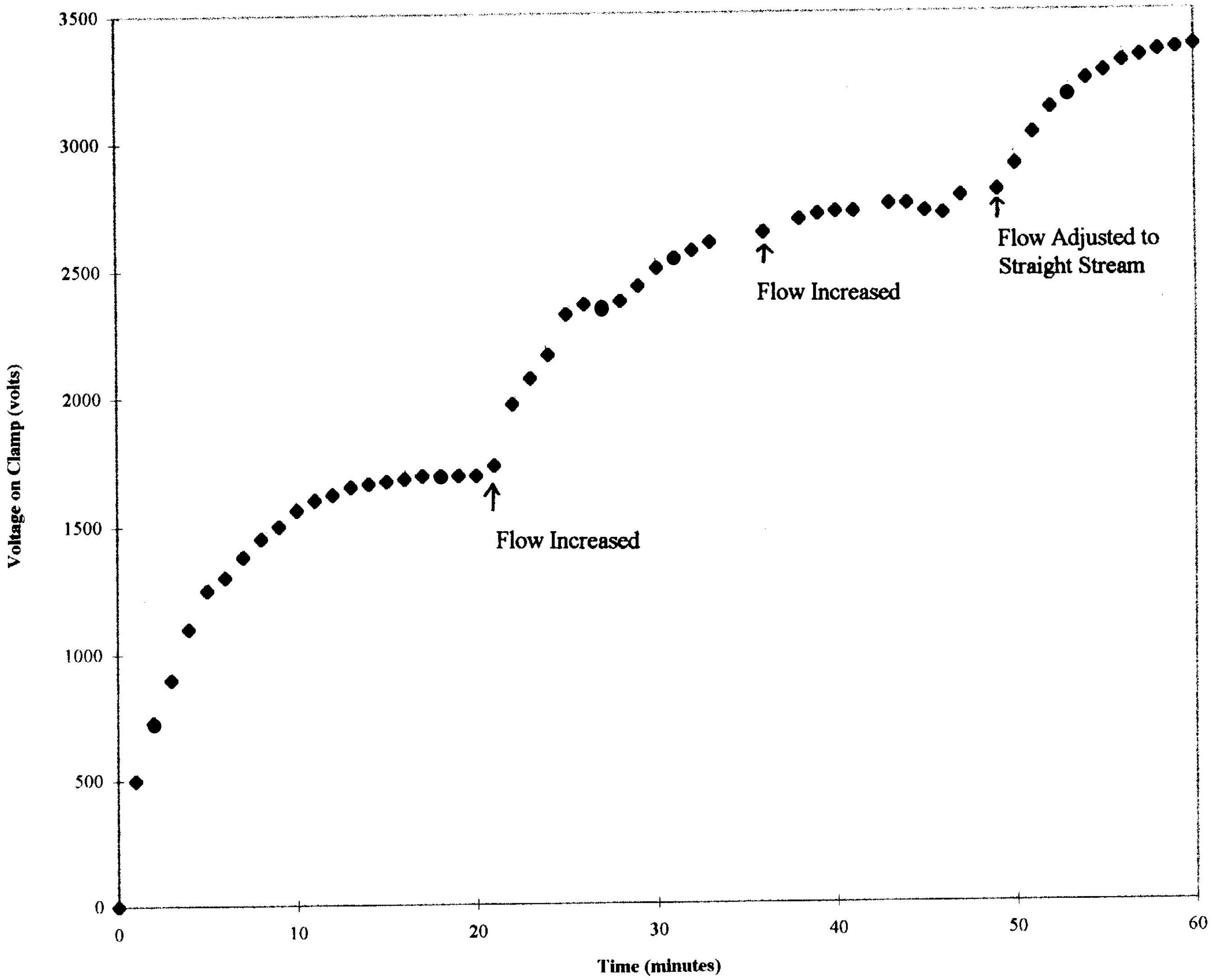


Fig. 7 - Voltage Buildup on Clamp Using Jet A + 100 ppm Gulf 178, Swinny Filter (Test 39)

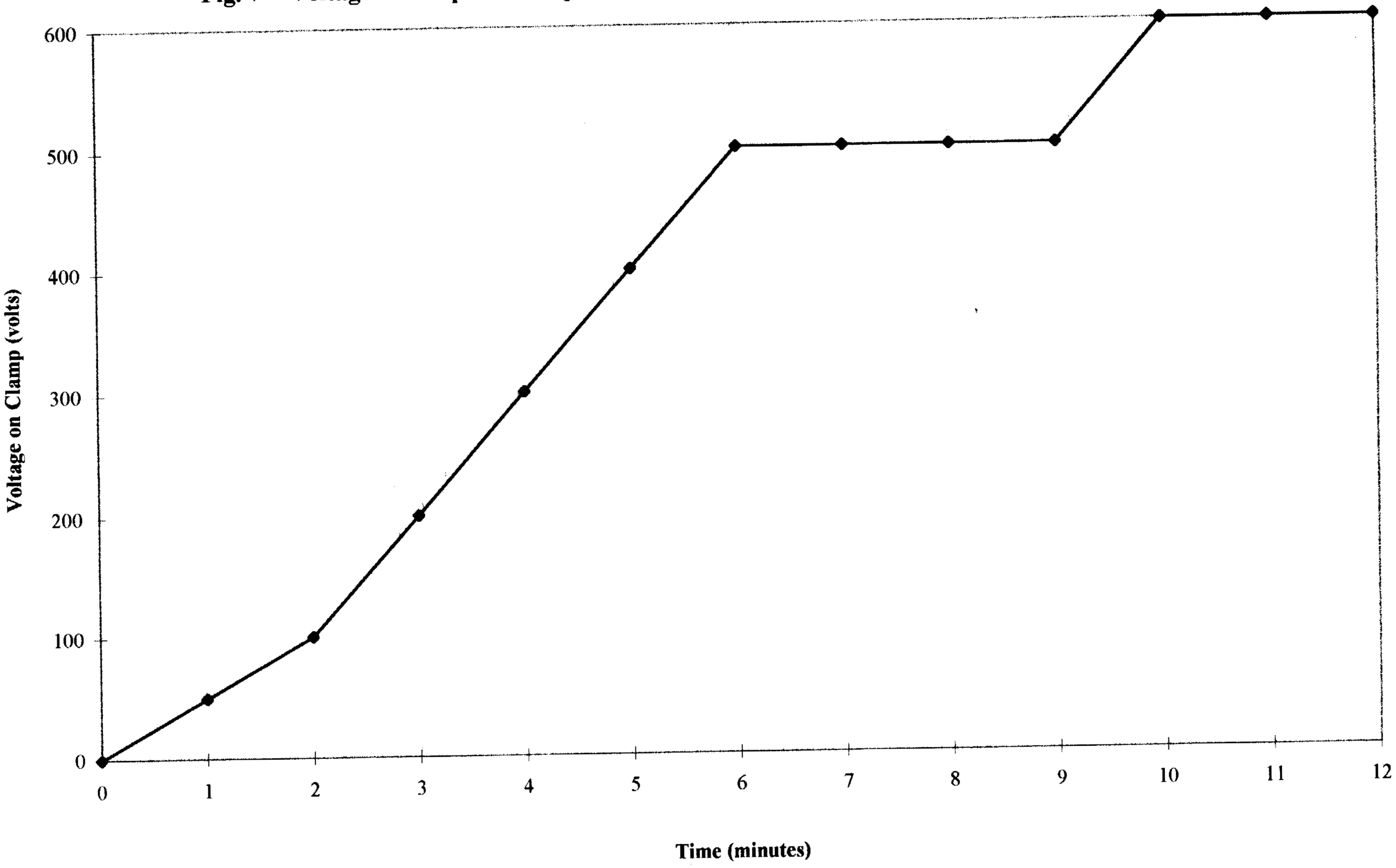


Fig. 8 - Voltage Buildup on Clamp Using Jet A + 333 ppm Gulf 178, Swinny Filter (Test 41)

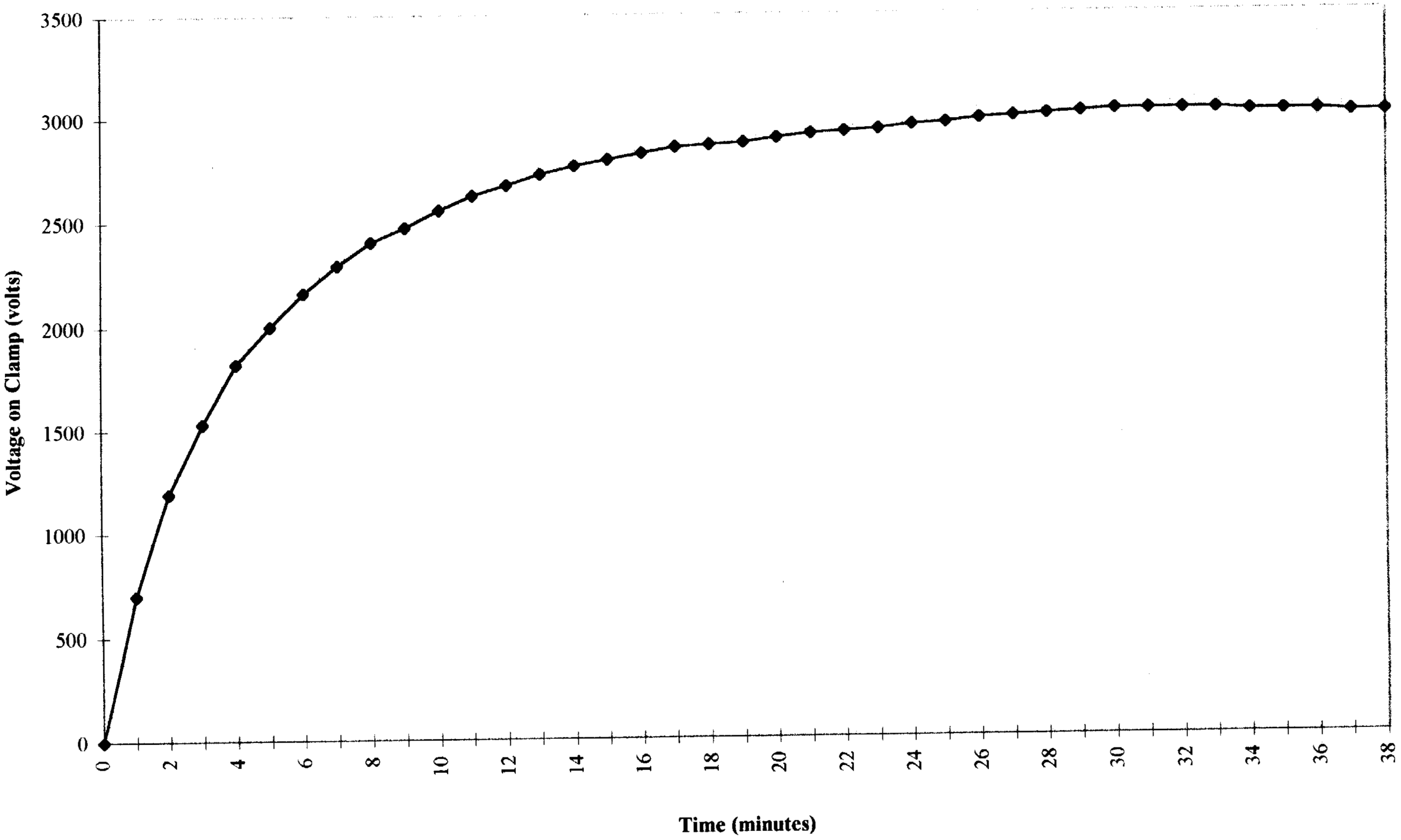


Fig. 9 - Voltage Buildup on Clamp Using Jet A + 1000 ppm Gulf 178, Swinny Filter (Test 43A)

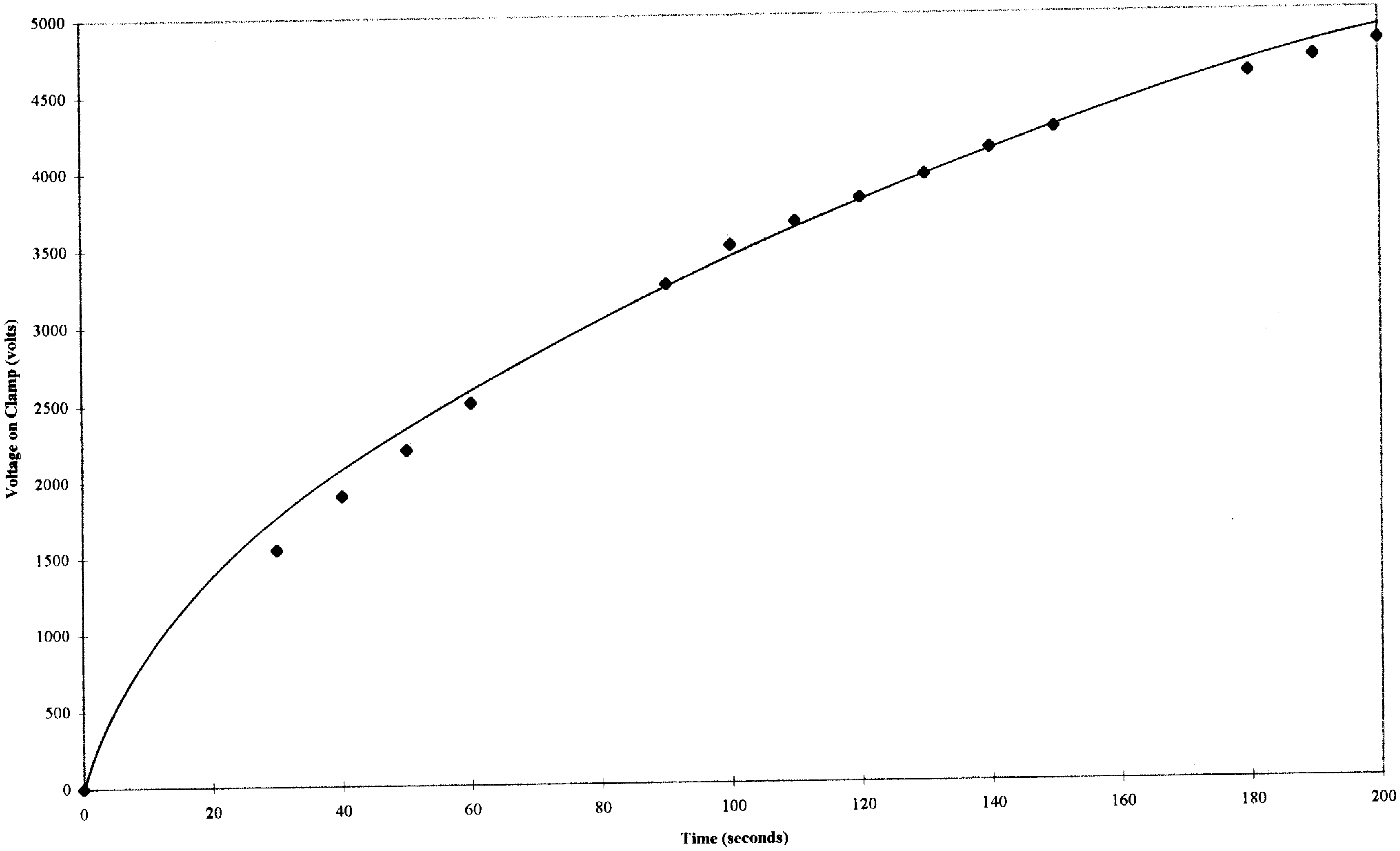


Fig. 10 - Voltage Buildup on Clamp Using Jet A +1000 ppm Gulf 178, Swinny Filter (Test 43B)

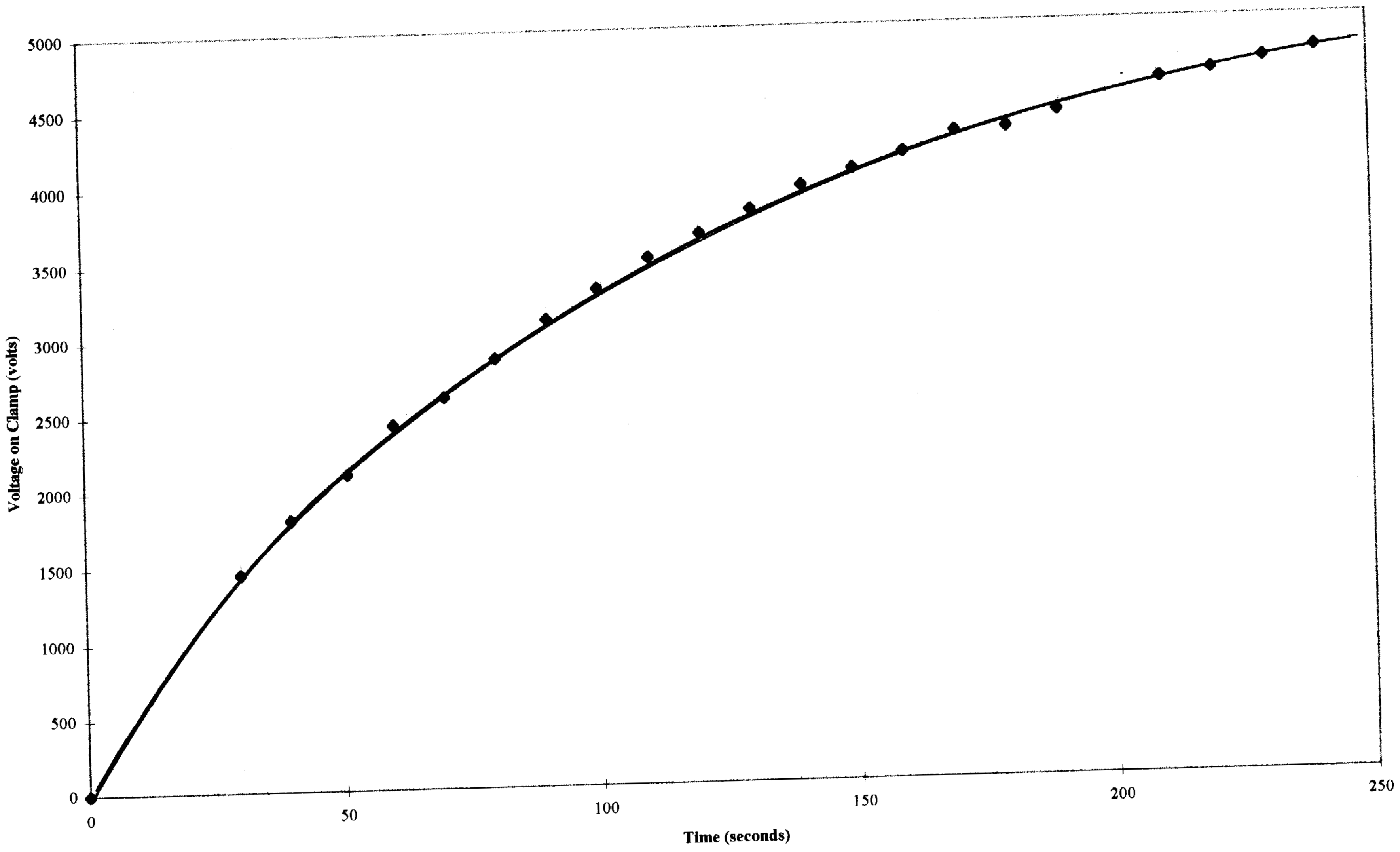
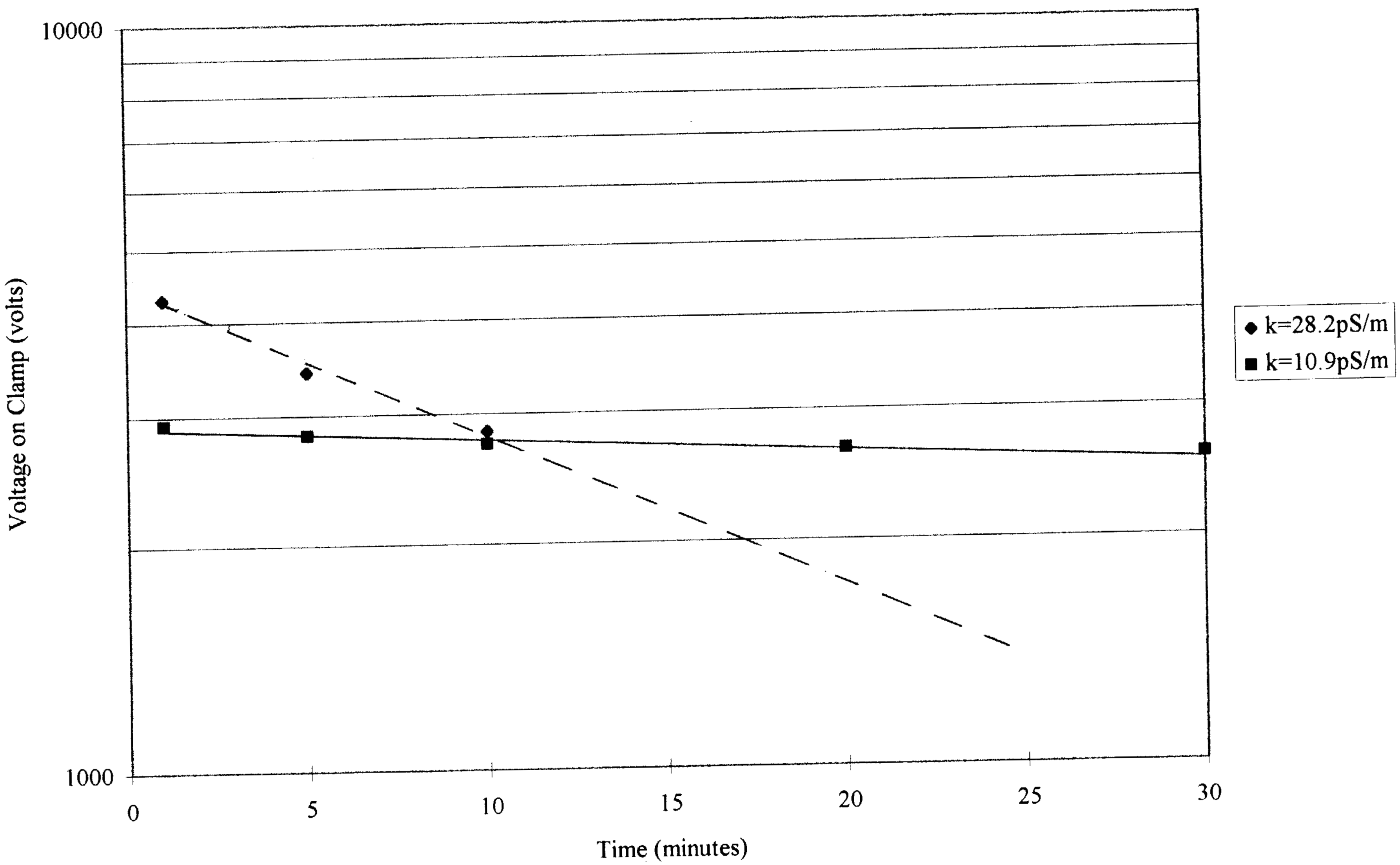


Fig. 11 - Voltage Decay for Fuels of Different Conductivities (Tests 41&43)



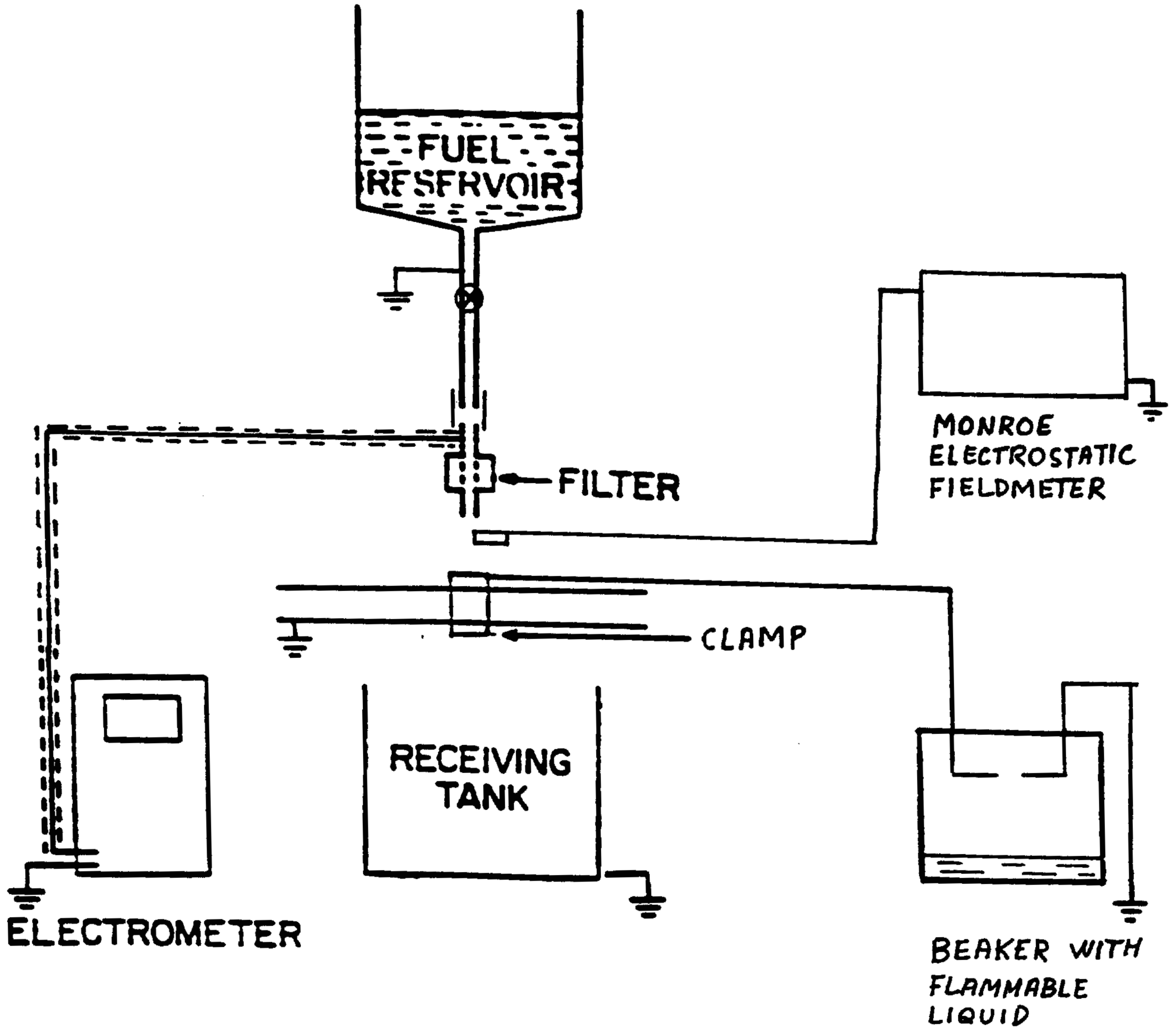
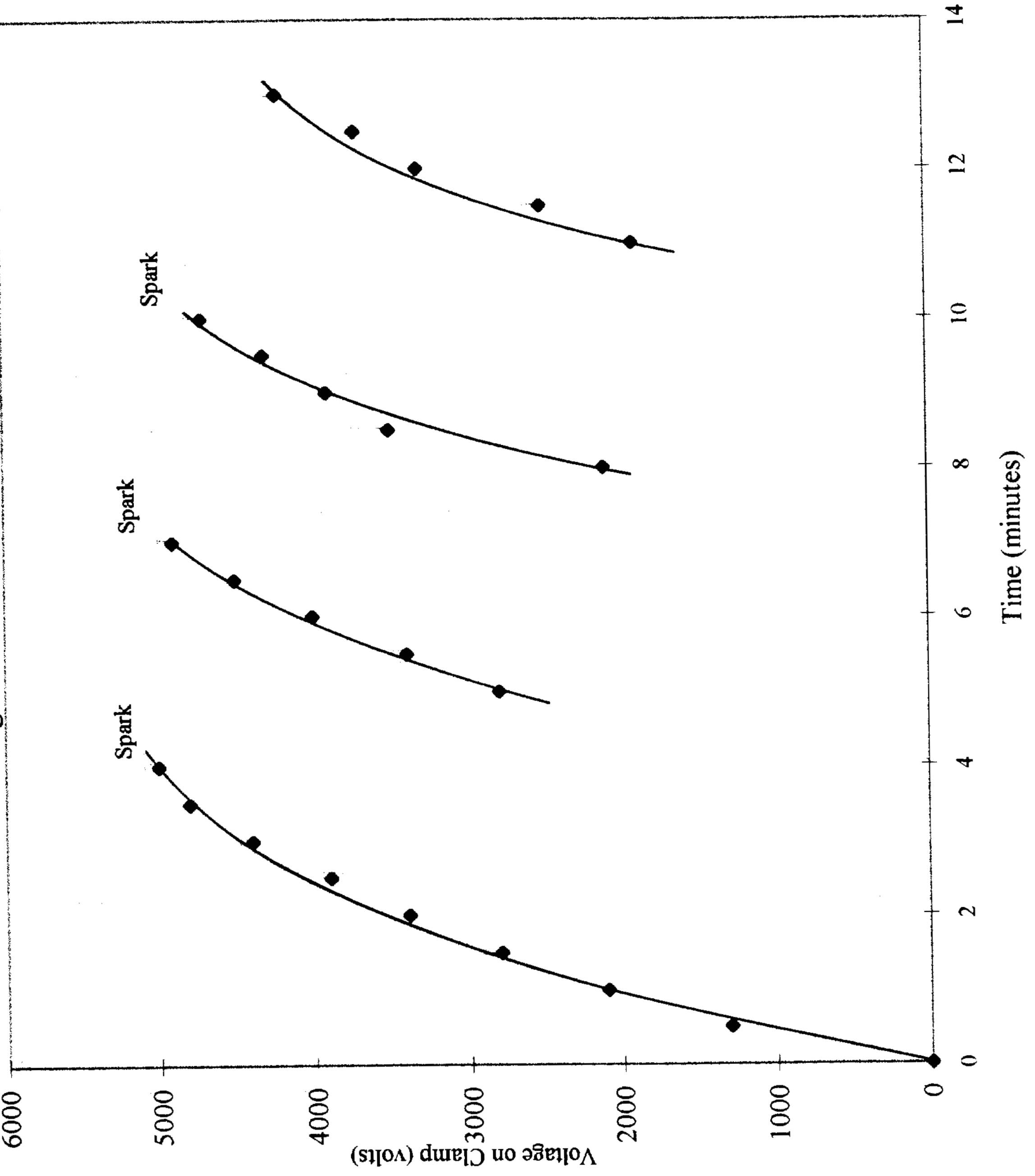


Fig. 12 - Fuel Charging Apparatus Modified
to Include Spark Gap

Fig. 13 - Effect of Water on Voltage Buildup on Clamp (Test 58)



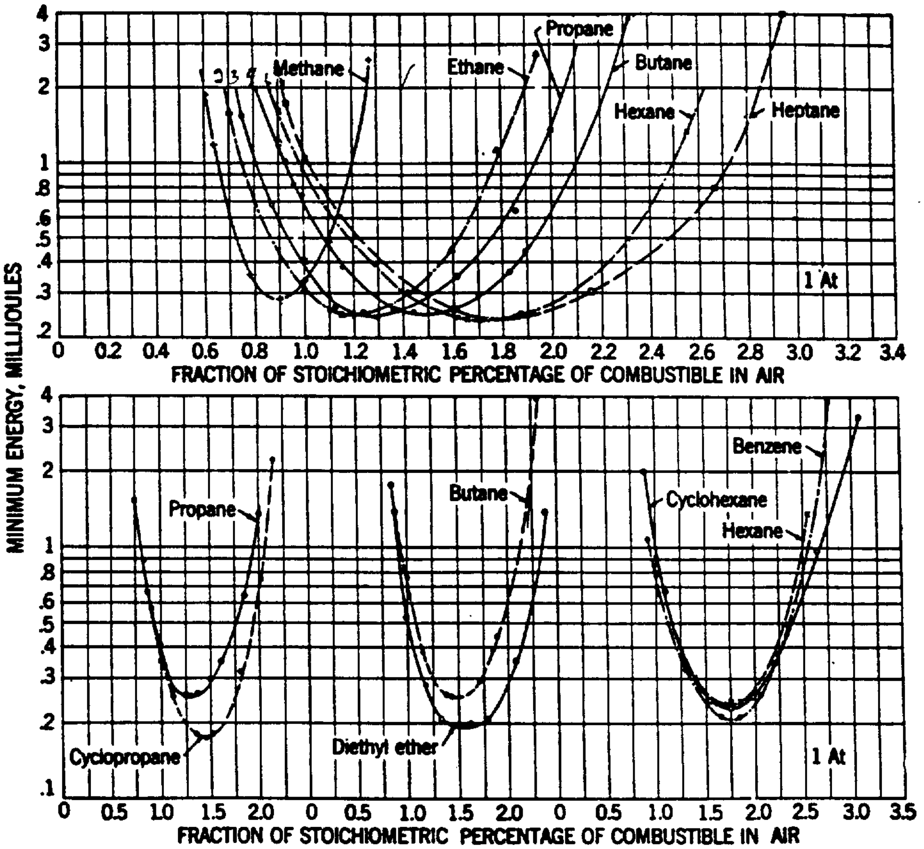


Fig. 14 - Minimum ignition energies of combustible-air mixtures in relation to the stoichiometric percentage in air. (Lewis and von Elbe (3))

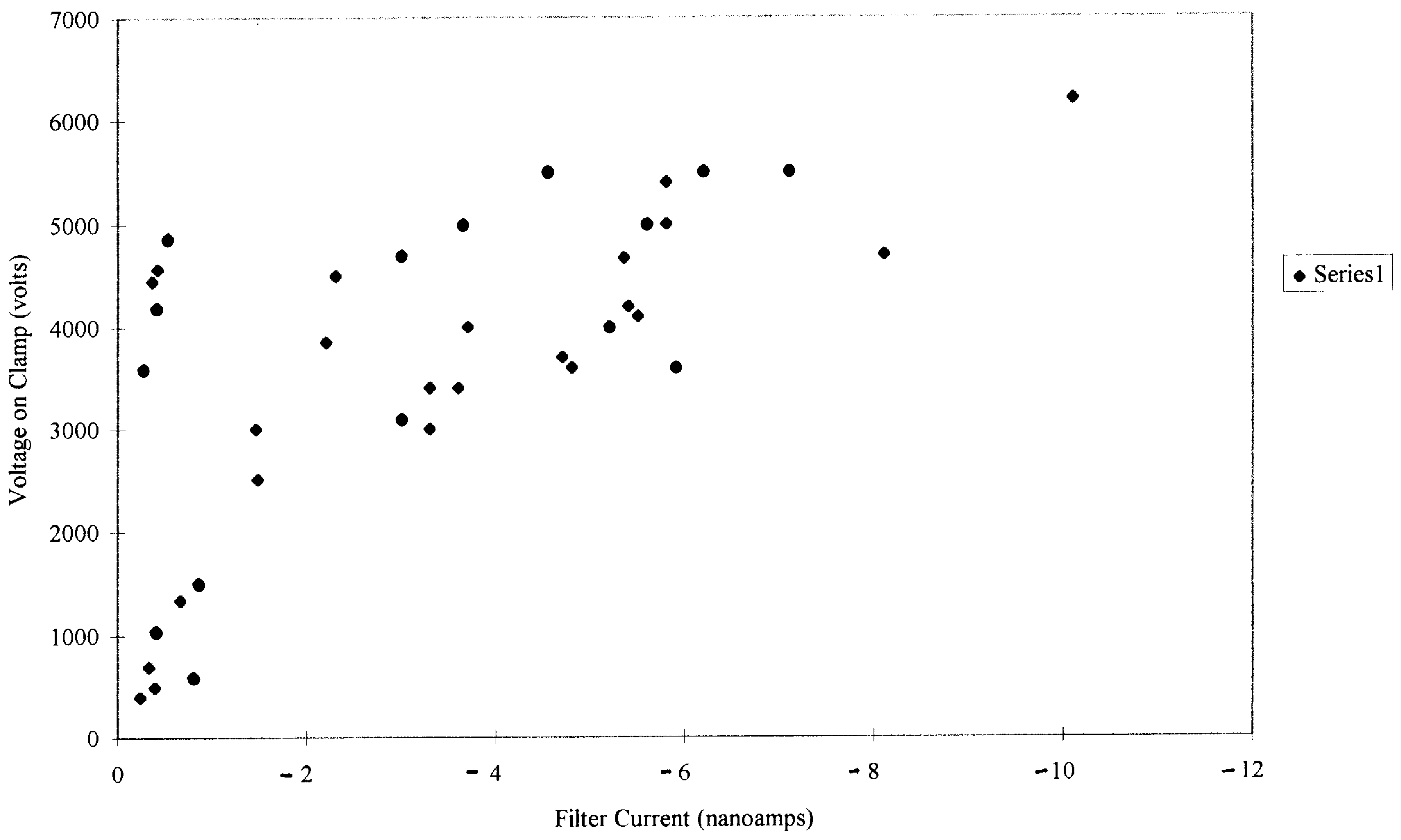


Fig. 15 - Effect of Filter Current on Voltage on Clamp

ANALYSIS OF FUEL SAMPLES FROM AN OLYMPIC AIRWAYS 747 AIRCRAFT

Fuel samples were taken during refueling of an Olympic Airways 747 aircraft on June 26, 1997 at JFK International Airport. The aircraft had just arrived from Athens where it was fueled with fuel containing the Static Dissipator Additive, Stadis 450. Samples were taken from the center wing tank sump and from Tank 2 sump upon arrival from Athens, from the hydrant truck prior to refueling, and from the Tank 2 sump at 20 minute intervals during refueling. The samples were shipped to the Naval Research Laboratory where the following tests were performed:

(1) Fuel Conductivity - using an Emcee Precision Fuel Conductivity Meter;

(2) Electrostatic Charging Tendency - using a specially designed apparatus (Fig. 1) that employs the same filter as used in the Exxon Mini-Static test procedure (1). With this apparatus, the fuel is charged by passing through a high charging filter paper (Type 10) before passing over an insulated charge collector (teflon-lined clamp) which is mounted on a grounded tube. Both the filter current and the voltage on the teflon-lined clamp are measured to give an indication of the electrostatic charging tendency of the fuel being tested. The capacitance of this teflon-lined clamp when mounted to the grounded tube is 50.4 pF. The voltage required to produce a spark from this clamp having the minimum ignition energy for hydrocarbon vapors of 0.26 mJ (1) is 3224 V.

The results of the tests are given in Table 1 and a comparison of these data with earlier tests (2) is given in Table 2. It is apparent that the charging tendencies of the samples from JFK, as indicated by the maximum voltage on the clamp and the filter currents, are consistent with the results of the earlier study. Also, since a voltage of 3224 V would be required to produce a spark discharge from the teflon-lined clamp having the minimum ignition energy (MIE) for hydrocarbon vapors, the voltages for the JFK samples would be considered quite low.

A plot of the maximum voltage on the clamp vs. filter current, as shown in Fig. 2, indicates that the voltage is dependent on the filter current. It was shown in the earlier study (2) that filter currents in excess of 2 nA were required to produce high voltages on a teflon-lined clamp. The maximum filter current shown on Fig. 2, viz. 11 nA, is far below this value.

A plot of the fuel conductivity vs. refueling time (Fig. 3) indicates rather efficient mixing of the incoming fuel with the fuel that was already in the tank.

In summary, the maximum voltage on the teflon-lined clamp and the corresponding filter currents obtained with samples from JFK are consistent with the earlier study, and at best, are about half of the voltage and current required to produce a spark having the required MIE.

TABLE 1

ANALYSIS OF FUEL SAMPLES TAKEN AT JFK ON 26 JUNE 1997					
Sample No.	**Sampling Location and Time**	**Conductivity, pS/m @ 28°C**	**Max. voltage on Teflon-lined Clamp, V**	**Filter Current x 10^{-10} A *****	**Flow Velocity, ml/min**
1	CWT sump, upon arrival from Athens*	187.5	1500	-11.0	5
2	CWT sump, unable to get this sample; sump was dry				
3	Tank 2 sump, upon arrival from Athens	149.8	1480	-11.0	53.8
4	Tank 2 sump, 20 min. after refueling started.	84.8	1500	-7.8	48.4
5	Tank 2 sump, 40 min. after refueling started.	34.2	1880	-9.1	41.7
6	Tank 2 sump, 60 min. after refueling started	18.12	1200	-6.6	48.4
7	Tank 2 sump, 70 min. after refueling started (end of refueling).	11.77	880	-5.0	50.0
9	Hydrant truck 871 (Ogden) before refueling	8.68	780	-5.2	50.0
10**	Hydrant truck 871 (Ogden) before refueling.	--	--	--	--

*** Olympic Airways 747**
**** Merrit Birky's sample**
*****Filter current midway through the run.**

TABLE 2

COMPARISON OF RESULTS FROM JFK SAMPLES WITH EARLIER DATA(2)

Test	Fuel	Fuel Conductivity pS/m	Maximum Voltage on Clamp, V	Filter Current x 10^{-10} A
	Neat Fuels (No Stadis 450)			
27	Jet A (NRL 95-118)	3.50	500	-3.9
28	Jet A (NRL 95-7)	0.93	0	-1.0
	Sample 9 from JFK Hydrant truck	8.68	780	-5.2
	Fuels Containing Stadis 450			
29	Sample E (Jet A + Stadis 450)	10.15	400	-2.4
30	Sample E (Jet A + Stadis 450)	10.15	700	-3.3
	Sample 7 from JFK	11.77	880	-5.0
31	Sample C (Jet A + Stadis 450)	30.2	1050	-4.0
	Sample 5 from JFK	34.2	1880	-9.1
32	Sample B (Jet A + Stadis 450)	57.3	1340	-6.6
33	Sample B (Jet A + Stadis 450)	57.3	1510	-8.5
	Sample 4 from JFK	84.8	1500	-7.8

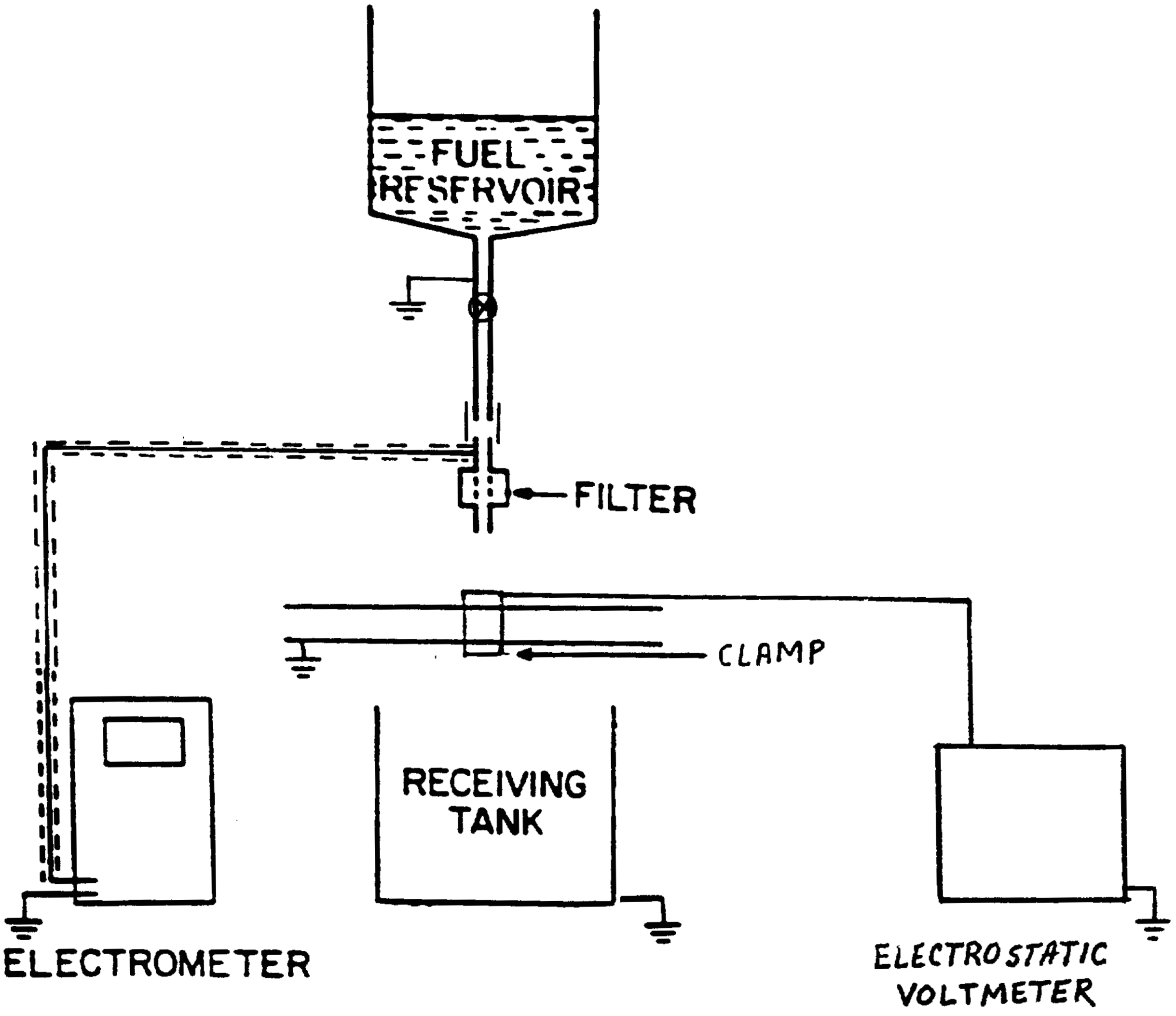


Fig. 1 - Fuel Charging Apparatus

ATTACHMENT # 11
PAGE 5 OF 7

Fig. 2 - Effect of Filter Current on Voltage Buildup on Clamp

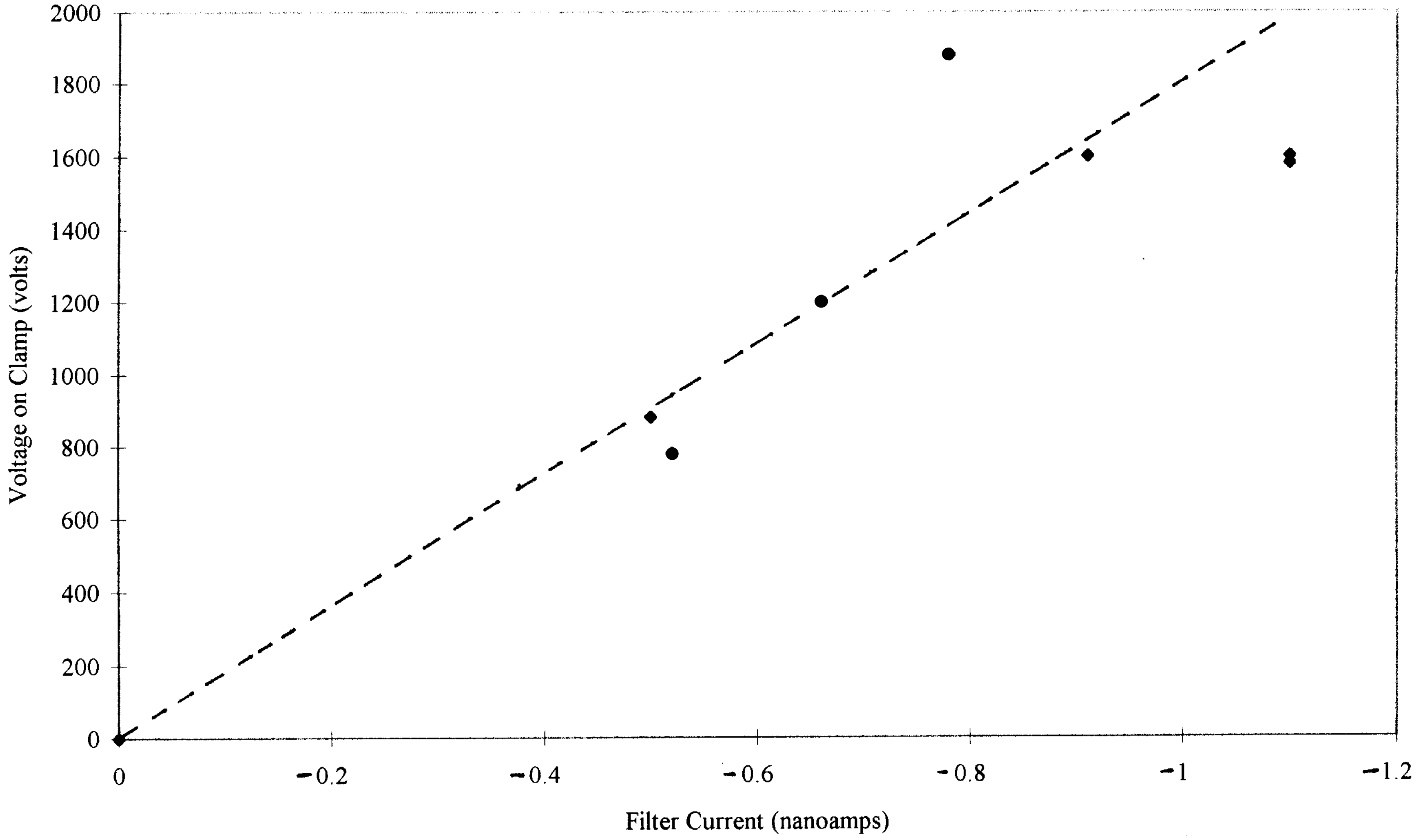


Fig. 3 - Conductivity of Fuel in Tank 2 During Refueling

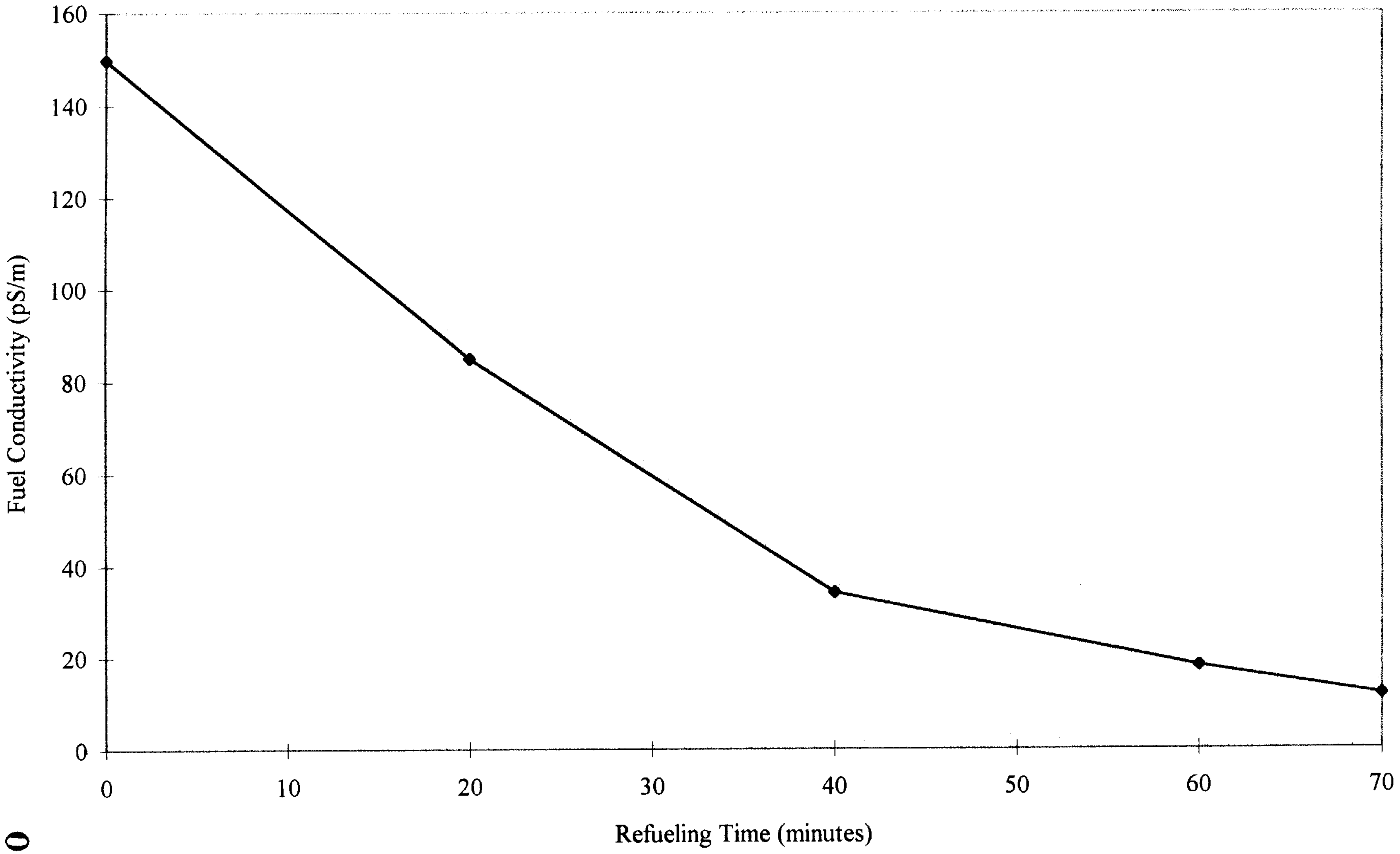


TABLE 6
EFFECT OF DIESEL FUEL ON THE CONDUCTIVITY AND CHARGING TENDENCIES OF JET A

Test		**Conductivity pS/m**	**Voltage on Clamp, V**	**Filter Current x 10^{-10} A**
109	Diesel Fuel (93-33)	641	30	-0.55
110	Diesel Fuel 93-33 diluted (0.03:1) w/JFK fuel	87.3	800	-5.3
111	Sample from Test 110 diluted (1:1) w/JFK fuel	74.0	950	-6.1
112	Diesel fuel 93-33 diluted (1:500) w/JFK fuel	36.5	1200	-6.8
113	JFK fuel, Sample 9	8.68	780	-5.2

sodium dioctyl sulfosuccinate (Aldrich Chemical Co.). Solutions of these sulfonates in jet fuel were prepared initially at the 1 ppm level. The results of testing these solutions are given in Table 7. At the 1 ppm level, Petronate L actually decreased the conductivity and charging tendency of the jet fuel (as indicated by the voltage on the clamp and the filter current), whereas the sodium dioctyl sulfosuccinate increased both the conductivity and charging tendency. At the 10 ppm level, sodium dioctyl sulfosuccinate increased the voltage on the clamp to 4400 volts and the filter current to -39 nA. These values are comparable to the levels achieved with Gulf 178 at the 1000 ppm level. However, the high conductivity (141 pS/m) indicated that charge leakage would act against charge retention. At the 100 ppm level, Petronate L produced a voltage of only 1050V indicating that it was not as effective as sodium dioctyl sulfosuccinate.