AFAPL-TR-70-22

AN EVALUATION OF THE STATIC CHARGE REDUCER FOR REDUCING ELECTROSTATIC HAZARDS IN THE HANDLING OF HYDROCARBON FUELS

CHARLES R. MARTEL

TECHNICAL REPORT AFAPL-TR-70-22

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AIR FORCE AERO PROPULSION LABORATORY
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

This report was prepared by the Fuel Branch, Fuel, Lubrication and Hazards Division of the Air Force Aero Propulsion Laboratory, Project 3048, Task 304805. The experimental data was partially collected under Contract F33615-69-C-1166 by Southwest Research Institute under the direction of Mr. Robert Brown and partially through an in-house program under the direction of Mr. Paul C. Linder (APFF).

The work described in this report was conducted between June 1969 and November 1969 and was performed in Bldg 42D, Area B, Wright-Patterson Air Force Base, Ohio.

This report was submitted by the author on 16 February 1970.

This technical report has been reviewed and is approved.

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ABSTRACT

This report describes the results of an experimental evaluation of the Static Charge Reducer invented by the American Oil Company and marketed by the A.O. Smith Company. The Static Charge Reducer is a device which automatically neutralizes an electrically charged fuel as the fuel flows through it. The tests conducted confirmed the claims that the Static Charge Reducer would reduce the charge density of a flowing hydrocarbon fuel to below 30 microcoulombs per cubic meter. The tests also indicate that two corrosion inhibitor fuel additives significantly affect the electrical conductivity of fuel containing the Shell Oil Company's ASA-3 antistatic additive.

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INTRODUCTION

The objective of this program was to evaluate the effectiveness of the Static Charge Reducer (SCR) in reducing the static charge in a flowing hydrocarbon fuel. The Static Charge Reducer, invented by the American Oil Company and marketed by the A.O. Smith Company, is claimed to reduce the charge density of a flowing hydrocarbon fuel to below 30 microcoulombs/cubic meter (Reference 1). This claim applies to commercial aviation fuels, heating oils, and gasolines with a flow rate up to 1200 gpm and with a fuel temperature of 20° to 100°F. This report discusses the results of this evaluation. A brief discussion of various methods used to prevent static electricity initiated fires and explosions is also included in this report to aid in the evaluation of the Static Charge Reducer.

SECTION II

BACKGROUND

1. STATIC CHARGE HAZARDS

Many fires and explosions occur each year in the handling of hydrocarbon fuels. In a large number of these accidents, the ignition source is attributed to static electricity discharges. Hydrocarbon fuels are normally excellent electrical insulators and dielectrics, and when a flowing hydrocarbon fuel contacts another material, static electricity will be generated. Although all major components of a fueling system are electrically bonded and grounded, the fuel itself becomes charged. As fuel is an excellent insulator, static electricity may be generated faster than it can bleed off allowing a hazardous charge to accumulate. This charge accumulation may subsequently discharge as an incendiary spark to a tank wall, a fuel nozzle, or some other grounded metal structure and ignite any flammable vapor/air mixture present.

Static discharge initiated fires and explosions have occurred during the servicing of aircraft and in the loading and unloading of refueling vehicles, tank trucks, storage tanks, barges, and tankers.

The American Oil Company has conducted a comprehensive study of the mobile tank truck loading problem, probably the most common location for static electricity initiated fires and explosions. In their analysis, a typical tank truck of 5000 gallons capacity is divided into 5 equal compartments of 1000 gallons capacity each. The maximum safe charge density in the fuel during the loading (or unloading) of the 1000 gallon compartment was found to be about 30 microcoulombs/cubic meter. Charge densities in excess of this may result in static spark discharges with sufficient energy to ignite any combustible vapor/air mixture. Note, however, that this critical charge density of 30 microcoulombs/cubic meter applies only to tanks of 1000 gallons capacity with a configuration similar to that of a tank truck. Larger tanks and tanks of different geometry may have substantially lower critical charge densities (Reference 2).

2. CHARGE GENERATION IN FUELS

Electrostatic charge generation and accumulation is a function of the fuel's electrical conductivity, the charging tendency of the fuel, and the fuel system design and flow conditions. The charging tendency of a fuel is the least understood as it may vary greatly from one fuel to another, but it is greatly affected by the presence of various fuel impurities. The fuel's electrical conductivity which also affects the fuel's charging tendency, directly controls the rate of charge bleed-off (relaxation). Thus one method of reducing charge hazards is to increase the fuel's electrical conductivity to ensure that any generated charge will rapidly bleed off to prevent the accumulation of a hazardous charge. A fuel conductivity of 50 conductivity units (conductivity unit is equal to 1 picomho/meter) is generally accepted as the minimum safe value. Recommended practice is to maintain the fuel's conductivity between 150 and 450 conductivity units (CU) measured at 60°F (Reference 4).

3. ANTISTATIC ADDITIVE

The fuel additive, ASA-3, manufactured by the Shell Oil Company, is widely used as an antistatic additive to increase the electrical conductivity of fuel. Recommended concentrations range from about 0.5 to 1.0 ppm. Although this additive may increase the charging tendency of a fuel, it will greatly increase the charge relaxation rate by about 2 orders of magnitude.

4. CHARGE GENERATION PREVENTION

Any movement of a hydrocarbon fuel in relation to some other substance will cause static charge generation. However, the magnitude of the charge generated is proportional to the rate of flow, i.e., flow velocity. High flow velocities in a pipe will result in much higher charge densities in the fuel than will low flow velocities. Thus, one of the commonly used techniques to decrease charge hazards is to limit fuel flow velocities. It is generally accepted that 3 ft/sec is a safe flow velocity. For example, in the top loading of tank trucks, the fuel velocity through the drop tube is normally limited to 3 ft/sec until the tube outlet is covered with fuel. This greatly decreases turbulence, splashing, and charge generation.

5. RELAXATION OF CHARGE

For any given fuel there is some finite time required for the static charge to bleed off to some fraction of its initial value. The relaxation time (in seconds) is the time required for the charge to bleed off to 1/e, i.e., about 37% of its initial value, and is directly proportional to the fuel's conductivity. Another common value is the half-time value, i.e., the time (in seconds) for the charge to decrease to 50% of its initial value. See Appendix I for the method of calculating the relaxation time and for typical relaxation values.

A relaxation chamber is often used to allow any accumulated charge time to bleed-off (relax) to a safe value. The relaxation chamber is nothing more than an enlarged pipe or tank having a minimum residence time of about 30 seconds. (At a flow rate of 600 gpm this would require a volume of 300 gallons.) However, it is no longer unusual to find fuels with relaxation times measured in the hundreds of seconds, and a residence time of 30 seconds may not be sufficient to ensure sufficient charge bleed-off. Larger relaxation chambers are often impractical.

6. STATIC CHARGE REDUCER

The Static Charge Reducer consists of a flanged 10-inch pipe 36 inches long with a 2-inch thick, full length polyethylene liner. Protruding through the liner are sharpened electrodes which are electrically bonded to the outside pipe but project slightly above the inner surface of the polyethylene liner. In operation the charged fuel acts as one plate of a capacitor with the outside metal pipe as the other plate. The 2-inch thick polyethylene liner separating the two plates of the "capacitor" is an excellent dielectric material. As the "capacitor" is charged by the flowing fuel, the voltage potential between the fuel and the outside pipe creates a very high electric field at the points of the grounded electrodes. The high electric field creates a corona discharge which effectively injects charges of the opposite sign into the fuel. These injected charges subsequently neutralize most of the charges in the flowing fuel. There is a delay of up to 30 seconds before the SCR becomes fully effective. Also, the SCR is not effective in preventing charge generation downstream (References 1 and 2).

7. TANK INERTING

Another way to prevent static electricity initiated fires and explosions is to remove or prevent the formation of a combustible fuel/air mixture. This can be done by forced ventilation to remove fuel vapors faster than they are released or by removing the oxygen necessary for combustion, i.e., inerting. Carbon dioxide and nitrogen are often used to inert a fuel tank. This technique has certain economical disadvantages which limits its use.

SECTION III

TEST RESULTS AND DISCUSSION

1. TEST SETUP

As shown in Figures 1 and 2, the Static Charge Reducer was installed in a 600 gpm test loop made up of tank number 2 and its deep-well turbine pump, connecting 8- and 10-inch steel piping between the tank and Bldg 42D, and the test equipment installed within the main test bay of Bldg 42D, Area B, Wright-Patterson AFB, Ohio. Tank number 2 is a horizontal cylindrical underground tank of 15,000 gallons capacity and is located approximately 80 feet from the test bay. Within the test bay the 8-inch piping was reduced to 4-inch piping with the fuel passing through a strainer, a totalizing flowmeter, filter-separator, influent charge density meter, the SCR, and the effluent charge density meter. A separate 4-inch bypass loop was used to vary the flow rate through the test loop. Flow rates were determined using the totalizing flowmeter and a stopwatch. A temperature probe was installed just upstream of the filter-separator to measure the fuel temperature. See Appendix II for a listing of the test equipment.

To measure the static charge density in the flowing fuel, two A.O. Smith Static Charge Density Meters were used. These are described in Reference 1 but are basically rotating vane field strength meters which measure the charge density of a given volume of fuel. An external drive head assembly is used to rotate the vanes and an electrometer is used to measure the current generated by the rotating vanes. This current is then converted to the charge density of the fuel through an appropriate

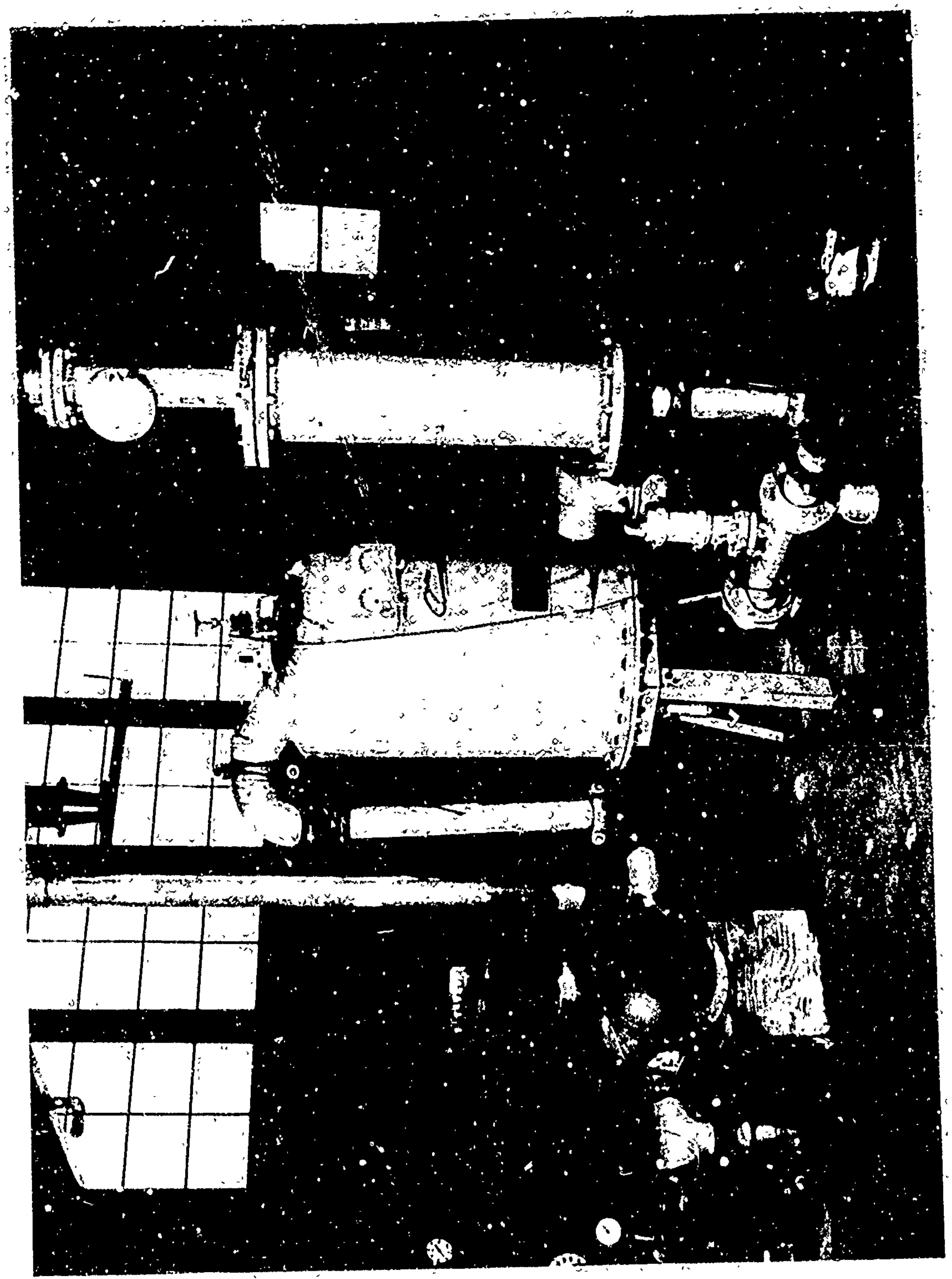

Figure 1. Photograph of the Test Setup

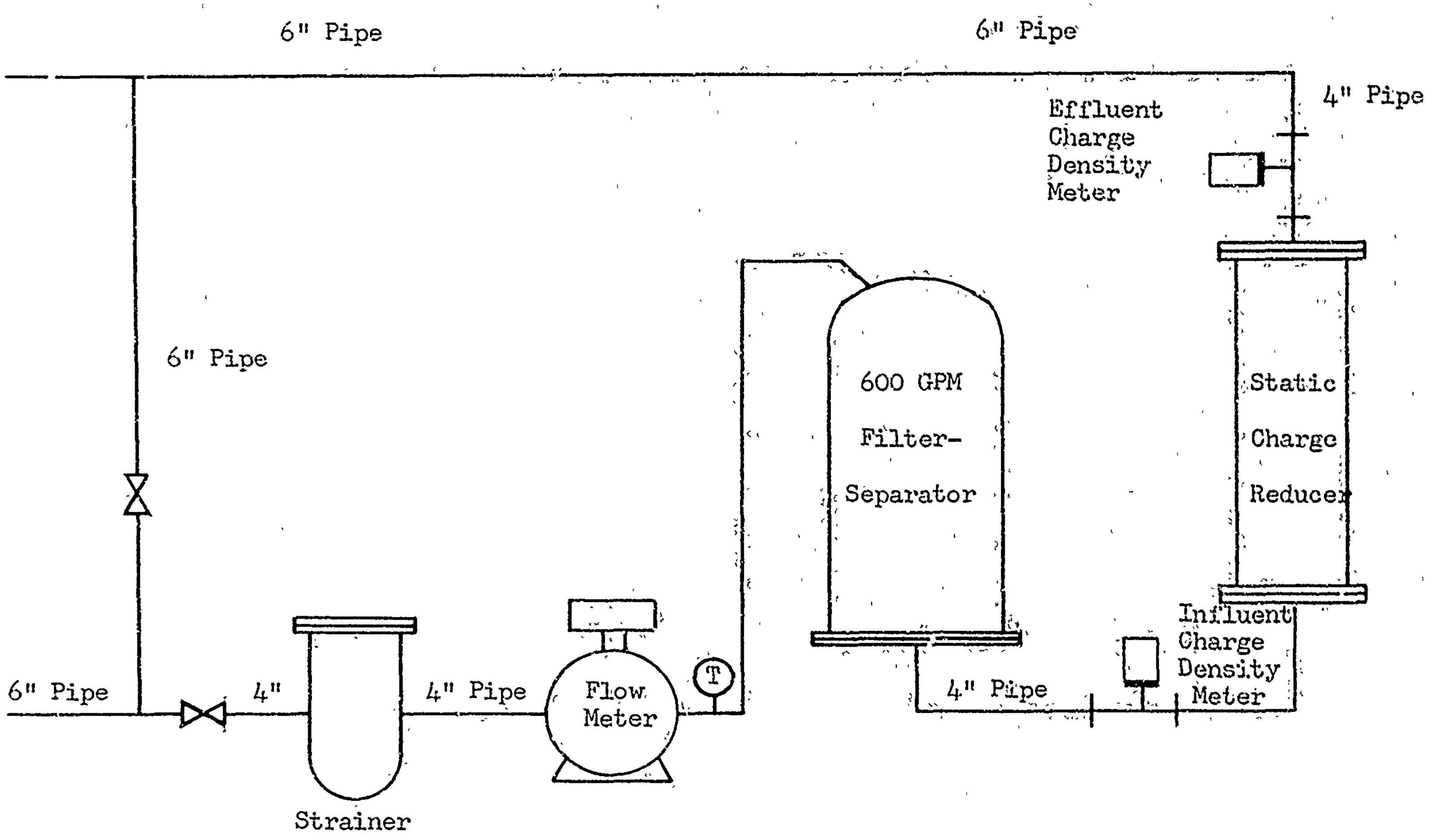

Figure 2. Schematic Flow Diagram of the Test Loop

conversion chart supplied with the static charge density meters. Note that only one drive head assembly and one electrometer were available. These were switched between the influent and effluent static charge meters for each set of readings; thus, there was always about a 60 second lag between the influent and effluent charge density meter readings.

The carbon steel piping between the tank-pump and the test loop is approximately 16 years old. The test loop was flushed with clean fuel prior to use but it had not been operated for several years and was quite rusty and dirty. The use of various fuel additives during the test program apparently loosened much scale and rust as both the basket strainer and the filter-separator plugged during the test.

2. TEST PROCEDURES

Prior to each test the fuel was circulated through the test loop for a 15-minute period to allow temperatures to stabilize and to permit accurate adjustment of the fuel flow rate. Static charge density readings were taken upstream and downstream of the SCR and the fuel temperature measured at 10 to 15 minute intervals. Immediately before each test and approximately 15 minutes after each test the electrical conductivity of the fuel was measured using a Maihak fuel conductivity meter.

The electrical properties of the fuel were varied by the addition of Shell ASA-3 antistatic additive and by corrosion inhibitors Santolene C (Edwin Cooper, Inc.) and AFA-1 (DuPont Corp.). The additives were blended into the fuel as it was circulated and the circulation continued for several hours to ensure the additives were homogeneously dispersed throughout the fuel. Usually the blending was done at least 24 hours prior to each test.

Some test results with the SCR were voided due to problems with the charge density meters. These problems were later traced to excessive water in the fuel shorting out the charge density meters and giving highly inaccurate readings.

3. TEST RESULTS

a. SCR Effectiveness

The charge density of the fuel leaving the Static Charge Reducer was found to be below 30 microcoulombs/cubic meter in all cases, and was less than 20 microcoulombs/cubic meter in all but 2 cases. Charge densities of up to 494 microcoulombs/cubic meter were measured at the inlet to the SCR. When tested with fuels of relatively high conductivities, i.e., 75 to 100 CU, the SCR usually increased the charge density but the charge density was always well below 30 microcoulombs/cubic meter. Table I and Figures 3 and 4 illustrate the measured change in the fuel's charge density before and after the SCR for flow rates of 300 and 600 gpm. Note that these measurements are the mean of 3 or 4 readings taken 10 to 15 minutes apart. The sign of the charge (i.e., positive or negative) was ignored in plotting the data in Figures 3 and 4.

The effect of fuel conductivity on SCR performance was of interest and the charge density of the fuel leaving the SCR appears to increase with increasing fuel conductivity (Figure 5). The dashed-in curve is the

TABLE I

SUMMARY OF STATIC CHARGE REDUCER TEST DATA

Test Number	Average Fuel Conductivity CU at 60°F	Average Charge Density Influent	($\mu C/M^3$) Effluent	Fuel Composition
300 GPM FLOW RATE				
1	0*	-408	0	Neat JP-5 (Batch 24)
4	22	-99	7	JP-5 with 0.2 ppm ASA-3
6	85	18	15	JP-5 with 1 ppm ASA-3
8	77	16	23	JP-5 with 1 ppm ASA-3, 4 lb/Mbbl AFA-1
10	8	-268	0	Neat JP-5 (Batch 25)
14	22	-115	0	JP-5 with 0.2 ppm ASA-3, 4 lb/Mbbl AFA-1
16	30	-100	-8	JP-5 with 1 ppm ASA-3, 4 lb/Mbbl AFA-1
10A	0*	-124	4	Neat JP-5 (Batch 28)
11A	22	-15	6	JP-5 with 0.2 ppm ASA-3
11B	27	-17	-1	JP-5 with 0.2 ppm ASA-3
12A	85	15	10	JP-5 with 1 ppm ASA-3
13A	100	10	10	JP-5 with 1 ppm ASA-3, 4 lb/Mbbl Santolene C
600 GPM				
2	0*	-494	7	Neat JP-5 (Batch 24)
3	22	-150	-8	JP-5 (Batch 24) with 0.2 ppm ASA-3
5	88	-7	18	JP-5 (Batch 24) with 1 ppm ASA-3
7	75	-123	19	JP-5 (Batch 24) with 1 ppm ASA-3 and 4 lb/Mbbl AFA-1
9	8	-431	0	JP-5 (Batch 25)
11	7	-396	-21	JP-5 (Batch 25) with 4 lb/Mbbl AFA-1
12	9	-384	-10	JP-5 (Batch 25) with 4 lb/Mbbl AFA-1
13	24	-262	-6	JP-5 (Batch 25) with 4 lb/Mbbl AFA-1 and 0.2 ppm ASA-3
15	32	-241	-8	JP-5 (Batch 25) with 4 lb/Mbbl AFA-1 and 1 ppm ASA-3
10A	0*	-156	-8	Neat JP-5 (Batch 28)
11A	28	-18	3	JP-5 (Batch 28) with 0.2 ppm ASA-3
11B	27	-27	-1	JP-5 (Batch 28) with 0.2 ppm ASA-3
12A	62	37	15	JP-5 (Batch 28) with 1 ppm ASA-3
13A	95	22	15	JP-5 (Batch 28) with 1 ppm ASA-3 and 4 lb/Mbbl Santolene C

*Fuel cannot have zero conductivity; rather the instrument used is insensitive at conductivities below about 1 conductivity unit and registers zero.

NOTE: Tests 1 through 16 were conducted by Southwest Research Institute. The remainder were conducted in-house by Air Force personnel.

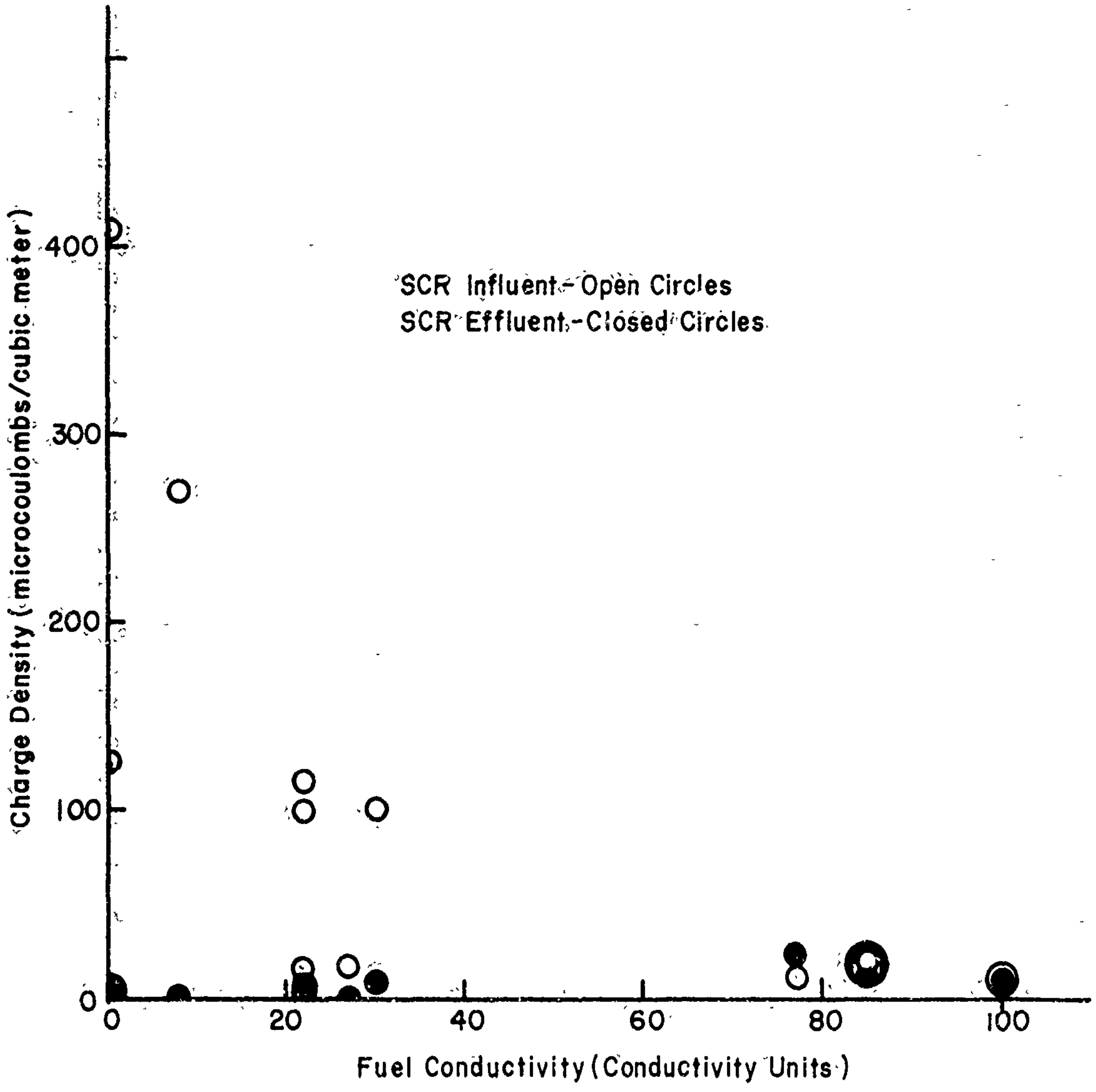

Figure 3. Static Charge Reducer Performance - 300 gpm

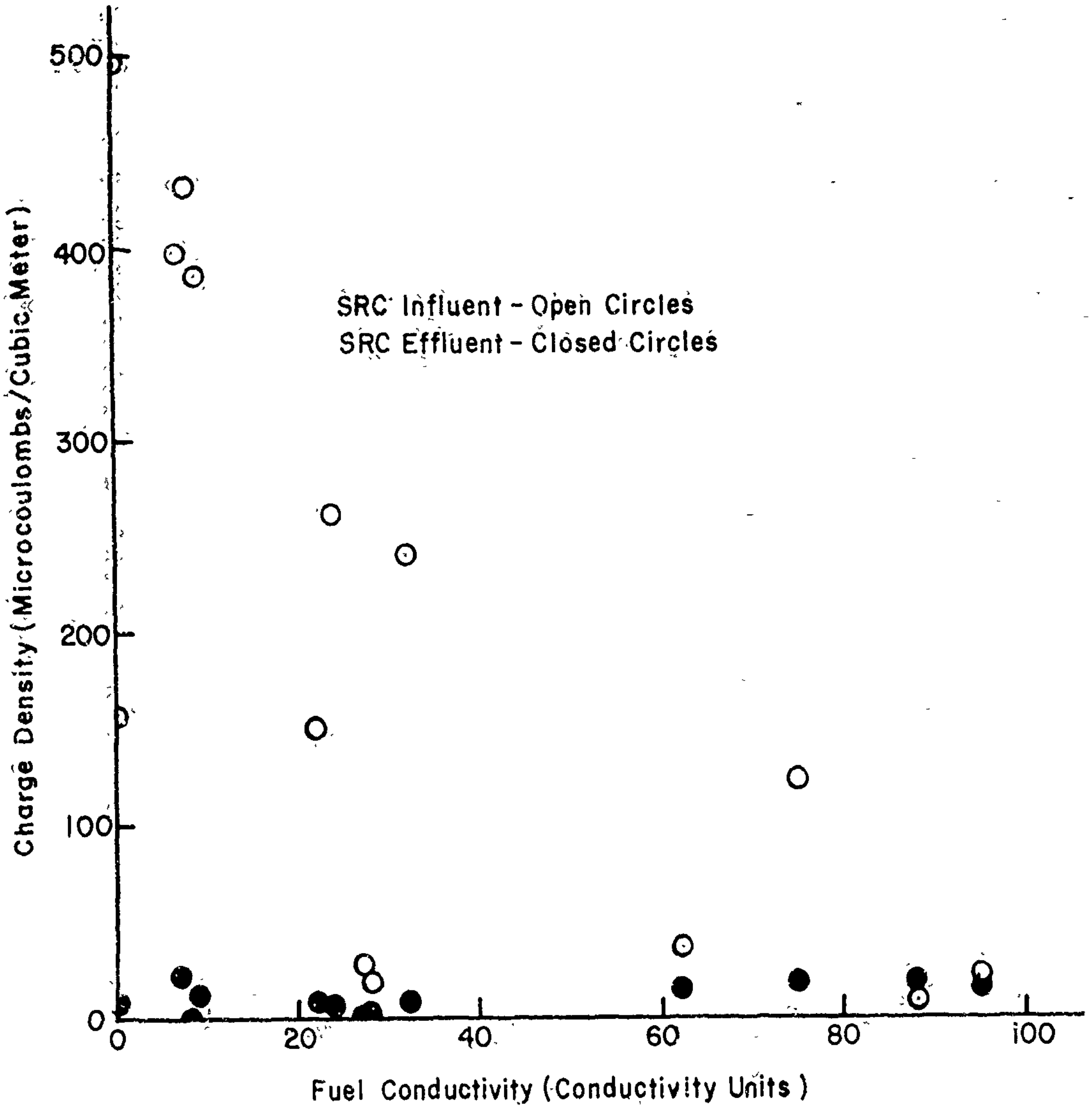

Figure 4. Static Charge Reducer Performance - 600 gpm

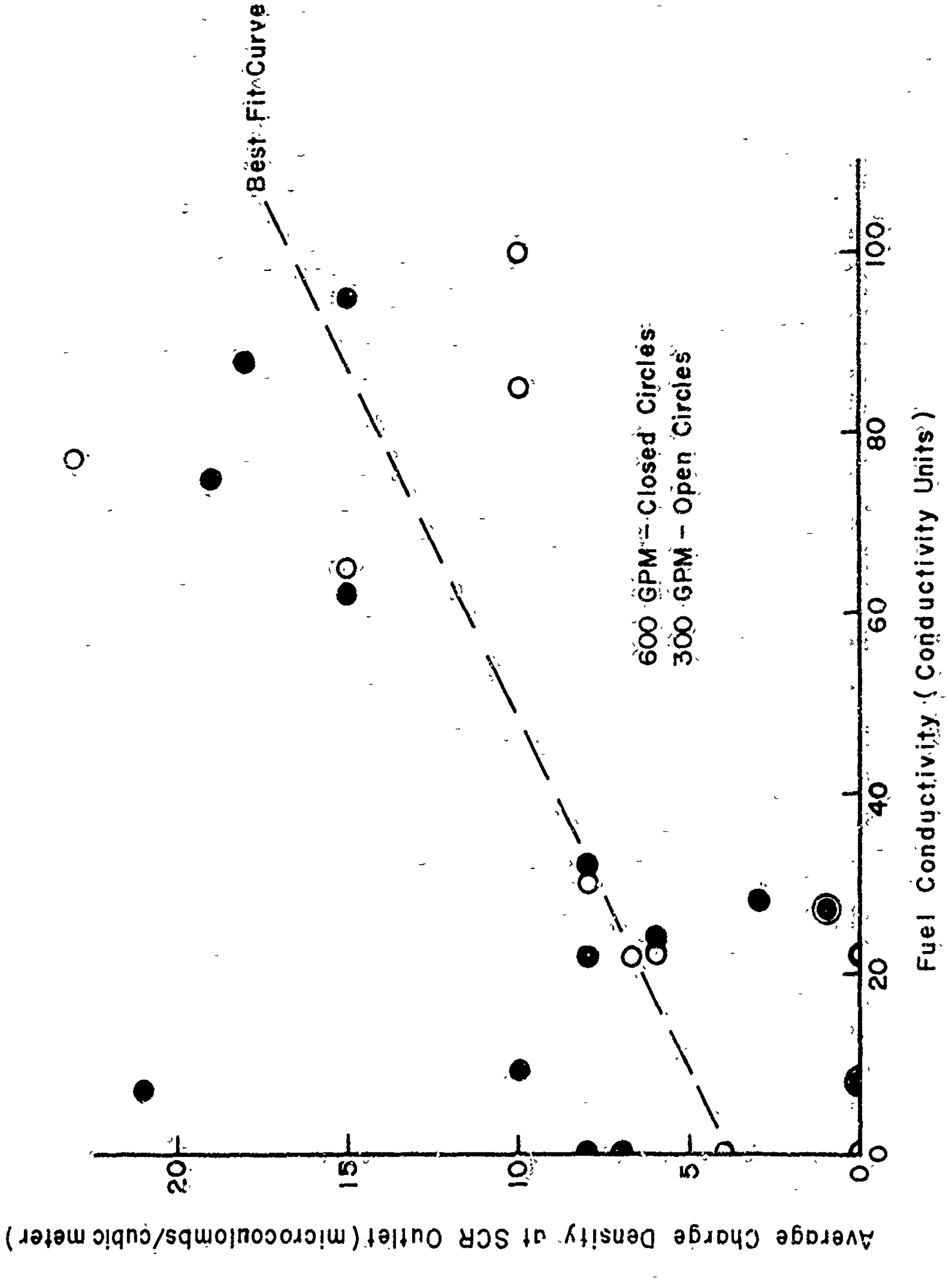

Figure 5: Effect of Fuel Conductivity on Static Charge Reducer Performance

best fit linear curve using the method of least squares and has the equation $y = 3.88 + 0.128\ x$, where y is the charge density and x is the fuel conductivity. This was calculated neglecting the sign of the fuel charge, as the magnitude was of primary interest. The increase in the charge density of the fuel leaving the SCR with increasing fuel conductivity appears to be of no consequence, however, and is believed to be caused by charge generation between the two charge density meters. The turbulence created by the abrupt change in piping diameter from 4 to 6 inches and back to 4 inches (the SCR has a 6-inch I.D.) could possibly account for this charge generation.

The significance of the sign of the charge density is unknown, but as can be observed from Table I, the sign is normally negative except for fuels having a high conductivity.

b. Estimated Results With SCR Inoperative

In an effort to better understand the test results, the charge densities at the filter-separator outlet and at the effluent charge density meter were calculated. The assumptions made included: (1) the SCR had been replaced with an equivalent length of 6-inch pipe, (2) no additional charge generation occurred, and (3) the relaxation rate was directly proportioned to the fuel's static conductivity.

The rate of charge bleed-off (relaxation) was calculated using the equation:

$$\rho = \rho_0 e^{-\frac{t}{\tau}}$$

where ρ_o is the initial charge density, t is the residence time (seconds), and $\tau = 1.91 \times 10^{-11}/\sigma$ (seconds) using a dielectric constant of 2.16 for the JP-5 fuel. ρ is the conductivity in mho/m (1 conductivity unit = 10^{-12} mho/meter) (see Appendix I). The residence times, based on the flow velocities, the length of the piping, and the piping diameter, were estimated to be: 0.45 seconds at 300 gpm and 0.23 seconds at 600 gpm between filter-separator outlet and influent charge density meter, and 1.45 seconds at 300 gpm and 0.73 seconds at 600 gpm between influent charge density meter and effluent charge density meter.

Table II lists the measured charge density at influent and effluent charge density meters (with SCR in use), the estimated charge density at the filter-separator outlet, and the estimated charge density at the SCR effluent with the SCR inoperative.

Examination of Table II and Figures 6 and 7 reveals several interesting factors. It is shown that substantial static charge densities can be generated by fuels with relatively high conductivities. For example, with conductivities in the 20 to 30 CU range, charge densities may exceed 300 microcoulombs/cubic meter at the filter-separator outlet, and most of this charge was still present at the SCR influent charge density meter.

The longer residence times associated with the 300 gpm flow rate results in substantial charge relaxation as opposed to the 600 gpm flow rates for all but the very low fuel conductivities. With fuel

TABLE II

ESTIMATED CHARGE DENSITY vs. MEASURED CHARGE DENSITY

Run No.	Fuel Conductivity (CU)	Charge Density (microcoulombs / cubic meter)			
		F/S Effluent* (Calculated)	SCR Influent (Measured)	SCR Effluent (Measured)	SCR Effluent** (Calculated)
300 gpm					
1	0***	-408	-408	0	-408
4	22	-166	-99	7	-18
6	95	138	18	15	1
8	77	100	16	23	1
10	8	-330	-268	0	-80
14	22	-195	-115	0	-21
16	30	-200	-100	-8	-10
10A	0***	-124	-124	4	-124
11A	22	-25	-15	6	-3
11B	27	-32	-17	-1	-2
12A	85	115	15	10	1
13A	100	111	10	10	1
600 gpm					
2	0***	-496	-496	7	-496
3	22	-195	-150	-8	-63
5	88	-20	-7	18	-1
7	75	-310	-123	19	-7
9	8	-473	-431	0	-315
11	7	-430	-396	-21	-305
12	9	-427	-384	-10	-268
13	24	-350	-262	-6	-102
15	32	-352	-241	-8	-69
10A	0***	-156	-156	-8	-156
11A	28	-25	-18	3	-6
11B	27	-37	-27	-1	-9
12A	62	79	37	15	3
13A	95	69	22	15	1

*Calculated using the measured charge density at the influent charge meter and working backwards to eliminate charge density at filter-separator outlet.

**Calculated by estimating charge reduction between influent and effluent charge meter assuming that the SCR was replaced by a pipe of equivalent diameter and length.

***Fuel cannot have zero conductivity ; the instrument used is insensitive below 1 Conductivity Unit and registers zero.

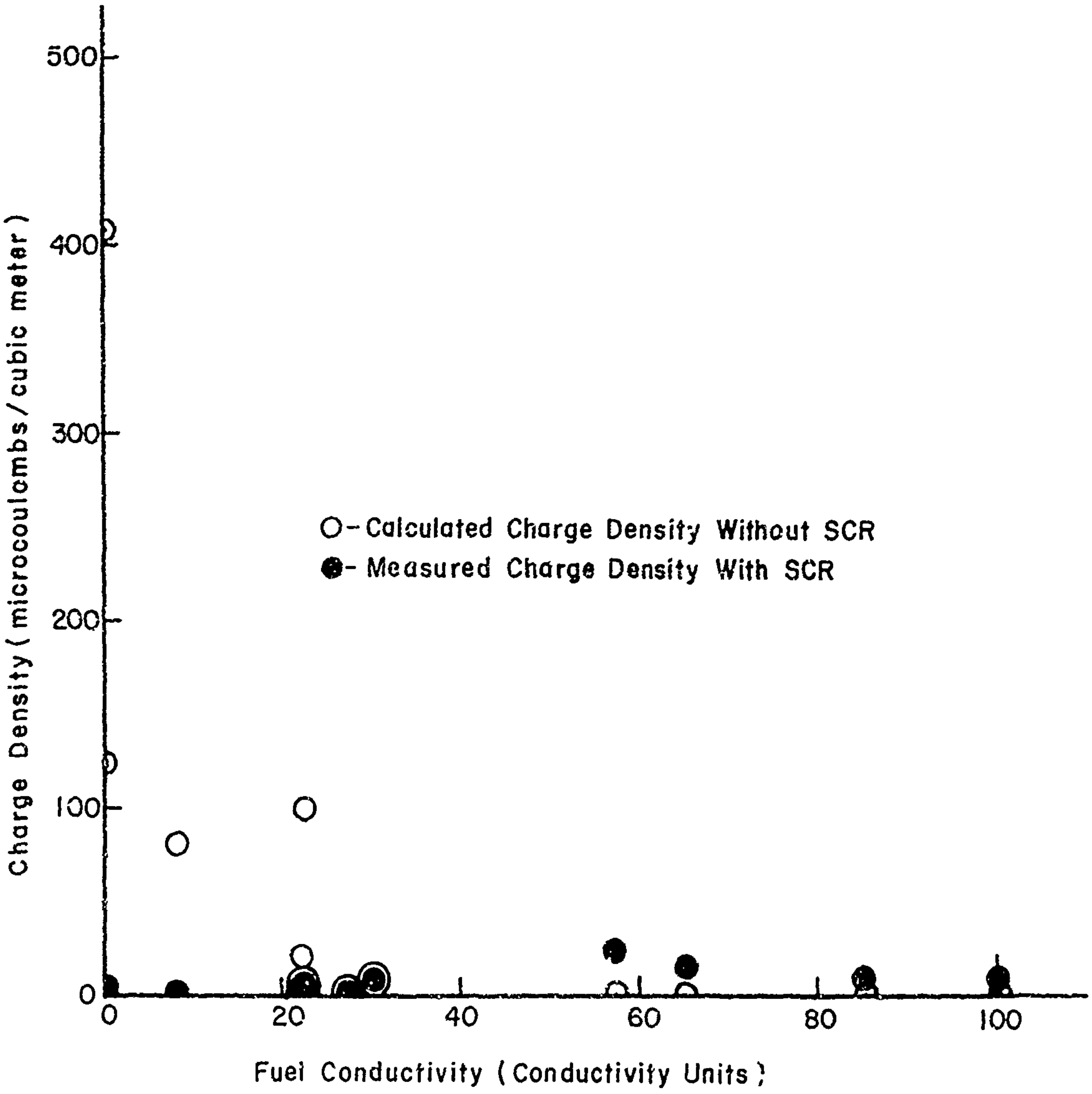

Figure 6. Estimated Charge Density Versus Measured Charge Density at Static Charge Reducer Effluent - 300 gpm

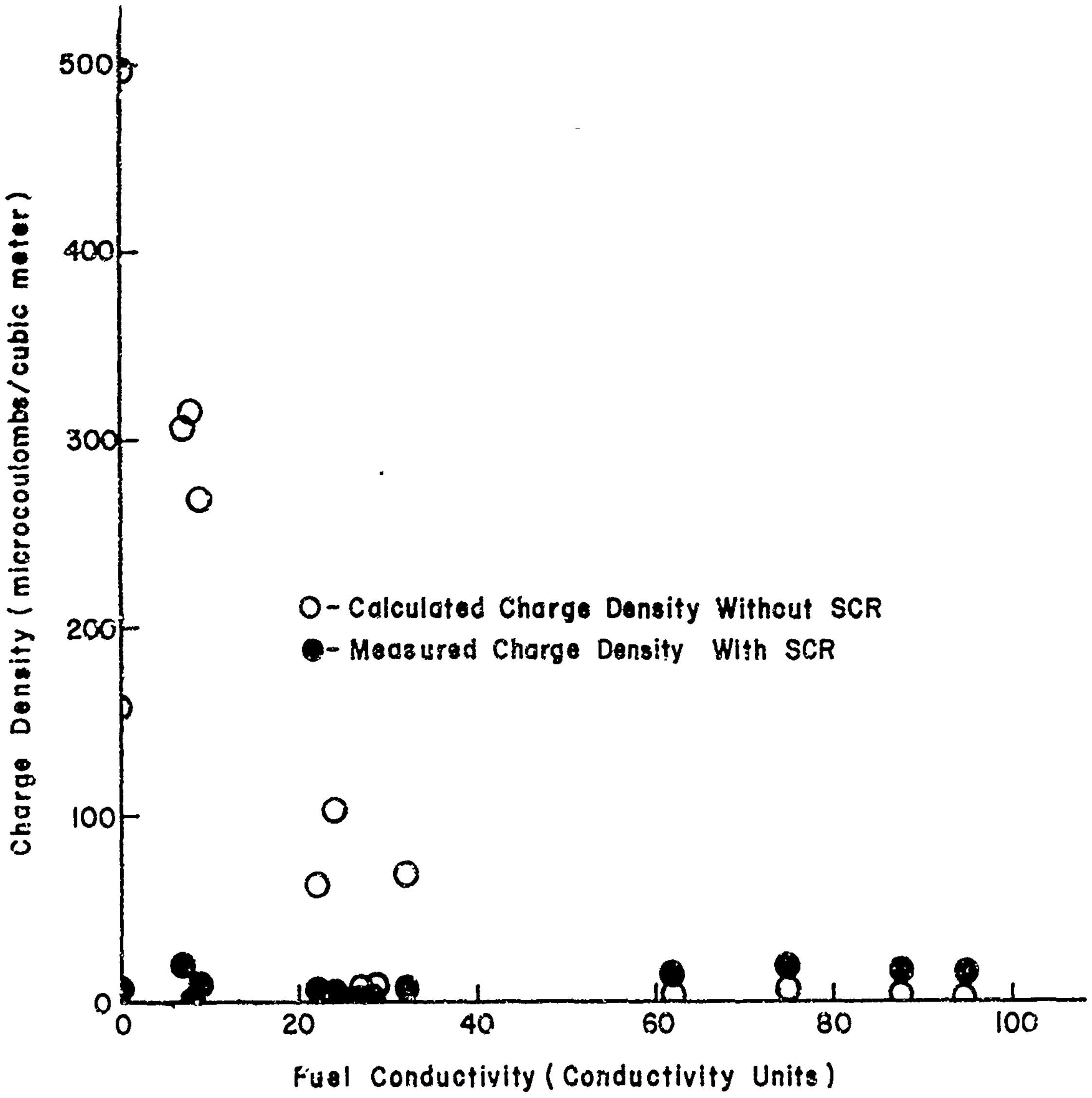

Figure 7. Estimated Charge Density Versus Measured Charge Density at Static Charge Reducer Effluent - 600 gpm

conductivities below about 10 CU it is obvious that several seconds of relaxation time would be required to reduce the charge density to below 30 microcoulombs/cubic meter.

With conductivities in the 75 to 100 CU range substantial charge densities may still be generated by the filter-separator but only a short residence time equivalent to a few feet of travel is required for the fuel to relax to a safe charge density level.

Note that for fuel conductivities below 10 CU the Maihak conductivity meter is relatively insensitive and a 0 CU reading is somewhat greater than 0. The calculated charge density values would not be greatly different, for example, if the conductivity was 1 or 2 CU rather than 0 CU for the residence times involved.

Comparison of the measured charge densities with the calculated charge densities at the SCR effluent (assuming that the SCR was replaced by an equivalent length of pipe) shows that the SCR is highly effective with fuels having conductivities below about 40 CU. (See Figures 6 and 7). However, for conductivities of about 60 and above the measured charge density is higher than the calculated charge density. As discussed above, this is believed to be caused by additional charge generation downstream of the influent charge meter and is of no significance.

c. Effectiveness of ASA-3 in Eliminating Charge Hazards

The data presented in Table II and Figures 6 and 7 illustrates the effectiveness of increasing the fuel conductivity to reduce electrostatic hazards. With conductivities of 85 to 100 CU only a few feet of pipe are necessary for the charge to relax to safe values, i.e., to well below 30 microcoulombs/cubic meter.

d. Effect of Fuel Additives on Fuel Conductivity

Table III and Figures 8, 9, and 10 summarize the measured fuel conductivities (corrected to 60°F) with and without fuel additives. Two primary observations are made from this data.

The first observation is that the two corrosion inhibitors, Santolene C and AFA-1, have no apparent effect on the conductivity of neat JP-5. However, when the fuel contains ASA-3 antistatic additive, the addition of AFA-1 tends to decrease the fuel's conductivity while the addition of Santolene C tends to increase the fuel's conductivity (See Figures 8, 9, and 10). This is in agreement with the results reported by Jones and French (Reference 4).

The second observation is that the ASA-3 did not increase the fuel's conductivity as much as anticipated. Shell Oil states that, usually, 0.75 ppm of ASA-3 is adequate to raise the conductivity of a typical kerosene fuel of 1 to 5 CU to between 150 and 200 CU (Reference 3). Jones and French reported conductivities ranging from 255 to 595 CU after the addition of 1.0 ppm ASA-3 to JP-4 fuel (Reference 4). Figure 10 shows the maximum conductivity obtained with 1.0 ppm ASA-3 added to JP-5 was only 123 CU with similar runs below 100 CU.

TABLE III

EFFECT OF FUEL ADDITIVES ON FUEL CONDUCTIVITY

Run Numbers	Mean Conductivity Corrected to 60°F (Conductivity Units)	Fuel Additives and Amount
1, 2	0	None - Fuel Batch 24
3, 4	22	0.2 ppm ASA-3*
5, 6	86	1.0 ppm ASA-3
7, 8	76	1.0 ppm ASA-3 and AFA-1**
9, 10	8	None - Fuel Batch 25
11, 12	8	4 lb / Mbbl AFA-1
13, 14	23	0.2 ppm ASA-3 and AFA-1
15, 16	31	1.0 ppm ASA-3 and AFA-1
3A	11	None - Fuel Batch 26
4A	11	Santolene C
5A	46	0.2 ppm ASA-3 and Santolene C***
6A	123	1.0 ppm ASA-3 and Santolene C
7A	97	Same as 6A - Measured 3 days later
8A	94	Same as 6A - Measured 8 days later
9A	77	Same as 6A - Measured 21 days later
10A	0	None - Fuel Batch 28
11A	25	0.2 ppm ASA-3
11B	27	Same as 11A - 1 day later
12 A	74	1.0 ppm ASA-3
13A	98	1.0 ppm ASA-3 and Santolene C

* ASA-3 - Antistatic additive manufactured by Shell Oil Company.

** AFA-1 - Corrosion inhibitor additive manufactured by DuPont Corp.

*** Santolene C - Corrosion Inhibitor additive manufactured by Monsanto Corp.

Note: Both AFA-1 and Santolene C were used at concentration of 4 lb of additive per 1000 Bbls of fuel.

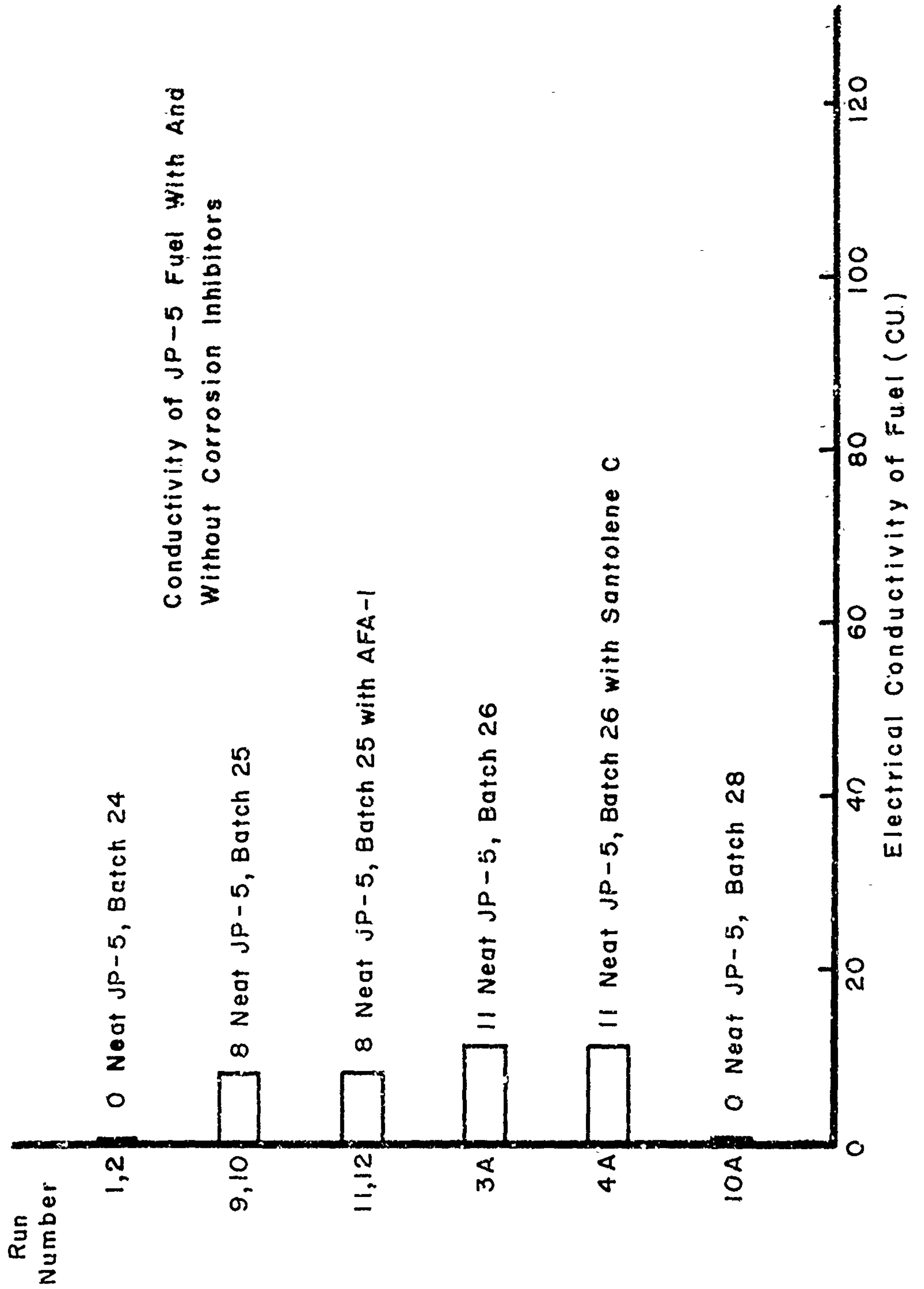

Figure 8. Conductivity of JP-5 Fuel With and Without Corrosion Inhibitors

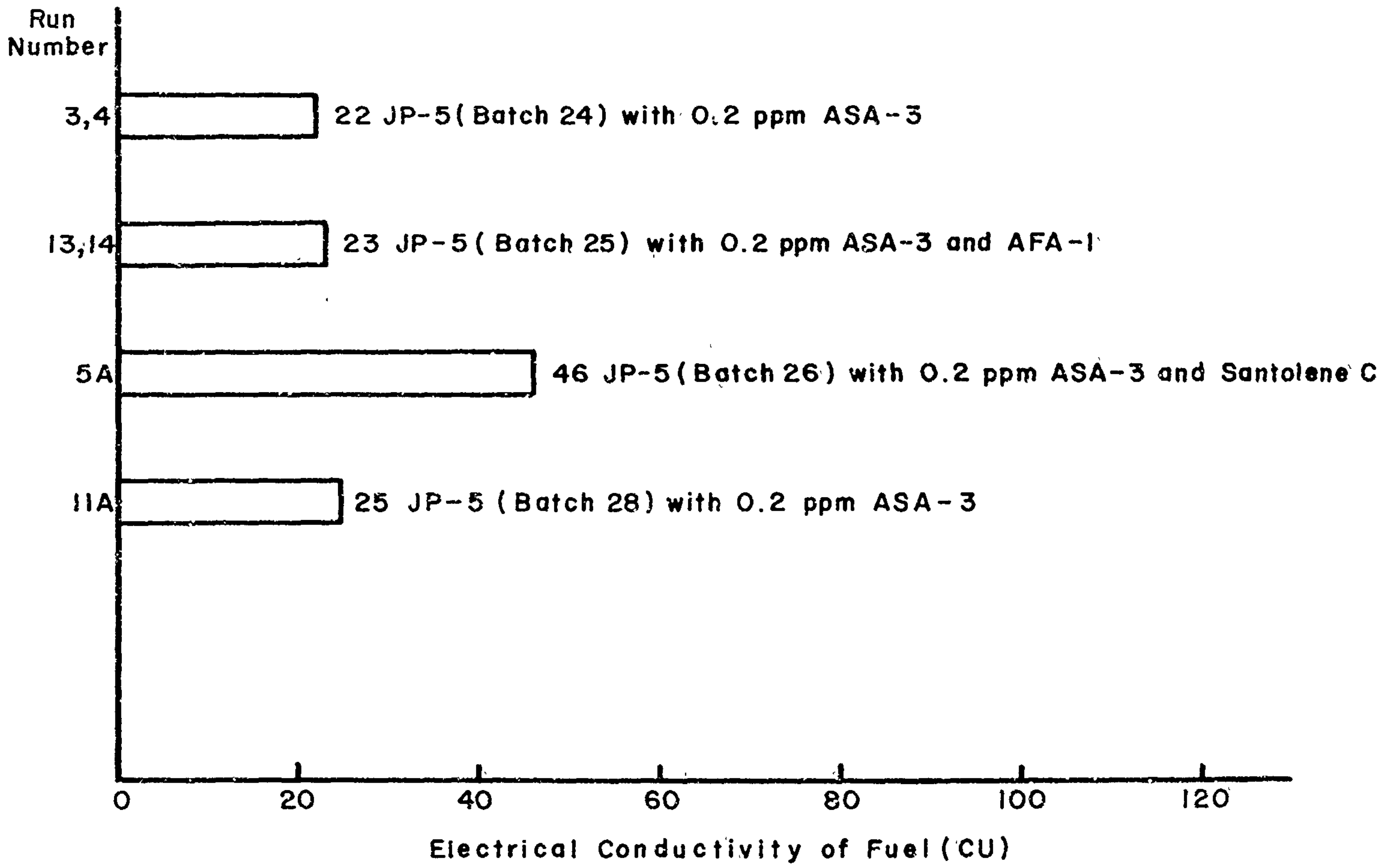

Figure 9. Conductivity of JP-5 Fuel Containing 0.2 ppm ASA-3

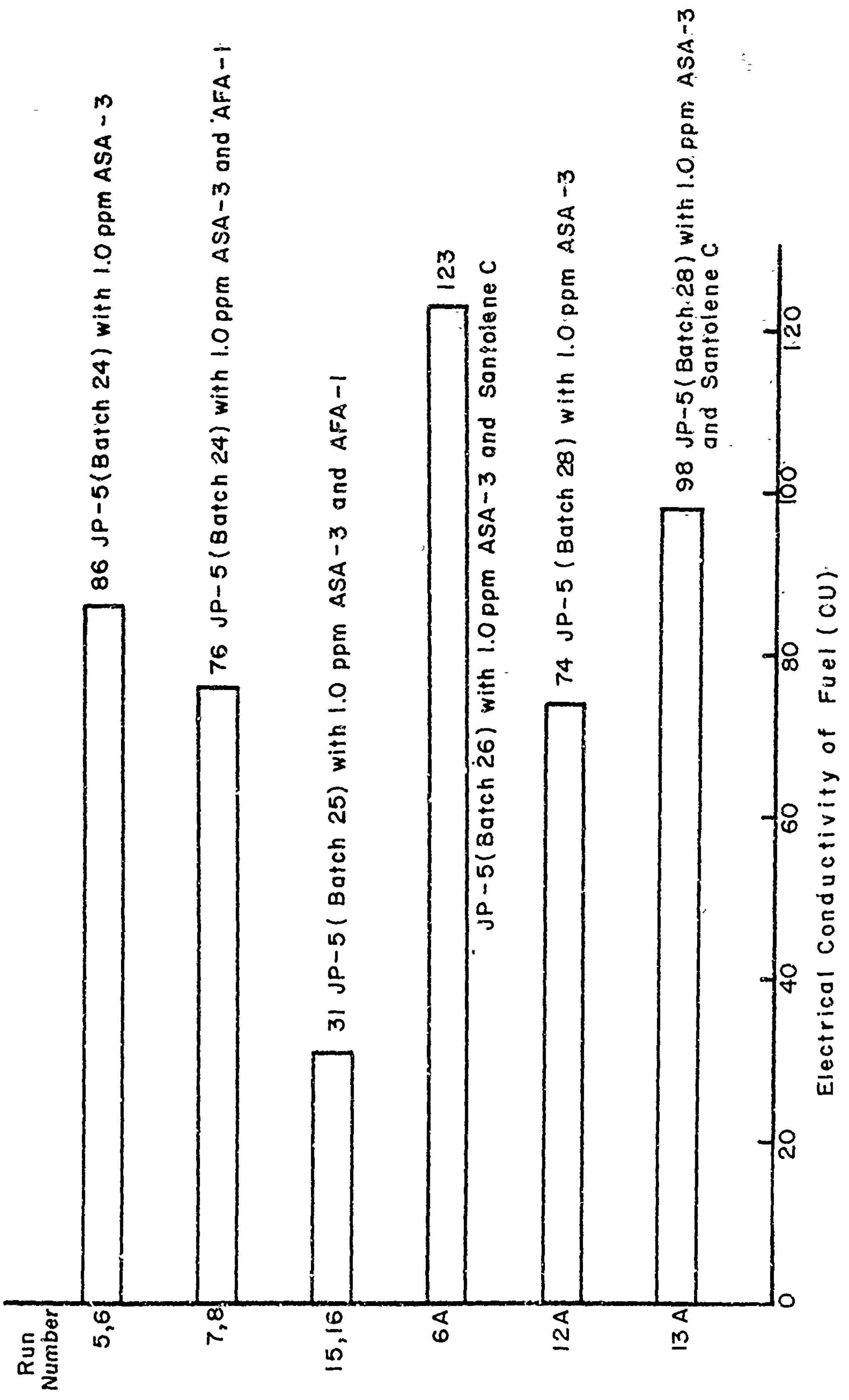

Figure 10. Conductivity of JP-5 Fuel Containing 1.0 ppm ASA-3

The cause of this small increase in fuel conductivity with the addition of 1.0 ppm ASA-3 is believed to be the adsorption of part of the ASA-3 onto the pipe and tank walls and onto the many rust and scale particles in the test loop. Jones and French (Reference 4) reported substantial decreases in fuel conductivity as the fuel was transported through different systems, and this was attributed to the adsorption of the ASA-3 onto tank and pipeline walls. With the considerable quantities of rust and scale present (sufficient to plug both the strainer and filter-separator during the test series) and the small quantities of fuel and additive used (10,000 gallons of fuel and 0.01 gallon of ASA-3), it appears likely that significant quantities of ASA-3 were lost through adsorption. The continual decrease in the fuel conductivity for runs 6A through 9A reinforces the belief that part of the ASA-3 was lost by adsorption.

SECTION IV

CONCLUSIONS

The Static Charge Reducer was found to be an effective means for reducing the static charge of a flowing fuel to below 30 microcoulombs/cubic meter at the two flow rates measured (300 and 600 gpm). However, prior to adoption of the SCR by the Air Force, additional data is needed to determine the possible magnitude of charge generation downstream of the SCR.

It is concluded that corrosion inhibitors such as AFA-1 and Santolene C will significantly affect the electrical conductivity of a fuel that contains Shell Oil Company's ASA-3 antistatic additive. By themselves the corrosion inhibitors appear to have no affect on the fuel's electrical conductivity.

It is concluded that a fuel with an electrical conductivity of 100 CU or more would not constitute a static charge hazard due to the rapid relaxation of any charge in the fuel.

SECTION V

RECOMMENDATIONS

It is recommended that an investigation be conducted to better define the magnitude of charge generation and accumulation for kerosene and JP-4 type fuels for various servicing operations. Of special interest is the top-loading of tank trucks and aircraft fuel tanks where splashing of the fuel occurs as it free falls from the loading nozzle to the fuel level. The effects of flow velocity, tank configuration and size, degree of splashing and turbulence, and fuel properties should be determined so that definite guidelines for top loading can be established. This information is also needed to aid in the selection of static hazards preventive techniques, i.e., Static Charge Reducer, antistatic additive, relaxation chambers, or low flow velocities.

APPENDIX I

CALCULATION OF RELAXATION TIMES

In a homogeneous medium the continuity equation can be written,

$$\frac{\partial \rho}{\partial t} + \frac{\sigma \rho}{\epsilon} = 0$$

which, when solved, is

$$\rho = \rho_0 e^{-\frac{\sigma}{\epsilon} t} = \rho_0 e^{-\frac{t}{\tau}}$$

where ρ is the charge density (coulombs/cubic meter), ρ_0 is the charge density at time = 0 (seconds), σ is the conductivity of the fuel (mho/meter), and ϵ is the permittivity of the medium (farad/meter). τ is called the relaxation time, where $\tau = \frac{\epsilon}{\sigma}$, and is the time required for the charge to decay to 1/e of its original value. The permittivity ϵ can be calculated ($\epsilon = K_\epsilon \epsilon_0$) from the dielectric constant (K_ϵ) and the permittivity for free space ($\epsilon_0 = 8.854 \times 10^{-12}$ farad/meter).

Typical values of conductivities and dielectric constants for various hydrocarbon products are presented in the Table IV.

The relaxation times for various conductivities of a petroleum product with a dielectric constant of 2.0 are given in Table V.

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TABLE IV

CONDUCTIVITIES AND DIELECTRIC CONSTANTS FOR PETROLEUM PRODUCTS

Product	Conductivity (mho/meter)	Dielectric Const. (dimensionless)
Benzene	7.6×10^{-6} to 1×10^{-16}	2.3
Heptane	less than 1×10^{-11}	2.0
Hexane	1×10^{-18}	1.9
Toluene	less than 1×10^{-12}	2.4
Xylene	less than 1×10^{-13}	2.4
Gasolene, Naphtha, Aviation Turbine Fuels, Kerosenes	10^{-13} to 10^{-11}	
Very Volatile, Straight-Run Fractions	down to 10^{-14}	
Aviation Gasolene at 60°F		1.95
JP-4 at 60°F		2.07
JP-5 at 60°F		2.16

TABLE V

RELAXATION TIMES VERSUS CONDUCTIVITIES

Conductivity		Relaxation Time
(Conductivity Units)*	(Mho / Meter)	
0.001	10^{-15}	5 hours
0.01	10^{-14}	30 minutes
0.1	10^{-13}	3 minutes
1.0	10^{-12}	18 seconds
10.0	10^{-11}	1.8 seconds
100.0	10^{-10}	0.18 seconds

* A conductivity unit is equal to 10^{-12} mho/meter

APPENDIX II

TEST EQUIPMENT AND ACCESSORIES

Static Charge Reducer, A.O. Smith Model SCN-6, Serial Number 313-AM214

Static Charge Density Meters, A.O. Smith

- Head Assembly, Model SH-1, Serial Numbers JK-260 and JK-261
- Head Drive Assembly, Model SD-1, Serial Number JC-27
- Charge Density Meter Housing, Model H-44 (2 each)
- Keithley Electrometer, Model 600B, Serial Number 59596

Liquid Separator Filter, Fram Corp., Warner Lewis Division, Model FCS-1259-12E2, Serial Number 17596

Fuel Flow Meter, Brodie Company, Type B-820-BC, Serial Number 155036

Strainer Assembly, Brodie Company, Model D-6, Size 6

Temperature Probe, Model 410 Remote Probe with a Yellow Springs Instrument Company Tele-Thermometer Model 46TUC, Serial Number 1087

Fuel Conductivity Meter, Maihak, Serial Number 64092

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13. ABSTRACT

This report describes the results of an experimental evaluation of the Static Charge Reducer, invented by the American Oil Company and marketed by the A.O. Smith Company. The Static Charge Reducer is a device which automatically neutralizes an electrically charged fuel as the fuel flows through it. The tests conducted confirmed the claims that the Static Charge Reducer would reduce the charge density of a flowing hydrocarbon fuel to below 30 microcoulombs per cubic meter. The tests also indicate that two corrosion inhibitor fuel additives significantly affect the electrical conductivity of fuel containing the Shell Oil Company's ASA-3 antistatic additive.

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