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THE EFFECT OF AVIATION FUELS CONTAINING LOW AMOUNTS OF STATIC DISSIPATER ADDITIVE ON ELECTROSTATIC CHARGE GENERATION

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(CRC Project No. CA-36-61)

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Prepared by the

CRC-Aviation Electrical Discharges Liaison Group

MAY 1994

Aviation Fuel, Lubricant, and Equipment Research Committee

of the

Coordinating Research Council, Inc.

I. Acknowledgments

An effort such as the one mounted in this study requires the dedication and support from many people and sponsors. Not only did the Ad Hoc Panel on Commingled Fuels provide a dedicated effort but also a number of other people provided invaluable input in both time and money. The Ad Hoc Panel wishes to thank the following companies for their financial support and/or their permitting key people to participate in the program:

- Exxon Research & Engineering, Federal Express, United Airlines, Shell Research & Development, Shell Research Centre, Emcee Electronics, Chevron Research, E.I. DuPont de Nemours & Co., McDonnell Douglas, Boeing Co., Colonial Pipeline, Gammon Technical, Naval Research Laboratory

In addition, we would like to thank AMR Combs in Denver for their help in constructing the test equipment, and their dedication to making the tests run smoothly.

Finally, we would like to acknowledge the support and encouragement from CRC, especially Al Zengel's help in obtaining funding and providing encouragement throughout the effort.

II. CRC Ad Hoc Panel on Commingled Fuels

A. Panel Membership

The CRC Ad Hoc Panel on Commingled Fuels was authorized by the CRC Electrical Discharges Liason Group on April 16, 1989. The Members of this Ad Hoc Panel are:

Bill Dukek (Leader), Howard Gammon, Cy Henry, Vic Hughes, Joe Leonard, Bob Mason, Ed Matulevicius, Jack Muzatko, Frank O'Neill, Tom Peacock, John Schmidt, Bob Wayman, and Gregg Webster

The Panel decided to conduct field surveys and full-scale simulated aircraft fueling tests. In developing these programs, the Panel sought to minimize costs by soliciting member cooperation to the maximum extent possible. The degree of cooperation by members and their companies in carrying out the highly successful program was unprecedented.

In addition to the CRC Ad Hoc Panel Membership many others contributed their time and talent to specific tasks. Specific tasks were:

1. Mini Static Tests

- Work to select the reference filter for the Mini Static field survey was performed at Exxon Research & Engineering by Ed Matulevicius and Larry Stevens.
- The field survey was taken at three different locations:
  + Colonial Pipeline (Bob Mason) with measurements at Exxon Research & Engineering (Larry Stevens)
  + O'Hare International Airport (Frank O'Neil) with measurements at Shell (Gregg Webster)
  + Los Angeles International Airport (Frank O'Neil) with measurements at Chevron Research (Jack Muzatko)
- The laboratory program was undertaken at E. I. DuPont de Nemours & Co. by Cy Henry

2. Stapleton International Airport Full Scale Tests

The full scale field tests were performed at the United Airlines Test Facility at Stapleton International Airport. The test participants at Stapleton International Airport were:

Vic Hughes, Ed Matulevicius (Leader), Frank O'Neil (Co-Leader), Tom Peacock, Jim Quinnette, Larry Stevens, Bob Wayman, and Gregg Webster

In addition, H.L. Walmsley of Shell Thornton provided significant technical input in interpreting the data.

3. Field Survey of Equipment

The field survey to determine residence typically encountered in the field was undertaken by Jack Muzatko of Chevron Research. Cy Henry of E. I. Dupont de Nemours & Co. helped develop the mailing list of various users of aircraft fueling equipment.

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1. Executive Summary

1.1. Purpose & Scope

The purpose of the CRC program was to determine whether commingled fuels containing low levels of static dissipater additive pose any additional electrostatic hazard over unadditized fuel. Specifically, the program conducted the necessary experiments to determine electrostatic effects of commingled fuels containing static dissipater additive with a conductivity less than 50 picoSiemens/meter (pS/m). It was also a goal of this program to survey existing systems and make an assessment whether future fueling systems could cause additional electrostatic hazards during the fueling operation. In order to achieve these goals, it was the scope of this program:

- To assess the range of conductivities present in Jet A at various locations.
- To assess the charging tendency of Jet A presently being used in the United States.
- To develop large scale data regarding the charging tendency of Jet A when it contains:
  - ASA-3 at conductivities less than 50 pS/m.
  - Stadis 450 at conductivities less than 50 pS/m
  - ASA-3 which has been clay treated from a conductivity of greater than 100 pS/m to less than 50 pS/m
  - Stadis 450 which has been clay treated from a conductivity of greater than 100 pS/m to less than 50 pS/m
- To perform laboratory scale tests to further study the charging tendency of ASA-3 and Stadis 450 in both commingled Jet A and clay treated Jet A as needed to verify the results of the other tests.
- To develop a database of the residence times typical of existing fueling systems.

1.2. Background

Static charge generation during fueling of an aircraft which can result in electrical discharges was observed as early as 40 years ago. Since then there have been several significant ignitions during ground fuel transfer or aircraft operations involving foam-filled tanks. Most ground vehicle ignitions involved filling tank trucks which previously contained more volatile fuels with kerosene, a practice known as "switch loading". Large commercial aircraft have had only three significant incidents, none of which resulted in injury. Two of these incidents involved the same airport location and were connected with the introduction of a high charging filter paper in the filtration and coalescence equipment. The paper was immediately removed from service. The other occurrence, in an early type turboprop aircraft, was attributed to electrostatic discharge during refueling when no other cause for the ignition could be found. In addition, there were a number of electrostatic incidents involving military aircraft that were being fueled with JP-4, particularly in tanks that were filled with reticulated foam.

Static charges normally are generated by fuel flowing through micro porous devices such as micro-filters, filter coalescer elements, or absorbing media elements in common use today. Jet fuel is low in conductivity and can retain any static charge generated for significant lengths of time, thereby promoting the possibility of an electrical discharge. Two additives, ASA-3 and Stadis 450, were approved for use in aviation fuel to increase the conductivity and, hence, to dissipate the static charge more quickly. A conductivity of at least 50 pS/m was required in most specifications permitting these additives. In addition to static dissipater additive, other measures were adopted to reduce the charging tendency of ground fuel systems.

Sufficient residence time in the piping and hoses after the filter vessel, and elimination of high charging paper separators have helped limit the total charge which enters the aircraft fuel tanks. No specific limit on the charge density entering aircraft fuel tanks has been established. However, a survey of the charge densities being delivered to aircraft at 6 commercial airports in 1970 reported charge densities within a range of -398 μCoulomb/m^3 to 2000 μCoulomb/m^3. The approach to the design of ground equipment should be to limit the charge density of the fuel to the level established as acceptable by the historical record. Since 1970, no accidents to commercial aircraft have been attributed to static electricity charges generated in the refueling equipment, indicating that the charge densities are below the hazardous level in current ground fueling equipment and practice.

Several companies add static dissipater additive before loading trucks with jet fuel. This is an optional company policy intended to enhance protection for personnel and equipment at the loading rack when filling fuel trucks, especially when switch loading between gasoline and jet fuels is permitted. This has produced instances where delivery and commingling of additized with non-additized fuel has resulted in conductivities below 50 pS/m in the storage tank.

The issue whether these commingled fuels present an increased hazard over the non-additized fuels with which the industry has had a significant safe fueling history was considered at *ASTM* but not resolved. As a result *ASTM* asked the *Coordinating Research Council* (*CRC*) to undertake the necessary work to determine whether commingled fuels could be used safely. The *ASTM* request to the *CRC* included the following questions:

- Do fuels containing static dissipater additive with a conductivity of less than 50 pS/m present an electrostatic risk in US. handling systems?
- If fuels are clay filtered to a conductivity less than 10 pS/m can they be considered additive free?
- Do likely changes in ground fueling systems for aircraft lead to any change in the assessment that static dissipater additives are not needed to protect facilities during aircraft fueling?

1.3. Program

The program developed to address the *ASTM* questions consisted of a number of phases which looked at the effect of static charge generation of fuel containing low levels of static dissipater additive flowing through filter/coalescers or absorbing media monitors. The key elements of the program were:

- *To measure the charge generating tendency of fuels presently found in non-additized systems.* The charge generating tendency of randomly selected fuels at three sites were measured using the filter paper from a CA-22[1] filter/coalescer element.
- *To determine the effect of commingling and/or clay treating fuels containing ASA-3 or Stadis 450.* These experiments were performed in the laboratory using the Mini Stati· ·-st procedure as the charge generation measurement. The CA-22 filter paper anc ...e absorbing media material from a CDF-H[2] monitor were used as reference filters.
- *To determine the effect of commingling and clay treated fuels with static dissipater additive in a full scale test.* An 8000 gal horizontal vessel was used as a receiving tank to measure the charge generated as a function of flow rate, static dissipater additive type, and fuels which were commingled or clay treated to conductivity ranges of 10-30 pS/m.
- *To determine the residence time typically found in ground fueling equipment during fueling operations.* The was achieved by surveying a wide variety of users. Residence times for hydrant servicers and refuelers with filter/coalescers and for hydrant servicers with monitors were obtained.

1.3.1 Mini Static Program

A field program to examine the range of conductivity present in unadditized fuels found in the field was undertaken. Tests, using the Mini Static procedure, were performed on a number of samples from three sites. The charge density was measured as the fuel passed through a filter paper from a Facet International Model CA-22 coalescer element. This paper was chosen as a reference because it provided a relatively high, consistent charge density in the reference fuel (clay treated Jet A). It should be noted that while this paper was relatively high charging, material from absorbing media and filter/coalescers were on the same order of magnitude.

This paper provided a reference material to look at relative charge densities of fuels from various sites. It does not imply that the charge density would be high for the CA-22 element. The actual charge density through an element is a sum of various factors, viz., the material, the configuration, and the manufacturing process as well as the fuel itself. The actual charging tendency of a given element would require a much more extensive program which was beyond the scope of this effort.

The charge density measurements on fuels from the three sites indicated:

- *The charge density could vary substantially.* The charge density seemed to increase in variability as the conductivity increased. The absolute variability was higher in the multi-product pipeline than for samples in dedicated pipelines.
- *The charge density and sign of the charge is dependent on the source of the fuel.*
- *A significant number of fuel samples (~ 16% of the samples collected) had an intermediate conductivity, i.e., 10-50 pS/m.* There is no indication that these have electrical discharge problems in the present ground fueling system. This also agrees well

[1]Consists of section of pleated paper from Facet International CA-22 Filter Coalescer element
[2]Consists of section of the first layer of Velcon Filters 2" diameter absorbing media element Model Series CDF-H

with previous work[3] where approximately 10% of samples had an intermediate conductivity.

In addition to the field samples, a laboratory program was undertaken to examine the effect of several variables on charging tendency. The data indicated:

- *The charge generating tendency of Stadis 450 is proportional to conductivity.*
- *Clay treated fuels containing Stadis 450 behave similarly to commingled fuels containing Stadis 450.*
- *For ASA-3, the charging tendency for both clay treated fuel and commingled fuel shows a higher tendency than Stadis 450 for the same intermediate conductivity.*
- *Clay treated ASA-3 containing fuel shows a charging tendency higher than would be realized by commingling fuel to the same conductivity level.*

Based on this work, it was concluded that there are no effects which could make the charge generating tendency of a fuel/filter combination worse than would be predicted from extrapolating the results from a fully additized fuel to a fuel without additives. The increase in charge density for reference fuel additized with static dissipater additive is 12 to 45 % of the charge density variation in the fuel samples tested from the field. The effect of commingling additized fuel samples with some of the higher charging fuel samples was not measured. The conductivity in most cases would be sufficient to relax the charge to the levels found in unadditized fuel. When ASA-3 is clay treated, significantly higher charge densities could result than one would expect from conductivity alone. The level of charge density could be higher than for an commingled fuel of the same conductivity entering an aircraft.

Other tests indicated that residual static dissipater additive which may have adsorbed on a filter when additized fuel passed through it does not pose an additional hazard by desorbing into non-additized fuel.

1.3.2 Full Scale tests

A full scale program was initiated at Stapleton International Airport to examine the charge generated for commingled and clay treated fuels containing Stadis 450 or ASA-3. Fifteen tests were run covering the range of fuel conditions which could result during an operation where commingling is possible. The lower flow rate tested represented two cases. One case was when the velocity at which the surface in the tanks rises, known as the rise velocity, of fuel in the tank was similar to that found in an aircraft wing tank. The other flow rate was significantly higher in rise velocity but similar in flow rate to some high fill-rate operations.

The data indicated that the charge density into the tank decreases as the conductivity increased. This is expected as there was sufficient residence time between the charge generator and measurement point at the tank to relax the charge. However, this was not the case for clay treated ASA-3. The charge density is higher than for any of the other fuel combinations tested.

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[3] *A Survey of Electrical Conductivity and Charging Tendency Characteristics of Representative Fuel Samples from Ten Major Airports* CRC Report (1975)

ASA-3 is a three component solution where conductivity is a result of the synergistic effect between two of the components. The implication is that clay treating to remove ASA-3 does not remove all the constituents which cause electrostatic charge generation. The lower conductivity resulting from the clay treating could not overcome the additional charge generated in the residence time available in this test system.

During the high flow tests, a number of electrical events were observed. A LOW level "hiss" in the tank during fueling and which was heard by two investigators. A HIGH level event that gave a perceptible discrete noise during the run. It also was recorded on a chart through the radio antenna present in the system. HIGH level events were noted primarily at high flow rates in non-additized fuel. Fuels with residence times less than ~1.9 seconds exhibited electrical events except when the conductivity was greater than 50 pS/m. Fuels with a residence time of greater than 2.5 seconds did not exhibit any electrical event.

These electrical events occurred as a function of total charge in the tank and the conductivity. Higher conductivity fuel required a lower threshold before an electrical event was observed. This agreed with previous observations where electrical discharges within the fuel were observed. Similar analysis of the field strength at the top of the tank showed similar type of behavior.. While there is some debate as to the hazards involved with this type of discharge, for the purpose of this study, a conservative approach was taken that no electrical event would be acceptable during refueling.

It is recognized that the tank used in these experiments did not closely resemble an actual aircraft fuel tank. However, further analysis indicated that while there is not an immediate recognized hazard in fueling aircraft with low conductivity fuels, whether additized or unadditized, it did indicate that there is not a large margin of error to accommodate fuels at significantly higher flow rates or charge densities.

1.3.3 Residence Times in Ground Fueling Systems Available for Charge Relaxation

Due to the complexity of fuel tank configurations, prediction of the charge density or field strength cannot be made reliably. One needs to rely on the historical record to determine whether there is sufficient residence time in current fueling systems to avoid electrical events. **The data indicate that if a ground fueling system is being operated without electrical incidents, then there is no additional hazard to using unadditized fuels which have been commingled with fuels containing static dissipater additive.** To provide some guidance, a survey was conducted to determine the type of residence times presently found in the field. The results indicate that residence times for hydrant servicers using filter/coalescers average about 12.8 seconds from the element to the aircraft. For refuelers using filter/coalescers, the residence time is comparable (~13 seconds). This is because significant residence time is available in the vessel after the fuel has passed through the charge generating filter/coalescer element. In systems using absorbing media monitors, the residence time averages 4.5 seconds, with many units having residence times of 3.1 seconds. This is because the piping provides the sole volume available for relaxation of the charge.

In order to prevent electrical events during fueling , one can follow two paths:

- additize the fuel to a conductivity greater than 50 pS/m. Under these conditions, no electrical event was observed in this program. This is in line with previous work.
- maintain a sufficiently long residence time for sufficient charge relaxation to occur. This relies on the historical record at a given site. If one has had a long history of using a given system without electrical incident, then the addition of commingled fuel or clay treating fuel containing Stadis 450 will not increase the probability of an electrical event occurring. It is the operator's responsibility to recognize that changes such as different filters, new designs of equipment, etc., can have a significant impact on the charge density entering the aircraft.

1.4. Conclusions & Recommendations

1.4.1. Conclusions

The following conclusions resulting from the *CRC Ad Hoc Panel on Commingled Fuels* program must be judged with respect to the design and operation of ground fueling systems for aircraft. Tests were representative of the residence time for relaxation of charge in two systems: one was indicative of current systems; the second was indicative of future trends involving higher flow rates and shorter residence times in piping, hoses, and manifolds downstream of the filter elements.

The main conclusions from this study are:

1. Providing sufficient residence time for charge relaxation is critical in aircraft fueling operations. When changes are made to the residence time available, such as
   - replacing filter/separators with absorbing media monitors,
   - operating at higher flow rates or with shorter piping runs following the charge generating equipment,

   or, if ground fueling system for aircraft become less conducive to charge relaxation than current systems, situations may be created in which undesirable static discharges become possible. Similar situations may result when changes in filter media or filter design result in increased charge generation in the fuel.

2. Commingled fuels that combine fuels containing static dissipater additive (SDA) with non-additized fuel do not exhibit unusual static charging behavior. These can be handled as safely as non-additized fuels.

3. Fuel containing SDA with a conductivity of 50 pS/m or greater does not present a hazard in aircraft fueling in present day systems or in any anticipated future fueling systems.

4. Fuels with conductivity below 50 pS/m, including additive-free fuel, do not present a hazard of static discharge with typical fueling practices currently employed. However, fuels in this conductivity range (< 50 pS/m) could produce static discharges if future changes in ground equipment, aircraft design, or fueling practice significantly reduce residence time .

5. Fuel containing SDA should not be clay treated (unless re-additized to a conductivity greater than 50 pS/m) since clay treatment can change the relative proportions of components remaining in the fuel. This can produce unpredictable static behavior[4].

[4]In this program, only ASA-3 showed a large charging tendency at low conductivity when clay treated. When ASA-3 is no longer used, this restriction need not be followed for ASTM approved SDA.

1.4.2. Recommendations

1. Aircraft fueling systems should be evaluated periodically to determine if any exceed the traditional practices in residence time (e.g., as surveyed in this report) or equipment charging tendency. Such systems may require modification or addition of SDA.

2. A small-scale charging tendency test should be developed to sense residual charge after fuel flow through an apparatus that simulates aircraft fueling practice. This could be used to test fuels, additives, and filter media.

3. Fuel with conductivity less than 50 pS/m can be used in current fueling systems. Where higher flow rates or lower residence times than current practice are seen, consideration should be given to additizing the fuel.

2. Introduction

2.1. Static Electricity in Aviation Fuels

Static charge generation during fueling of an aircraft which can result in electrical discharges was observed as early as 40 years ago. Since then there have been several significant ignitions during ground fuel transfer or aircraft operations involving foam-filled tanks. Most ground vehicle ignitions involved filling tank trucks which previously contained lighter fuels with kerosene, a practice known as "switch loading". Large commercial aircraft have had only three significant incidents, none of which resulted in injury. Two of these incidents involved the same airport location and were connected with the introduction of a high charging filter paper in the filtration and coalescence equipment. The paper was immediately removed from service. The other occurrence, in an early type turboprop aircraft, was attributed to electrostatic discharge during refueling when no other cause for the ignition could be found. In addition, there were a number of electrostatic incidents involving military aircraft that were being fueled with JP-4, particularly in tanks that were filled with reticulated foam.

Static charges are normally generated by fuel flowing throu micro-porous devices such as micro-filters, filter coalescer elements, or absorbing media elements. The refining and handling of kerosene fuels has yielded a product which is low in conductivity and able to retain static charges for significant lengths of time, thereby promoting the possibility of an electrical discharge. This recognized potential hazard of flowing jet fuel through a charge generating surface led to the development of static dissipater additives which, when added to the fuel, increase the fuel conductivity and speed relaxation of the charge. Two additives, ASA-3 and Stadis 450, were approved for use in aviation fuel and were adopted in various specifications. In these specifications, a conductivity of at least 50 picoSiemens/meter *(pS/m)* was required. In addition to static dissipater additive, other measures to reduce the charge tendency of ground fueling systems for aircraft were also adopted.

Sufficient residence time in the piping and hoses after the filter vessel, and elimination of high charging paper separators have helped limit the total charge which enters the aircraft fuel tanks. No specific limit on the charge density entering aircraft fuel tanks can be established. The approach to designing ground equipment should be to limit the charge density of the fuel to the level established as acceptable by the historical record. Since 1970, no accidents to commercial aircraft have been attributed to static electricity charges generated in the refueling equipment.

The use of static dissipater additive to improve fuel conductivity is universal in military JP-4 fuel and in commercial Jet A1, the fuel employed by commercial airlines outside the USA. However, the use of static dissipater additive has not been widely adopted in the USA for Jet A fuel commonly used by domestic airlines. In the United States, the fuel delivery system is largely through multi-product pipelines. Thus, in order to ensure fuel cleanliness, clay treatment of the fuel is commonly employed throughout the fueling network. This trade-off between ensuring the delivery of clean fuel and minimizing static charge generation has resulted in airlines using non-additized aviation fuel and relying on other operating parameters, gained through a long history of experience, to limit the amount of static charge delivered with the fuel to the aircraft. This history has been generally obtained with fuels of conductivity less than 50 pS/m. The ASTM D1655 specification for aviation fuel recognizes the value of static dissipater additives by permitting their use provided the conductivity falls between the limits of 50-450 pS/m[5].

Technically, the ASTM D1655 specification does not recognize the use of any fuel additized with static dissipater additive which has been commingled with non-additized fuel resulting in a conductivity of the fuel less than 50pS/m. On the other hand, several companies specify the addition of static dissipater additive before loading trucks with jet fuel. This is an optional policy intended to enhance the protection of personnel, the loading rack and fuel truck, especially where switch loading between gasoline and jet fuels occurs. This has produced instances where delivery and commingling of additized with non-additized fuel has resulted in conductivities below 50 pS/m in the storage tank. This has raised an issue of whether these commingled fuels presented an increased hazard over the non-additized fuels with which the industry has had a significant safe fueling history.

An attempt was made to resolve this issue within *ASTM*. A Task Force formed to study the issue was presented with data which showed that there were components in static dissipater additives which were significant pro-static compounds. These components increase the conductivity of the fuel and improve its ability to relax electrostatic charge. However, they also tend to increase the amount of charge that can be generated. It was accepted that, at conductivities greater than 50 pS/m, charge relaxation due to the high conductivity more than adequately compensated for the higher charge generation encountered by using the additized fuel. However, data for commingled fuels with conductivities less than 50 pS/m were not clear cut. Some data presented suggested that fuel containing traces of static dissipater additive with conductivities less than 50 pS/m presented a greater hazard than non-additized fuels. Other data disputed this finding, indicating that the additional charge generated was adequately compensated by relaxation resulting from the increased conductivity of the fuel and the existing residence time of typical ground fueling systems.

There was another pragmatic problem that resulted from having fuels with conductivities less than 50 pS/m. One could not determine whether the fuel contained traces of static dissipater additive or the conductivity was a result of natural, and presumably, lower charging, contaminants often found in the fuel. Since no adequate test is readily available to measure the charge density in the field, conductivity measurements greater than 10 pS/m were considered as an indication of a potentially high charging fuel. There was no consensus on how to deal with such fuels.

Because the issue of the hazards involved with commingled fuels at low conductivities could not be resolved without further experimental investigation, *ASTM D.02.J Subcommittee on Aviation Fuels* requested that the *Coordinating Research Council* resolve the technical issues.

2.2. ASTM Mandate

The purpose of the *CRC* program was to answer the questions posed by *ASTM*, viz.,

[5]*Annual Book of ASTM Standards*, Vol. 5.01

- Do fuels containing static dissipater additive with a conductivity of less than 50 pS/m present an electrostatic risk in US. handling systems?
- If fuels are clay filtered to a conductivity less than 10 pS/m, can they be considered additive free?
- Do likely changes in ground fueling systems for aircraft lead to any change in the assessment that static dissipater additives are not needed to protect facilities during aircraft fueling?

2.3. Purpose & Scope

The purpose of the *CRC* program was to answer the questions asked by *ASTM*. Specifically, the purpose of the program was to carry out the necessary experiments and tests to determine whether commingled fuels containing static dissipater additive with a conductivity less than 50 pS/m pose any additional electrostatic hazard during the fueling of aircraft. It was also a goal of this program to survey existing systems and make an assessment whether design changes in ground fueling systems for aircraft could cause additional electrostatic hazards during the fueling operation. In order to achieve this purpose, several issues had to be resolved. It was the scope of this program:

- To assess the range of conductivities encountered in Jet A at various locations.
- To assess the charging tendency of Jet A presently being used in the United States.
- To develop large scale data regarding the charging tendency of Jet A when it contains:
    + ASA-3 at conductivities less than 50 pS/m.
    + Stadis 450 at conductivities less than 50 pS/m
    + ASA-3 which has been clay treated from a conductivity of greater than 100 pS/m to less than 50 pS/m
    + Stadis 450 which has been clay treated from a conductivity of greater than 100 pS/m to less than 50 pS/m
- To perform laboratory scale tests to further study the charging tendency of ASA-3 and Stadis 450 in both commingled Jet A and clay treated Jet A as needed to verify the results of the other tests.
- To develop a database of the residence times typical of existing fueling systems.

3. CRC Program

The program which was developed consisted of a number of phases which looked at the effect of static charge generation of fuel flowing through filter/coalescers and water absorbing media monitors. A schematic of the program is shown in Figure 1. The various elements of the program are described in the following sections.

3.1. Mini Static Program

In order to understand the variability of charging tendencies of fuel in typical United States delivery systems, a Mini Static charging program was developed. A clay treated Jet A fuel was used as a reference fuel. All test programs and sites had a 5 gallon epoxy lined can of the same fuel to check the behavior of their Mini Static system. A study to develop a reliable reference filter had the goal of:

- Providing consistent charge generation when fuel was passed through it.
- Providing a high charge generating material for comparing charging tendencies of a variety of fuels
- Providing a reference filter which was typical of materials in the field today. A number of filter papers or absorbing media from a variety of elements were tested for level and consistency of charging. This program is described in Section 4.1.

The choice of reference paper is not meant to provide guideance of maximum or representative charging tendency. It does provide a methodology for assessing relative effects. This has been a method which has been found to be useful in prior work and has been adopted for this study.

Using the reference filter paper, Mini Static tests were conducted at three sites, viz., Colonial Pipeline, Los Angeles Airport, and O'Hare International Airport. Fuel samples were taken over time at random. These fuel samples were then tested for charging tendency using the reference filter and Mini Static test. The purpose of these tests was to get a measure of the charging tendency of unadditized fuels present in the field. The presumption was that this distribution of fuel charging tendencies was being safely handled in the ground fueling systems located in the United States. Thus if the variability of charging tendency of commingled fuels fell within the same range then one could presume that these fuels could be handled without electrostatic hazard. The results of this work are described in Section 4.2.

In the final portion of these tests, a laboratory study was performed to study the effects of commingling and clay treating on charging tendency. The purpose of this work was to determine the range of charging tendency which could be expected when additized fuel was clay treated and/or commingled with non-additized fuels. These efforts are described in Section 4.4.

3.2. Full Size Field Test

In order to determine the charging tendency and field strengths which could develop in representative equipment at actual flow rates encountered in the field, a full scale field test was developed in which an 8 foot diameter, 8000 gallon horizontal cylindrical tank was filled at different rates using a hydrant servicer equipped with water absorbing media elements (Velcon CDF-H). This configuration using absorbing media was chosen because the elements are located closer to the point of delivery to the aircraft. The shorter residence time provided in this system reduces the time for relaxation of charge before delivery and hence provides a higher charge entering the receiving tank than filter/coalescer systems. Tests were performed using additized fuels at various conductivities before and after clay treating. These tests were done with both ASA-3 and Stadis 450.

The configuration of the tank did not directly represent the typical configuration found in aircraft tankage. However, this system was chosen because it offered the following advantages:

- The fill rates were typical of the maximum fill rates in fueling aircraft.
- The charge density from the hydrant servicer is representative of that found in the field
- The charge density entering the tank was sufficiently high to provide electrical measurements which could be analyzed
- The configuration was relatively simple and amenable to analysis. Thus, the data obtained could be used to analyze other systems such as aircraft fueling systems.

The tests are described in Section 6.

3.3. Analysis

To back up data obtained from the limited configuration of the full size field test and the limited number of test data, an analysis was conducted to obtain a better understanding of the importance of various elements which could lead to electrical discharge in real systems. In this phase, charge relaxation , and electrical field strength were modeled and applied to the data obtained. Based on work by Boeing, an attempt was made to qualitatively assess the sensitivity of electrical charge and field strengths to various system factors.

The analysis is presented in Section 5.

4. Mini Static Program

4.1. Mini Static Test

In order to establish a measure of charging tendency in fuels, the Mini Static charging test was used. The Mini Static Test protocol used in this program is described in Appendix A.

In this procedure, the charging tendency of a test fuel is measured as it passes through a reference filter paper at a constant flow rate of 100 ml/min. The charge density generated in the fuel is calculated by measuring the streaming current from the reference filter holder. The charge density is:

$$q_{mst} = \frac{i_{mst}}{F_{mst}} \qquad 4.1.1$$

(The charge density is reported with the polarity of the fuel itself unless otherwise noted.[6])

This measurement can be used to measure charge density generated by a given fuel relative to a specified reference filter. That is, if a reference filter of consistent quality is used, then fuels from the field can be tested to give a relative rank order of charging tendency. Alternatively, if a specified reference fuel is used, then the effect of various filter or absorbing media material can be ranked.

The charge density generated depends on a number of factors such as the particular fuel/filter type and contaminants or additives in the fuel. As such, the results obtained from the Mini Static test does not provide an absolute measure of a fuel's ability to generate a charge. However, with the selection of a reference filter which has a high charging tendency, the Mini Static test can provide a consistent ranking of fuels sufficient to draw conclusions about variability of fuels, effect of additives, and other pertinent factors.

In this study, a reference fuel was necessary to compare various materials which were considered for a reference filter. It was also used to measure the charge density produced by the reference filter obtained when the test was performed at various sites and at various times.

4.2. Reference Fuel & Reference Filter

4.2.1. Reference Fuel

The reference fuel was a hydrotreated Jet A fuel. It was clay treated in accordance with ASTM D3948[7]. Four reference fuel samples were made in this way from the same batch of Jet A fuel. They were stored in 5 gallon epoxy lined cans

[6]The variables are defined in Section 9

[7]Annual Book of ASTM Standards, Vol. 5.03

4.2.2. Reference Filter

A reference filter is essential to provide a reliable common reference for use in the program examining the charging tendency of fuels in the field. It also is required for referencing the results of the laboratory tests examining various process parameters. For this study, a reference filter was chosen:

- that has relatively good reproducibility and reliability
- that is representative of the types of materials in the field

To achieve this, representative filter/coalescer elements and absorbing media filters commonly used in commercial fuel handling systems were evaluated to obtain reference filter candidates. For filter coalescer elements, the element was cut open and the pleated filter paper was removed. Reference filter pads were stamped from the paper, being careful not to intersect the crease in the paper. For the absorbing media elements, the first layer of absorbing media paper was selected for the reference filter tests.

The elements selected for trial are given in Table 1. Each reference filter was stamped out and placed in a dessicator for at least 5 days. Sufficient reference filter pads were made to provide filters for the entire program.

In this selection process each reference filter candidate was tested in two fuels. The first was a clay treated Jet A. The average water content of the fuel was 51 ppm and it had a conductivity of ~1 pS/m. The second fuel was the same clay treated Jet A fuel as above, but this fuel was dried by passing it through a molecular sieve filter. The average water content for this fuel was 18 ppm. The conductivity was ~ 1 pS/m.

For each material, four reference filter pads were tested to get an average charge density in each fuel. In each of these tests, the charging tendency of each reference filter pad was obtained three times with the reference fuel using the Mini Static procedure. Clay treated fuel results are shown in Figure 2. All materials showed relatively low charging tendency except for the Facet CA22 Series filter/coalescer paper element and the Quantek FGO absorbing media material. When the clay treated fuel was dried, the charge density dropped significantly (Figure 3). This was especially true for the high charging materials. The variability also decreased significantly. The average charge density is shown in Figure 4.

The data show a mix of charge densities for both filter/coalescers and absorbing media elements. This indicates that there is no inherent higher or lower charge generating tendency for a given type of material. However, a given material within a type can be significantly different. For example, the charge density of the FGO water absorbing media is higher and more variable than the other absorbing media and the filter papers tested. The overall charge generation for a given element/fuel is dependent on the summation of the charge generated by each layer of material in the element as the fuel passes through it. Thus, the actual charge generation must be tested for a given element and fuel type combination and cannot be judged *a priori* from a single portion of an element.

For the purpose of this test, the Facet CA22 Series filter paper was selected as the reference filter. Several factors went into selection of the Facet CA22 Series paper, viz.,

- It was a relatively high charging material (-51 $\mu C/m^3$ [$\mu C/m^3$] ± 17 $\mu C/m^3$)
- It had significantly less variability than the Quantek FGO absorbing media element in the clay treated fuel. (-155 $\mu C/m^3$ ± 60 $\mu C/m^3$)
- Field samples were likely to contain a significant amount of water. Therefore, the results from the clay treated only Jet A fuel were germane in deciding whether sufficient charge generation would occur.

It was also interesting to note that charge generation was dependent on the material/fuel combination. Both negative and positive charged fuel was generated. Thus, fuel alone cannot be used to determine the magnitude or the sign of charge which will be generated. While the CA22 paper was relatively high charging, it did not provide the charging tendency of Type 10 paper which was used in similar Mini Static tests[8].

4.3. Field Results

In order to be able to make a judgment about the differences in charge generation in fuels additized with static dissipater additive, it was necessary to obtain an indication of the charge generation tendency of unadditized fuels found in the field. To do this, fuels were selected at random from three sites and measured for charge generation tendency using the Mini Static Test and the CA-22 reference filter. For each fuel, two Mini Static tests were run, each using a new reference filter. For each test, the fuel was run through the filter three times; the last two runs were used to obtain the static charge density. The initial run, using a new reference filter, normally had higher values of charge for the first few seconds of the run. The latter two runs using the same filter were close in magnitude. Figures 5 through 9 show the last two measurements for each sample.

Three sites were chosen for these tests:

- *Colonial Pipeline in Linden, NJ*-- Fuel from this facility was representative of fuel from a multiproduct pipeline.
- *Los Angeles International Airport* -- This fuel came from three refineries through a dedicated pipeline.
- *O'Hare International Airport* -- This fuel was from specific sources which came to the airport through dedicated pipelines.

In each case, samples of fuel where taken in 1 gallon epoxy lined cans and sent to a laboratory for a Mini Static Test. The labs all had the same reference filters and the same

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[8] *A Survey of Electrical Conductivity and Charging Tendency Chcracteristics of Representative Fuel Samples from Ten Major Airports* CRC Report (1975)

reference fuel stored in the 5 gallon epoxy lined can for calibration. Given the large variability normally expected for the test, the data did not indicate a marked bias between laboratories

Figures 5 through 8 indicate the results of the field test program. The greatest variation in conductivity and highest charge densities occurred in the Colonial Pipeline samples. As seen from this data, the variation in charge density increases with conductivity of the samples. This is in some contrast with previous work by the CRC[9] which showed that while there was a wide variation of charge density, there did not seem to be any relation to conductivity. This could be because the previous work had more samples than the present. Also, there were more locations at which samples were taken. As seen from Figure 5, location can play an important role in the level of charge generated. Thus, the variation in conductivity could have been masked in the previous work by location effects. Finally, the previous work was based on a high charging paper, "Type 10". The charge generated was higher than in this study. The high charging nature of the paper could have reduced the variability of the magnitude of charge generated.

This study indicated that there could be a large variation in charge density generated. The sign of the charge generated also was dependent on the site. Fuel samples at O'Hare International Airport showed little correlation with conductivity and formed, in general, a negative charge in the fuel (Figure 7). The sign of the charge at LAX was mixed. One sample at higher conductivity showed a relatively high level of charge(Figure 6). However, others showed low charge levels of both signs. Careful analysis of the location of the fuel indicated the charge density and the sign of charge generated was dependent on the source of the fuel.

At locations where the fuel was transported through dedicated pipelines, the conductivities of the fuel were below 10 pS/m. However, in a multi-product pipeline, a small number of fuel samples had conductivities greater than 10 pS/m (Figure 8 and Table 2). Approximately 28% of the samples were above 10 pS/m. The reason for these higher conductivity levels is not clear. Presumably, these fuel samples were not additized with static dissipater. However, they still showed high charging tendencies.

Based on the field test program, it was concluded:

- There is a wide variation of charging tendency of fuels present in the field today. With the exception of one sample, the variation in charging tendency ranged from -200 $\mu C/m^3$ to 6000 $\mu C/m^3$.
- There is limited evidence that the charging tendency is more variable at high conductivity. Ground fueling of aircraft with these fuels has been safe despite this wide variation in charge density.
- The charge density and sign of the charge in the fuel is dependent on the source of the fuel. Multi-product pipelines can be expected to have wider variability than dedicated pipelines supplying fuel from a single source.

[9] *ibid*, CRC Report (1975)

- There is a significant number of fuel shipments which have an intermediate conductivity, i.e., 10-50 pS/m, which have had no electrical discharge problems using present fueling systems.

4.4. Laboratory Program

There were several questions regarding the charging tendency of fuels which were answered by a limited number of laboratory tests using the Mini Static procedure. This study addressed:

- *The effect of commingling or clay treating fuel additized with ASA-3 or Stadis 450*
  The purpose was to examine the effect that commingling of additized fuel with non-additized fuel might have on charge generation. Also included in the study was the effect that clay treating may have on static charge generation. It was hypothesized that since the static dissipater additives provided conductivity by a synergistic combination of different species, clay treating might reduce conductivity by a preferential adsorption of one particular component. The presence of the remaining compound might still provide significant charge generation capacity.

- *The effect of adding both products, viz. ASA-3 and Stadis 450 to the fuel.*
  Since both products, viz., ASA-3 and Stadis 450, are likely to be used for sometime in the future even though ASA-3 is no longer commercially sold, there was interest to see what effect addition of both additives to the fuel might have on the static charge generation tendency. This might occur in situations where one additive was initially used, but an additional increase in the conductivity was made after delivery using another static dissipater additive. A similar situation might occur where two fuels containing different static dissipater additives were commingled

- *The effect of other fuel additives on static charge*
  Corrosion inhibitors were tested at levels considered to be "trace" and at full MIL-I-25017 loading. This was to determine whether high charge generation was possible when these additives were present.

- *The effect of residual static dissipater additive adsorbed on filter on charge generation tendency of the fuel.*
  One possible effect of having commingled fuels is that static dissipater additive may adsorbs on the surface of a filter coalescer or absorbing media element. There is a possibility that the static dissipater additive could desorb when unadditized fuel is passed through the same element, thereby increasing the charge generation tendency of the fuel without the attendant high conductivity of an additized fuel

- *Miscellaneous tests*

Several samples from the full scale tests at Stapleton International Airport were tested using the Mini Static test to see whether there was any correlation between the field results and the laboratory results.

4.4.1. Effect of Commingling or Clay Treating fuel with Static Dissipater Additive

The Mini Static procedure in Appendix A was used. The charge densities were calculated from the average of the current values obtained at times when 20 and 25 ml of fuel remained in the syringe. Two runs through each pad were made to condition the reference filter and to reach steady charging tendencies for the fuel. The third run was used to obtain the charging tendency value for the test fuel.

The reference fuel was used as received in a 5 gallon epoxy lined can as the base fuel for all of the tests. Commingling (dilution) of the samples was attained by adding 400 ml of the reference fuel to clean 500 ml Teflon bottles. Fuel containing the maximum concentrations of additives (3.0 ppm Stadis 450 and 1 ppm ASA-3) was then added to the bottle to obtain the target conductivity.

Clay filtration was accomplished by filling a 12 mm I D chromatographic column with a variable amount of Attapulgus clay obtained from a clay bag. Approximately 400-500 ml of the test fuel was passed through the column at constant flow rate. The target conductivity was obtained by adjusting the flow rate or amount of fresh clay in subsequent runs. Multiple passes were required to removed sufficient ASA-3 to obtain fuel in the 5-12 pS/m range. Stadis 450 was much more easily removed.

The results from these tests are given in Figures 9-10. Data for each additive at conductivity less than 50 pS/m were linearly regressed. The lines from the linear regression are shown in the figures. Figure 9 indicated that an extrapolation of the line for the commingled Stadis 450 data passes close to the original charge density obtained with the fully additized fuel (3.0 ppm Stadis 450). The clay treated line shows a lower charging tendency. However, Figure 10 shows that the clay treated data for Stadis 450 is variable. The high value obtained at a conductivity of 12 pS/m significantly influences the regression. If eliminated, the regression would more nearly represent commingled fuel line. Removal of the worse point for ASA-3 clay treated fuel would narrow the difference between commingled and clayed treated fuel, but the trend would still be the same.

The data for ASA-3 indicate that the charging tendency for both the commingled fuel and clay treated fuel show a higher tendency than for Stadis 450. In addition, the clay treated data shows a significantly higher charging tendency than the commingled ASA-3 fuel.

Thus, this data indicate that the Stadis 450 additive tends to behave predictably, i.e., the charging tendency is proportional to the fuel conductivity. The ASA-3 additive does not behave with the same predictability. The charge tendency at low conductivity seems to be higher than would be predicted by a normal linear interpolation from a fully additized fuel. In addition the clay treated ASA-3 fuel also seems to show a higher charging tendency than the commingled fuel at the same conductivity. The difference in the data might result from the fact that ASA-3 containing fuels had to be clay treated more severely than Stadis 450 fuels to achieve the same conductivity. One can hypothesize that the ratio of components of Stadis 450 remains approximately constant during clay treating. Thus, the effect of clay treating would be similar to that of fuel commingling. On the other hand, the ratio of components in ASA-3 changes during clay treating. This could result in a non-linear conductivity response of the fuel to the remaining constituents. The remaining constituents could show a higher charging tendency than the conductivity level would suggest.

Figure 11 provides the same test data for commingled fuels as above. Fuel was diluted as described above to low conductivities using the maximum permissible amounts of ASA-3 (1 ppm) and Stadis 450 (3.0 ppm) as starting point. However, in this series of tests, the reference filter was changed to the absorbing media material from a CDF-H element. This was the same type of element as used in the hydrant servicer at Stapleton Airport in the full scale tests. Because of the known sensitivity of this media to humidity, the reference filter pads were placed into the filter holder and then equilibrated overnight in a dessicator containing a calcium chloride/water solution, which gives a relative humidity of approximately 32% at room temperature. The filter holder was used in the Mini Static tests immediately after removal from the dessicator. The CDF-H material showed a lower charging tendency than the CA-22 reference filter. Analysis of this data showed that both Stadis 450 and ASA-3 fuel behaved similarly. In fact, the charge density could be predicted by the equation:

$$q = -2.915 - 7.51k + 0.0066k^2$$

The conclusions reached in this study are very dependent on the fuel/filter combination. One explanation of the similarity in the charge density/conductivity relationship is that the much lower charging tendency of the fuel on the CDF-H filter makes differentiation more difficult. Another factor may be that Stadis 450 seems to be much more sensitive to the filter material. A compasion of Figures 9 and 11 show that ASA-3 did not change markedly between the CDF-H and CA22 material when fully additized (~ -2400 $\mu C/m^3$ at k=337 pS/m vs. ~-1050 $\mu C/m^3$ at k = 165 pS/m). On the other hand, Stadis 450 showed a marked difference (~ 2114 $\mu C/m^3$ at k= 528 pS/m vs. ~ - 10040 $\mu C/m^3$ at k=430 pS/m).

In addition, at intermediate conductivities (Figure 10), the charge density is within the range of variation of samples obtained from Colonial pipeline Thus, one could expect the same order of magnitude of charge density in commingled fuels as seen in present day pipeline samples. Also, the sign of the charge for the commingled fuel was always negative.

However, these data do confirm the data in Figure 9 that the commingled Stadis 450 fuel behaves as expected with conductivity. The ASA-3 additized fuel also behaves in the same manner.

Even though ASA-3 is no longer commercially available, it is expected that it will continue to be used until supplies are depleted. This raises the possibility that mixtures of ASA-3 and Stadis 450 could be in the fuel. To assess the impact of commingled additives, a fuel containing 0.5ppm ASA-3 and 1.5 ppm Stadis 450 was blended. This base fuel was then diluted to intermediate levels. The results are shown in Figures 12 and 13. Figure 12 shows the total range of conductivity. Figure 13 is a magnification of the low conductivity range. The lines in these figures are linear regressions of the data at low conductivities, i.e., at $k < 50$ pS/m. The results indicate that the charging tendency for high conductivities is similar to that obtained by additizing the fuel with ASA-3 only to the same conductivity level. Commingling this blend with non-additized fuel gives a reduced charging tendency which is proportional to the resulting conductivity. This is similar to results with Stadis 450 alone. Clay treating gives an elevated charging tendency to that of commingled fuel at the same conductivity. This confirms the data in Figure 9 indicating that fuel containing ASA-3 has a higher charging tendency when clay treated than does commingled fuel at the same conductivity level.

The clay treating in this program is significantly different than actual clay filtration of fuels in the field. The flow rate per unit hold up and multiple passes can potentially affect the constituents removed from the fuel and hence affect the charging tendency of the fuel. To study a more realistic situation, a simulation of field clay filtration was performed. These filtrations were accomplished using fuel containing either 3 mg/l of Stadis 450 or 1 mg/l of ASA-3. In these studies the fuel was the reference fuel which was additionally clay filtered using the ASTM D2550/D3948[10] procedure. Fresh attapulgus clay was used from a clay bag for each subsequent filtration of fuel. About 1200 ml fuel was charged to a 1 gallon stainless steel pressure vessel and was driven through the side-stream sensor (as described in ASTM D5000[11]) at a rate of 100 ml/min. This filtration simulates an actual clay filtration through clay bags or canisters. Mini Static tests were performed using both the CA22 and CDF-H filter pads. The results are shown in Figure 14. When the CA22 filter was used, clay treated ASA-3 fuel was only slightly reduced in charging tendency even though the conductivity dropped from 540 pS/m to 4 pS/m. On the other hand, the Stadis 450 fuel had a substantial drop in charging tendency. Using the CDF-H pad as reference filter. The charging tendency of the clay treated ASA-3 fuel showed an enhanced charging tendency over the fully additized fuel. The Stadis 450 fuel behaved normally with the charging tendency of the clay treated fuel being significantly reduced.

Based on these tests, the following conclusions could be made:

- *Commingling fuels reduces the charging tendency of the fuel roughly proportionally with reduction in conductivity for all static dissipater additives, i.e., ASA-3, Stadis 450, or mixtures.* This is mitigated somewhat by the Mini Static test work shown in Figure 9 which indicates a higher than proportional charging tendency for commingled fuels containing ASA-3. However, this was not supported by other experiments. In fact the conclusion as stated was supported in other tests in this program.

- *Clay treating of fuels containing Stadis 450 alone behaves similarly to commingled fuels.*

[10]*ASTM Book of Standards*, Vol. 5.02
[11]*Ibid*, Vol. 5.03

- *Clay treated fuels containing ASA-3 showed an increased charging tendency over that which occurs by commingling fuel to the same conductivity level.* The amount of enhanced charging tendency is a function of treatment, e.g., severity of clay treating, filter media where charge is generated, and also probably the source of fuel. In fact, in the side stream sensor simulation of clay treating, the charge density was higher for the clay treated ASA-3 containing fuel using the CDF-H filter than for the fully additized fuel before clay treating (Figure 14).

4.4.2. Effect of Other Additives

Tests were carried out using the reference fuel which were dosed with corrosion inhibitors. The additives, DCI-4A, Hitec 580, and DMD, were added at "trace" and maximum strength as specified by the U.S. Military Specification MIL-I-25017. Stock solutions of these inhibitors in toluene were added to 500 ml Teflon bottles containing the reference fuel. These tests were performed to ascertain whether fuel in pipelines might have a high charging tendency due to contamination by these corrosion inhibitors.

Results from these tests (Figure 15) indicate that there is little or no effect. The charging tendency using the CA22 reference filter showed relatively low levels of static charge generation. However, it should be noted that the corrosion inhibitor did have an effect on the charging tendency. In this fuel/filter combination, the charge generation tendency of the additive tended to provide a positive charge in the fuel. Thus, as the concentration of the additive was increased, the inherently negative charge of the base fuel was overcome and the fuel became positively charged.

When the CDF-H reference pad was used, there was a very slight change in the charging tendency from the base fuel (Figure 16). The levels attained were insignificant.

Also, a number of tests were performed using pipeline drag reducer additive. The results shown in Table 3 indicated that there is no charging tendency from the drag reducing additives used, not surprising since these additives are non-polar.

The conclusion of this work is that corrosion inhibitors and pipeline drag reducing additives are not likely to pose static charge generation problems.

4.4.3. Residual Effects of Additive Adsorbed on Filter Element

A further consideration was the possibility of static charge problems during the transition of fuel containing static dissipater additive being replaced with fuel that is unadditized. The possibility exists that static dissipater additive which adsorbs on the filter element during fueling with fuel containing static dissipater additive will desorb when unadditized fuel is passed through the element in subsequent fuelings. This desorption process may increase the static charge tendency of the fuel.

To test this hypothesis, CDF-H filter pads were conditioned by making six runs with base fuel followed by 5 runs containing 1 mg/l ASA-3 followed by a number of successive runs with unadditized fuel. This was repeated using 10 mg/ml ASA-3 for conditioning. The results are shown in Table 4.

The runs with 1 mg/l showed no lasting effect when unadditized fuel was passed through a previously conditioned filter. A similar conclusion can be made when 10 mg/l of ASA-3 was used. The actual charge density levels were quite different for the two concentrations of ASA-3. The very low charge density in the 10 mg/l fuel is a consequence of the very high conductivity of the fuel permitting rapid charge dissipation. Thus, when unadditized fuel was passed though the element the charge density increased, primarily because the charge relaxation time increased. The first series at 10 mg/l ASA-3 showed very little effect after the first test. A second run showed a much more gradual decrease. However, the charge levels generated were relatively modest.

The conclusion reached is that the effect of a static dissipater additive desorbing into unadditized fuel from a element previously exposed to static dissipater does not pose any additional static hazards.

4.4.4. Miscellaneous

Several samples of fuel taken during the test program were brought back from Stapleton International Airport. The results from Mini Static tests are provided for these runs in Appendix B.1.3. A description of the test number is found in Section 5. All samples referred to as Denver in Appendix B.1.3 are from the CRC Program at Stapleton Airport. Also, tables referring to S-450 as additive are fuels additized with Stadis 450.

While the data are presented in this report for completeness, results from these tests did not have a direct correspondence to the Stapleton International Airport test results. Conductivities of the fuel samples differed significantly from those obtained at Stapleton International Airport. The data suggest that samples change in their charge generation tendency during storage. The data indicate that Stadis 450 charges at a higher level than ASA-3; the reason for this is unexplained.

5. Full Size Field test

5.1. General Program

The purpose of this phase of the program was to obtain full scale results for a variety of fuel conditions. In this series of tests, an 8000 gallon tank was used to simulate an aircraft fuel tank. The tank was filled using a hydrant servicer equipped with Velcon CDF-H absorbing media elements. Measurements were made during each run of the following:

- Charge density entering the tank
- Electrostatic field strength
- Electrostatic discharges in the tank
- Streaming current from the tank

A series of 15 tests was run to encompass the range of fuel conditions which could result during an operation where commingling is possible. At each fuel condition, two flow rates were tested, one at high flow rate the other at low flow rate. These were set by the "rise velocity" of the fuel in the tank. The high flow rate was meant to be at the highest rise velocity which might be actually measured in an actual aircraft fueling; the low flow rate was set at a more typical rise velocity for fueling. The tests covered included:

- Jet A fuel unadditized
- Jet A fuel fully additized with ASA-3 (conductivity ~50pS/m)
- Commingled Jet A containing ASA-3 with resulting conductivity ~ 10 -20 pS/m
- Commingled Jet A containing Stadis 450 with resulting conductivity ~ 10 -20 pS/m
- A fully additized ASA-3 Jet A, clay treated to a conductivity ~10-20 pS/m.
- A fully additized Stadis 450 Jet A, clay treated to a conductivity ~10-20 pS/m.

In each case where the fuel was commingled or clay treated, the conductivity was targeted at 10 - 20 pS/m. This range was chosen because this is the region where the charging tendency of the fuel was high but the conductivity was sufficiently low so that the effects are not cancelled out. This was believed to be the worst case condition.

5.2. Facilities

The program used an 8000 gallon unbaffled tank (Figure 17). The tank was 8 feet in diameter and approximately 21 feet long. On one end of the tank, a 3 inch flanged inlet approximately 6 inches from the tank bottom acted as the inlet nozzle to the tank. The inlet was flush with the inside of the tank. The other end of the tank had a drain on the bottom of the tank. The tank could be emptied by attaching a hose to this drain, opening the valve and pumping the fuel back to the storage tank.

There were also two 1 inch taps approximately 3 inches from the top and bottom of the tank. A sight glass consisting of a 1 inch diameter Tygon tube was attached to these taps to measure the level in the tank during fueling. Demarcations at each 1000 gallons were drawn on the tank to provide a measure of the fuel in the tank.

A 1 inch tap was also placed about 3 inches from the top. A hose with a quick disconnect was attached to this tap to inert the tank before fueling.

On the top of the tank, there was a 3 foot diameter manway which rose approximately 6 inches above the tank wall. Instrumentation was placed through holes in the manway cover.

The tank was placed on a flatbed trailer towards the rear end (Figure 18). The wheels of the flatbed and the dolly wheels were placed on Teflon® pads (2 ft x 2 ft x 1/2 inch). On the top of the manway, a field strength meter was placed into a hole at the center of the manway cover. The meter was lowered into the tank so that the bottom of the meter was flush with the tank wall. The meter rested on a Teflon® pad to prevent streaming current leakage through the meter to ground.

A Radio Shack AM/FM radio was also placed on a Teflon® pad resting on the manway cover. The antenna from the radio was lowered into the tank so that the tip of the antenna was flush with the tank wall. The antenna and radio were electrically isolated from the tank. A wire was attached to the speaker lugs and connected to an amplifier and time relay. The purpose of this device was to amplify any static noise in the tank. If the voltage (noise) reached a threshold level, the voltage would be amplified and recorded through the time relay to a chart recorder. The time relay circuit was needed to reduce the noise frequency so that it could be recorded. Without this device, the electrical discharges would have an effective frequency which would be too fast to be picked up reliably by the recorder. The threshold was set so that a low voltage electrical arc placed approximately 60 feet away from the antenna would cause the amplification circuit to be activated. Thus a static discharge would be indicated on the chart recorder provided that it had a minimum intensity level of discharge.

A Keithley 617 Programmable Electrometer was used to measure the streaming current from the tank to ground. One wire was attached to the tank. The other lead from the meter was attached to ground. The tank was filled from the hydrant servicer using one or two hoses depending on the flow rate. The hose from the servicer was connected to the tank through a manifold as shown in the insert of Figure 18. The hose was connected to pipe which was supported over the flat bed by a stand resting on Teflon pads. A. O. Smith charge density meters were connected to each leg of the manifold to the tank. A valve on each leg of the manifold could be used to shutoff flow when required. The high flow runs used both legs; the low flow runs used only one leg of the manifold. The manifold was attached to the tank at the flange using an electrical isolation kit. That is, the manifold was isolated from the tank electrically.

The output of each A.O. Smith meter was connected to a separate electrometer. All measurements were taken manually during the test.

Before each run, the tank was inerted with nitrogen. Nitrogen was supplied though a pressure controller from a truck containing multi-tube banks of compressed nitrogen. This nitrogen supply was connect to the tank before each test using a hose with a quick disconnect.

The actual configuration at Stapleton International Airport is shown in Figure 19. Fuel from a 20000 gallon storage tank was pumped through a pump to a hydrant servicer. The rated flow of the servicer was 850 GPM. The output of the hose was connected to the manifold. After the tank was filled, it could be emptied through the drain valve to the return line of the system, and back to the storage tank.

The fuel was also clay treated using Attapulgus clay bags in a clay treater which was shipped to the site.

5.3. Experimental Procedure

Each test run was carried out as follows:

- The inert gas system was connected and the tank was purged for at least 15 minutes
- The inert gas line was removed and approximately 5 minutes were allowed for relaxation of static electricity generated during the inerting portion of the test. This was found to be sufficient to reduce the streaming current to less than 10^{-10} amperes.
- The tank was filled to ~ 600 gallon level at a low flow rate. This ensured that the inlet nozzle was totally covered before the test began.
- The formal portion of the test began, starting to fill the tank at the design flow rate. Adjustment of flow rate normally took only a few seconds. At this point in the test, measurements were taken of the volume, flow rate, streaming current from the tank, charge density readings from the A.O. Smith meters, the electric field strength, and observations for electrical discharge. Electrical events were noted in one of two ways: two investigators listened for electrical noise in the tank; and the amplified, time delayed antenna signal was recorded on a chart recorder. Experiments showed that two types of electrical events could occur. The first were discrete audible events which also were readily detected by the antenna. The second event was a low level "hiss" which was noted by the investigators. However, the energy level was not sufficient to detect this type of discharge using the amplifier time delayed antenna. An event's apparent strength was recorded as "high" or "low" on a relative basis depending on the perceived noise level and whether the event was detected on the amplified time-delayed system.
- At 7000 gallons, the test was terminated. The nitrogen system was turned on and the tank was drained back to the storage system.

Commingled fuels were prepared by adding the static dissipater additive in one of two ways. For the ASA-3 additized fuel, the fully treated fuel was commingled with non-additized fuel until the target conductivity (~10 - 20 pS/m) was achieved. For the Stadis 450, additive was added in small steps , circulating until steady state was achieved. If the conductivity level did not meet the desired conductivity range, then more static dissipater additive was added and the process repeated. Recirculation was accomplished by drawing from the storage tank and sending the fuel back through the return lines. Fuel did not pass through the hydrant servicer during this process. Both procedures were equivalent, since the amount of additive to achieve the intermediate conductivity was approximately the same.

For fully additized fuel, additive was added until the conductivity reached ~ 50 - 75 pS/m. Fuel was recirculated until equilibrium was achieved.

In the clay treated fuels, an additional 1 ppm of ASA-3 was added to the fully additized fuel. The storage tank was then recirculated through the hydrant servicer to the clay treater and back to the storage tank through the return lines. The flow rate through the clay treater was kept relatively low to maximize the conductivity reduction per pass. The fuel was recirculated several times until the conductivity reached a low level. The same procedure was followed for the Stadis 450 additized fuel except 3 ppm of Stadis 450 was added to the fully additized fuel before clay treating. In the tests, more passes were required to reduce the conductivity of the ASA-3 treated fuel than the Stadis 450 treated fuel (~ 6 passes for ASA-3 vs. ~3 passes for Stadis 450).

In the test program, new unadditized fuel was used for each additive study, i.e., one batch was used for ASA-3 related experiments and a new batch was used for the Stadis 450 experiments. New clay bags were used for each clay treating experiment. The Velcon CDF-H monitors were not changed out during the entire test period. Mini-Static tests indicated that there were no likely contamination effects by not changing out the elements (Section 4.4.3).

5.4. Experimental results

A summary of the data from the field tests at Stapleton International Airport is given in Table 5. A complete set of test data is given in Appendix C. The test numbers are the actual sequence of the tests. The additive is the type of static dissipater additive used for the tests. Treatment refers to the type of simulation achieved. Where no treatment is noted, the fuel was not treated or only the additive was added at full dosage to achieve a conductivity greater than 50 pS/m. The conductivity was measured at the fuel temperature. The conductivity was adjusted to 68°F by the following relationship:

$$k_{68^\circ F} = k e^{.02105(68-T)} \qquad 5.4.1$$

This regression was obtained by regression of data range lines in CRC Handbook of Aviation Fuel Properties[12]. The charge density is the average value measured by the A.O. Smith meters. The relaxation time, τ, is calculated by the following relation:

$$\tau = \frac{\varepsilon \varepsilon_o}{k} \qquad 5.4.2$$

$$\varepsilon = 2.181 - 0.00192\frac{(T-32)}{1.8}$$

[12] *Handbook of Aviation Fuel Properties* CRC Document 530, p 68, Coordinating Research Council Inc, 1983

The dielectric constant is calculated at the fuel temperature[13]

EFS is the maximum measured field strength using the field strength meter. The initial volume is the amount of fuel present in the tank before start of test.

The row in Table 5 marked Label is a reference for figures to identify the test number.

Within the table there are two rows which refer to discharge events which occurred during the test period. In the row marked discharge, a *Yes* indicates that an audible noise emanated from the tank during the test period which the investigators heard. The level indicates whether the discharge was **None, High,** or **Low** -- as described below

The charge density at the tank inlet is given for low flow rates in Figure 20 and the corresponding runs at high flow rate are given in Figure 21. The letter N on the bars implies that this a new batch of fuel. This was obtained from the fuel tank when the experiments with ASA-3 were completed to avoid contamination of additional fuel with ASA-3. The liquid holdup between the CDF-H monitor vessel on the hydrant servicer which caused the charge generation and the tank was 26 gallons. ***NOTE: The charge density in subsequent figures and in Table 5 are as measured; these are negative of the actual charge density in the fluid. These are maintained this way in order to simplify graphs.*** In Figure 20, one can see that , in general, the charge density decreases as the conductivity rises. This is to be to be expected in situations where there is relaxation time between the charge generator and the and the actual measurement point. Thus, ASA-3 which has been commingled seems to behave as expected. From this data, one can conclude that the additional conductivity was sufficient to relax any additional charge that was developed at the monitor vessel. Similar behavior is also observed for Stadis 450, although the smaller decrease in the N type Jet A was less than would be expected by an exponential decay of charge with time. Again, this implies normal behavior of charge relaxation compensating the additional charge generation which may have occurred for additized fuel. This conclusion is applicable for both clay treated and commingled Stadis 450 However, this is not the case for clay treated ASA-3. The charge density is significantly higher than any of the other measurements The implication is that clay treating does not remove all of the components which cause charge generation. The lower conductivity resulting from clay treating cannot overcome the additional charge generated in the time required for the fuel to get to the tank

The same type of generalizations can be made for the higher flow rate case (Figure 21) Commingled fuel behaves normally, i.e., the charge density at the tank is monotonically reduced with conductivity. Clay treating shows an increased charging tendency. The clay treated Stadis 450 shows a slight increase over the unadditzed fuel This implies that additized fuel increases the charge generation tendency of the fuel. This is in agreement with the laboratory tests in Section 4 Again, clay treated ASA-3 shows a significantly higher charge generation tendency which is not compensated by conductivity ... that while the charge density is less for the clay treated fuel at a conductivity of 25 pS/m than the clay treated ASA-3 at 12 pS/m, both have a significantly higher charge density than the corresponding ASA-3 bearing fuel which has been commingled

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[13]Ibid, p66 (regression for Jet A)

Figures 22 - 24 deal with electrical events which occurred during fueling. In the field tests, three levels of electrical events were observed:

- there was charge generation at the monitor but no perceptible static discharge in the tank. These were characterized as **None** in Figures 22 and 23.
- there was charge generation at the monitor with a perctible "hiss" heard by the investigators. This persisted during most of the test. This was characterized as **Low** in Figures 22 and 23.
- there was charge generation at the monitor and audible discrete noise was heard by the investigators. Also, the amplified time relay was activated, noting a static electrical event in the tank. This was characterized as **High** in Figures 22 and 23.

At high flow rates, Figure 22 indicates that **High** level events were detected at low conductivities in non-additized Jet A. **Low** level events were noted for all of the additized fuels, commingled and clay treated. No event was noted for fully additized fuel (k ~ 65 pS/m).

Figure 23 plots the level of the static electrical event as a function of residence time., i.e., the time the fuel had for relaxation between the monitor vessel and the measurement point at the tank. Fuels with a residence time less than ~ 1.9 seconds had electrical events except for the fully additized fuel. Fuels with a residence time of greater than ~ 2.5 seconds did not record any electrical event. The actual demarcation of the presence of electrical events was not made. Thus, one can conclude that for this configuration, static electrical events occurred at a residence time of 1.9 to 2.5 seconds. This could change depending on a number of factors, e.g., tank configuration, fuel, monitor or filter type.

Figures 22 and 23 indicate the region where electrical events occurred, but do not explain why these events happened. Figure 24 attempts to provide some idea of the factors involved. A plot of the total charge in the tank against conductivity can provide a demarcation of when electrical events would occur. The line is a boundary drawn between the occurrence of events and no events. That is, to the right of the line one can expect an electrical event; no event is expected to the left of the line. This also indicates that the charge nessessary in a tank to cause an electrical event decreases with increasing conductivity. This is in agreement with previous observations where electrical discharges within the fluid to the inlet nozzle were observed[14]. The investigators at Stapleton International Airport were not able to verify the type of discharge which occurred. For the purpose of this study, the conservative position was taken that no discharge would be acceptable during fueling. That is, while it is unclear that the discharges observed in the field tests could cause an incendiary event, one would not take the position that filling an aircraft would be acceptable while these events were going on.

Another approach to the data is to assume that a certain energy level is necessary before an electrical event will occur. Thus, when the conductivity is greater than 40 - 50 pS/m, no electrical event will occur because the energy level is too low in any practical fueling case

[14]Walmsley, H.L., Shell Research Centre, Thornton England, *personal communication 1992*

Similarly, no event would occur when the energy level is below the curve in Figure 24 for a given conductivity level. When the total charge in the tank is less than 60 - 70 μCoulomb then **Low** level events will occur when one is to the right of the line. Above 60-70 μCoulomb then **high** level events could occur. Neither the actual demarcation line between the level of the static electrical event, nor the validity of this hypothesis, has been proven in the study. Further work would be required. However, this type of analysis suggests that the additional charge generated in a commingled fuel must be compensated for adequately to avoid electrical discharge. This requires that the tank charge be reduced more effectively as the conductivity increases.

To obtain a measure of the charge present in a tank, the following general equation or curve (Figure 25) can be used. Consider a tank of volume V_T which is filled with V_O of fuel initially. The fuel in the tank can be considered to be fully relaxed, i.e., the charge density is equal to zero. A charge balance around the tank can be described as[15]:

$$\frac{dQ}{dt} = Fq_{in} - \frac{Q}{\tau}$$

where

$$\tau = \frac{\varepsilon_o \varepsilon}{k} \qquad 5.4.3$$

One can define a set of parameters such that:

$$\phi = \frac{Q}{Fq_{in}\tau}$$

$$\theta = \frac{t}{\tau} \qquad 5.4.4$$

Substituting 5.4.4 into 5.4.3 and integrating one obtains:

$$\phi = 1 - e^{-\theta} \qquad 5.4.5$$

Once the fueling stops, then the total charge in the tank decays as:

$$\phi_o = e^{-\theta_o} \qquad 5.4.6$$

The results are shown in Figure 25. Thus, it is possible obtain an estimate of the maximum charge in the tank by knowing the fuel conductivity, flow rate, and charge density entering the tank. While the conductivity shown in the figures and in Table 5 is the rest conductivity, i.e., the conductivity measured while the fuel is motionless, previous work has shown that the "effective" conductivity, not the measured conductivity, should be used in the charge equations. The "effective" conductivity must be derived by applying Equation 5.4.6 to measurements taken after fueling has stopped.

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[15]variables are defined in Section 9

To complete the analysis, we can define the charge density in the tank as:

$$\Psi = \frac{q}{q_{in}}$$

$$\Gamma = \frac{V}{F\tau}$$

then

$$\Gamma = \theta + \Gamma_o$$

$$\Psi = \frac{\Gamma_o}{\Gamma_o + \theta} \qquad 5.4.7$$

Thus the ratio of the charge density in the tank to the charge density entering the tank, ψ, is a function of two parameters, viz., the initial volume of fuel in the tank relative to the product of the flow rate into the tank and relaxation time of the fuel, Γ_0, and the time divided by relaxation time, θ. This relationship is shown in Figure 26.

Figure 26 indicates that the charge density in the tank is not very sensitive to time of filling after an initial period of time. It is very sensitive to the parameter Γ_0. That is, a partially filled tank with uncharged fuel can reduce the charge density in the tank significantly by dilution.

In general, the hazard in a fuel tank is often described by the field strength produced by the charged fuel in the tank. The field strength in a rectangular tank has been readily described by Carruthers and Wigley[16]. Walmsley[17] indicates that the field strength for a horizontal cylindrical tank of the same height and base area are not significantly different. Thus, the effect of a cylindrical configuration can be accounted for by some factor determined from experiments when compared to the solution of a rectangular tank.

For a cylindrical tank, we denote the width and height as equal to R. The length of the tank is L. Then the field strength at the top center of the tank can be expressed as

$$E_m = \sum_r \sum_s \frac{0.576(-1)^{\frac{r+s+2}{2}} q}{\pi r s \beta} \frac{\cosh(\beta h) - 1}{\sinh(\beta R) + (\kappa - 1)\cosh(\beta R)\sinh(\beta h - \beta R)}$$

$$\beta = \pi\left[\left(\frac{r}{R}\right)^2 + \left(\frac{s}{L}\right)^2\right]^{1/2} \qquad 5.4.8$$

where r, s are odd integers 1,3,5, ... and q is in μC/m³

[16]Carruthers, J. A., K. J. Wigley, Jl. Inst. Pet 48 180 (1962)
[17]Walmsley, H. L. Jl. Electrostatics 26(2) 201 (1991)

The charge density is described by Equation 5.4.7. It depends on the inlet charge density, q_{in}, the flow rate, F, and the volume initially present in the tank, V_0. Thus, the field strength at a given height in the tank can be described as:

$$E_{fi} = qX \qquad 5.4.9$$

where X is the remaining portion of Equation 5.4.8

In the full scale tests, the field strength was measured for each test. These data are shown in Table 5. The field strength is the maximum that was measured. However, this value was reached very early in the test. This is counter to what would be predicted from Equation 5.4.8. It is not easily discernible whether the data are correct. Calibration of the device showed that it was responsive to field strength applied. However, several factors could have effected the results:

- the field strength was reduced because of discharges occurring during the test
- the surface was coated with foam which reduced the surface potential
- the equipment was affected by environmental conditions resulting in poor results.

Regardless of the cause, the field strength data are believed to be unreliable. They are presented in Table 5 for completeness. An alternate method was to estimate the field strength in the tank. Data obtained from similar experiments in the same equipment[18], but using a different field strength meter, were used to predict the field strength. Figure 27 shows a typical run where the conductivity was 2 pS/m and the flow rate was 900 GPM. As seen, the field strength increases throughout the test to a maximum voltage where fueling was stopped. From Equation 5.4.9, it can be seen that, when fueling stops, q is the only variable which is time dependant. That is, the charge begins to relax. Equation 5.4.6 indicates that the charge should decay exponentially. This is verified in Figure 28. The value of τ can be derived from the slope. This procedure was followed for a number of tests made during the grounding study. The effective conductivity, k_{eff}, ranged from 0.57 to 1.02 with an average of

$$k_{eff} = 0.86 \qquad 5.4.10$$

The ratio of conductivity to "effective" conductivity of 2.3 agrees well with values of 2 previously found[19]. Using this value of k_{eff} and the data of the grounding study one can determine a constant X for the vessel when the volume is 6500 gallons. The results vs the actual measured value is shown in Figure 29. The agreement is quite good. Therefore, using the same arguments, the field strength at the 6500 gallon level can be calculated for this study. The results are shown in Figure 30.
The same type of boundary between electrical events can be drawn as for the curve with total charge. The field strength could have reached levels as high as 260 kV/m. The shape of the boundary suggests electrical events occur in the liquid as was previously discussed.

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[18]*Aircraft and Refueler Bonding and Grounding Study* CRC Report Number 583 (February 1993)
[19]Kramer, H., O. Schon Proc. 9th World Pet Congress Tokyo 1975.

The conclusion is that the field strength can be of the order where electrical events could occur. The need to maintain the level below the boundary line is done in today's operations in unadditized fuels by maintaining flow rates at levels where there is time to relax charges to sufficiently low levels before the fuel enters the tank. System design and operation should maintain these relaxation times in new designs. It would also be useful to develop a methodology to assure that new systems do not increase the charge beyond levels currently seen in conventional systems.

6. Discussion of Results

6.1. Mini-Static Results

The samples of fuel randomly obtained from three sites indicated that the largest variability is obtained from the multi-product pipeline. The charge generation capability of the fuel depended on the source and conductivity of the fuel. In this study, the variation in charge generation increased with increasing conductivity in the fuel. The differences in charge density for these fuels will be less at the aircraft since the conductivity will permit more relaxation of the high conductivity fuels in the piping from the filter or absorbing media vessel to the aircraft tank. It is also clear that in an unadditized fuel system, a significant fraction of fuel deliveries are likely to have conductivities greater than 10 pS/m; 28% in this sample of multi-product fuels, 8%-10% in the previous study.

Because one can expect a large variability of charge generation capability in the field, providing sufficient residence time is necessary to avoid having a highly charged fuel enter the tank. No good estimate can be provided for the minimum residence time. This has to be developed from the safe operation of the aircraft fueling systems in the United States over the past years.

In general, the effect of static dissipater additive on the charge generation is relatively predictable. In these fuels, the increase in conductivity most likely will compensate for the increase in charge if sufficient residence time is provided after the charge generating element. The sole exception is clay treated ASA-3. In this case the charge generated is disproportional to the conductivity. Thus there is a potential that the charge would not be sufficiently reduced if residence time was designed to accommodate the typical fuel. While ASA-3 is no longer available commercially, it is expected that ASA-3 will remain in use for a significant time. Thus, one should consider readditizing the fuel to greater than 50 pS/m after clay treating ASA-3 containing fuel.

6.2. Field Test

6.2.1. Relationship to Ground Fueling Systems

The data from these tests indicate the wide range of electrostatic effects which can occur. The key is the residence time between the filter/coalescer or monitor vessel where charging occurs and the tank inlet. If sufficient residence time is provided, then the level of charge density entering the aircraft tanks will be sufficiently low to avoid discharges. This "minimum residence time" was developed from the historical record of fueling aircraft in the USA. Section 7 provides a survey of existing systems which might be used to understand the range of ground fueling systems used today. However, it should be noted that, in the present study, a single type of water absorbing media monitor was used. New materials, different configurations of the element, new vessel designs and location on the chassis of the hydrant servicer can have an effect on the charge developed. Designs of ground fueling systems should take into account such changes which could affect the level of charge density going into an aircraft.

6.2.2. Relationship to Aircrfat Fuel Tanks

The tank used in the field test is larger than a typical aircraft fuel tank. It was used to illustrate the effects of static dissipater additive on the charge density and field strength. The actual magnitude of the effects in a aircraft fuel tank is a function of a number of factors. Integral wing tanks in aircraft are different from the test tank and refueling rates to individual tanks can vary from those tested. However, several observations can be made.

Ribs in an aircraft wing divide the tank into bays, each of which behaves as a discrete tank. Each bay is roughly rectangular. Typical dimensions are 20 to 30 inches (0.5- 0.7 m) wide, 5 to 20 feet (2 to 6 m) long and 1 to 6 feet (0.3 to 2 m) deep. In addition, stringers extend 2 to 4 inches (0.05 to 0.1m) from the tank bottom at spacings of 6 to 12 inches (0.2 to 0.3 m). The effect of stringers is to maximize charge relaxation during initial fueling. In later model aircraft, advantage is taken of these stringers by directing the incoming fuel into and along the spaces between stringers. Similarly, the initial volume of uncharged fuel in the tank reduced the charge density in the tank by dilution of the incoming charge.

The mechanics of filling the aircraft are different from those in the test. In this test, fuel was introduced at the bottom as a jet at a constant rate in order to promote good mixing. In aircraft, the filling process varies from simply dumping the fuel into a convenient bay to a careful introduction of the fuel into the bottom of selected bays to minimize electrostatic effects due to charge concentration and the effects of splashing. Communication between bays permits fuel to run to the lowest point, the bays with the lowest bottoms filling rapidly, then slowing as additional bays begin to fill. Finally, the bays with highest tops begin to fill rapidly as lower bays become full. This dynamic fueling rate in each bay occurs even though the overall fueling rate remains constant. Since mixing of fuel between bays is poor, fuel in a given bay may be highly charged, coming directly from the inlet, or may have experienced significant relaxation and mixing while flowing through other bays. In addition, the residence time of the fuel in the aircraft plumbing from the inlet to the tank can provide some additional charge relaxation before introduction to the tank. This residence time can vary from 0 to 2 seconds depending on the type of aircraft.

A theoretical comparison, using a proprietary model, was made of electrostatic effect in the test tank with those in a worst case aircraft tank. The tank is from an old model in which fuel is delivered at a single point in one bay, with no precautions to avoid splashing. This tank is regarded as "safe" because of its long history of use with no electrostatic incidents. It is the "worst case" because, by comparative analysis, systems in subsequent aircraft have been designed to be less hazardous.

The analysis accounts for variation in flow rates to bays, assumes perfect mixing in each bay, and neglects effects of internal structures. Because the analysis is based on a rectangular tank, the test tank was approximated as a rectangular tank, 7.08x7.08x21.32 feet (2.16 x 2.16 x 6.5 meters).

Surface charge densities, surface potentials, surface energies, and electric field strengths in the ullage space in the test tank were calculated for the conditions of each test. The same fuel conditions were used to calculate the charge density into the aircraft tank at the normal maximum refueling rate of 240 GPM.

In all cases, the tank bay displaying the most severe electrostatic conditions was the one where the refueling line first entered. Its dimensions were 10.83x2.29x1.85 feet deep (3.30x0.80x0.56 m deep). For all the tests which displayed electrostatic discharges, the electrostatic characteristics calculated for the test tank were more severe than for the worst bay in the aircraft, even when the relaxation in the aircraft piping was ignored. In these cases, maximum surface potentials and energies obtained in the aircraft tank were generally 1/2 to 2/3 of those found in the test tank. When relaxation in the piping was accounted for, the surface potential and surface energies in the case of the lowest conductivity runs were reduced only slightly to about 45% to 60% of those calculated in the test tank. For higher conductivity fuels, relaxation in the aircraft fueling piping became an increasing factor. The severity of the calculated electrostatic characteristics were significantly reduced.

None of the low flow test cases gave any evidence of electrical events. The electrostatic characteristics calculated for the test tank and aircraft tank (at the normal refueling rate) were nearly equal when relaxation in the piping was ignored.

In addition, hypothetical fuels with lower conductivities (1.0, 0.33, and 0.1 pS/m) were examined. While the results for the aircraft tank relative to the test tank were relatively the same for the 1.0 pS/m as for the 2 pS/m case, the maximum surface potentials and surface energies were much lower in the aircraft tank relative to those in the test tank for these lower conductivity fuels.

The results of these calculations indicate that aircraft tanks present a demonstrably lower level of electrostatic potential than present in the full scale field tests which displayed evidence of electrical events and approximately the same level as in the lower flow rates when no electrical events were observed. The worst case for the aircraft tank relative to the test tank occurred when the test tank indicated a **High** electrical event. Thus, while these results do not suggest that there is an immediate unrecognized hazard in fueling aircraft with low conductivity fuels, they do imply that there is a small margin of error to accommodate fuels at significantly higher flow rates and/or charge densities.

This attempt to correlate the actual aircraft test tank to the full scale tests suggests the desirability of developing a small scale test device that could measure charge and filed strength during fueling. This test would permit examining both fuel and fuel system variables -- the critical factors in assessing the possibility of electrostatic hazards in ground fueling systems.

7. Residence Time Distributions in Present day Systems

7.1. Description of Questionnaire

Because of the complexity of ground fueling systems, it is not possible to give a general set of rules for design which would preclude electrical events. This is due to the many variables which can influence the charge density, and the field strength in the aircraft tanks. Features such as material of construction of the filter/coalescer elements or absorbing media elements, the fuel source and contaminants present, the water content of the fuel, as well as system design features such as flow rate, residence time, piping arrangement, etc. have a significant influence on the charge density entering the aircraft tanks. As noted in section 6, the configuration of the aircraft fueling handling system also has an influence.

Because of this, there are two methodologies for avoiding electrical events during fueling. The first is to additize the fuel to a conductivity of greater than 50 pS/m. The other is to rely on the historical record of safe fueling at a given site. The results of this study imply that there are no increased electrostatic hazard involved in handling fuel which has been commingled with fuel containing static dissipater additive than for fuel which is additive free. Thus, if one operates with residence times downstream of the charge generation elements within the system equivalent to those which have been operated safely, and one uses the same equipment, then no discharge will occur if none occurred in the past.

To provide some indication of the typical residence times seen in typical ground fueling operations, a survey was given to a wide range of users of such equipment. This included airlines, petroleum companies, and FBO's. Each was asked to provide dimensions of their refueling vehicles, the model of the filter coalescer or absorbing media vessel, and the number of units involved. Vendors of each model of filtration vessel were asked to provide the volume of fuel which the vessel held after the filter elements. This volume provides additional residence time for charge relaxation.

Some of the vessels reported could not readily be identified. In these cases the total residence time could not be ascertained. These were still included in the piping residence time data, but were eliminated for the remaining calculations. Thus the data reported area sampling of the residence times typically seen at various sites. The data are reported in Appendix D.

7.2. Filter/Coalescer Systems

Two types of ground fueling systems using filter/coalescer elements were reported. One was hydrant servicers, the other was refueler trucks. The data for residence time distributions for the hydrant servicers are shown in Figures 31 through 33. Also, Table 6 gives the mode, median, and average residence times in each section. The mode is defined as the residence time reported most often, the median is the residence time which is the mid point reported, i.e., there is an equal number of units with residence times less than the median as there is greater than the median. The average is the average obtained by adding all the residence times for the sample surveyed and dividing by the total number of units.

In hydrant servicers, the piping provides on average 3.1 seconds residence time, the vessel provides an additional 10.1 seconds. The average residence time in hydrant servicers using filter/coalescers is 12.8 seconds. All of the filter coalescer vessels used Teflon coated separators which are known to have little or no effect on charge generation. Thus adding the vessel and piping residence time is valid. This would not be the case for a paper separator.

In the refueler case, one user reported 231 units of the same type. The model of the filter coalescer could not be identified. The residence time in the piping was lower than the rest. Therefore, the piping residence time which included this user is given in Figure 34. The residence times excluding this user are given in Figures 35 through 37. The statistics for refuelers using filter/coalescers are given in Table 7. Interestingly, the total residence time is similar for both the refueler and hydrant servicer.

The data indicate that there is significant residence time for relaxation in these systems. The total time of 12-13 seconds is significantly longer than for the times measured in this test program, viz., 2-3 seconds in the field tests.

7.3. Absorbing Monitor Systems

For hydrant servicers using absorbing media, the residence time is solely in the piping after the vessel. Hence the total residence time for these systems is much shorter than in systems using filter/coalescers. The statistics are shown in Figure 38 and in Table 8. The average residence time is 4.5 seconds for these systems. However, the mode is 3.1 seconds, indicating that there are many systems in the field with less than the average reported

The times reported here are much closer to those found in the field test. Thus, additional care should be taken to ensure that design changes in these systems do not reduce the residence time or increase the charge density entering into the aircraft

8. Conclusions & Recommendations

8.1. Conclusions

The following conclusions resulting from the *CRC Ad Hoc Panel on Commingled Fuels* program must be judged with respect to the design and operation of aircraft fueling systems. Tests were representative of the residence time for relaxation of charge in two systems: one was indicative of current systems; the second was indicative of future trends involving higher flow rates and shorter residence times in piping, hoses, and manifolds downstream of the filter elements.

1. *Providing sufficient residence time for charge relaxation is critical in aircraft fueling operations.*

When changes are made, such as

- replacing filter/separators with absorbing media monitors,
- operating at higher flow rates or with shorter hoses,

or, if ground fueling systems for aircraft becomes less conducive to charge relaxation than current systems, situations may be created in which static discharges become possible. Similar situations may result when filter media or filter design changes result in increased charge generation in the fuel.

2. *Commingled fuels that combine fuels with static dissipater additive (SDA) with non-additized fuel do not exhibit unusual static charging behavior.* These can be handled as safely as non-additized fuels.

3. *Fuel containing SDA with a conductivity of 50 pS/m or greater does not present a hazard in aircraft fueling in present day systems or in any anticipated future fueling systems.*

4. *Fuels with conductivity below 50 pS/m, including additive-free fuel, do not present a hazard of static discharge with typical fueling practices currently employed.* However, fuels in this conductivity range (< 50 pS/m) could produce static discharges if future changes in ground equipment, aircraft design, or fueling practice significantly reduce relaxation time.

5. *Fuel containing SDA should not be clay treated (unless re-additized to a conductivity greater than 50 pS/m) since clay treatment can change the relative proportions of components remaining in the fuel.* This can produce unpredictable static behavior[20].

8.2. Recommendations

[20]In this program, only ASA-3 showed a large charging tendency at low conductivity when clay treated. When ASA-3 is no longer used, this restriction need not be followed for ASTM approved SDA.

1. Aircraft fueling systems should be monitored periodically to determine if any exceed the typical practice (described in this report) in residence time or equipment charging tendency. Such systems may require modification or addition of SDA.

2. A small-scale charging tendency test should be developed to sense residual charge after fuel flow through an apparatus that simulates aircraft fueling practice. This could be used to test fuels, additives, and filter media.

3. Fuel with conductivity less than 50 pS/m can be used in current ground aircraft fueling systems. Where higher flow rates or lower residence times than current practice are seen, consideration should be given to additizing the fuel.

9. Nomenclature

Variable

E_{FS} .... Field Strength [kV/m]
F .... Flow Rate [Gal/min]
F_{mst} .... Flow Rate Through Mini-Static Tester (normally equal to 100 ml/min) [ml/min]
i_{mst} .... Streaming current from Mini-Static Tester [nano-amperes]
h .... liquid level in tank [m]
k .... Conductivity [pS/m]
k_{eff} .... effective conductivity [pS/m]
k_{68^oF} .... Conductivity of fuel at 68^oF
L .... Tank length [m]
Q .... Total Charge in Tank [μC]
Q_o .... Total Charge in Tank after fueling stopped [μC]
q .... Charge density [$\mu C/m^3$]
q_{in} .... Charge density of fuel into tank [$\mu C/m^3$]
q_{mst} .... Charge density obtained from Mini-Static Tester [$\mu C/m^3$]
R .... Tank diameter [m]
r, s .... odd integers 1,3,5,7,.....
T .... Temperature of fuel [^oF]
t .... Time (seconds]
t_o .... Time when fueling stopped [seconds]
V .... Volume of fuel in tank [gal]
V_o .... Initial volume of fuel in tank [gal]

Sub-scripts

eff .... effective
FS .... Field Strength
in .... into tank
mst .... Mini-Static Measurement

Greek Symbols

β .... Shape parameter [Equation 5.4.8]
ε .... Relative electrical permitivity of fuel
ε_o .... Dielectric Constant of fuel [8.84 pico-farads/m]
ϕ .... Dimensionless Total Charge = $Fq_{in}\tau$
ϕ_o .... Dimensionless Total Charge after Fueling Stopped = Q/Q_o
θ .... Dimensionless time = t/τ
θ_o .... Dimensionless time after fueling stopped = $(t-t_o)/\tau$

τ .... Relaxation time = $\varepsilon\varepsilon_o/k$ [sec]
Γ .... Reduced Volume = $V/F\tau$ [Equation 5.4.7]
Ψ .... Reduced charge density = q/q_{in} [Equation 5.4.7]
X .... Field strength at given height/ charge density [Equation 5.4.9]

Table 1 - Elements Used for Selecting Reference Filter

Filter/Coalescer Elements	Absorbing Media Elements
Velcon 83 Series	Velcon CDF-H
Velcon 84 Series	Aquacon ACO
Quantek CCN 8 Series	Quantek FGO
Facet UK CA22 Series	

Table 2 -- Distribution of Conductivity in Colonial Samples

Conductivity Range	*Frequency*	*Cumulative %*
0-5	13	46.43%
5-10	7	71.43%
10-15	6	92.86%
15-20	1	96.43%
20-25	1	100.00%
25-30	0	100.00%
30-35	0	100.00%
35 +	0	100.00%

Table 3 -- Effect of Pipeline Drag Reducer Additive

Sample	Charge Density $\mu C/m^3$	
Jet A	-46	-60
Jet A w/CDR-202, Unsheared 50 ppm	27	40
Jet A w/CDR-202, Sheared 50 ppm	39	-10

Note: Reference filter: CDF-H
Blockage occurred when CA22 reference filter used

Table 4 -- Effect of Residual Additive Adsorbed on Element on Charging Tendency

Series*	Type	Conc., mg/L	Conductivity pS/m	Temp., C	Charge Density, µC/m3
I	None	-	4	19	-47
	None	-	4	19	-37
	None	-	4	19	-27
	None	-	4	19	-35
	None	-	4	19	-33
	None	-	4	19	-27
II	ASA-3	1 0	197	19	-2246
	ASA-3	1 0	197	19	-2422
	ASA-3	1 0	197	19	-2570
	ASA-3	1 0	197	19	-2715
	ASA-3	1 0	197	19	-2911
	None	-	4	19	-85
	None	-	4	19	-53
	None	-	4	19	-49
	None	-	4	19	-37
	None	-	4	19	-36
	None	-	4	19	-29
	None	-	4	19	-30
	None	-	4	19	-31

*Same CDF-II Filter pad used for all runs in a series

Table 4 continued

Series[a]	Type	Conc. mg/L	Conductivity pS/m	Temp. C	Charge Density μC/m3
III	ASA-3	10	1850	20	-71
	ASA-3	10	1850	20	-71
	ASA-3	10	1850	20	-63
	ASA-3	10	1850	20	-60
	ASA-3	10	1850	20	-63
	None	-	4	20	-370
	None	-	4	20	-74
	None	-	4	20	-63
	None	-	4	20	-64
	None	-	4	20	-71
	None	-	4	20	-62
	None	-	4	20	-76
	None	-	4	20	-80
	None	-	4	20	-87
	None	-	4	20	-75
	None	-	4	20	-73

Table 4 continued

Series*	Type	Conc. mg/L	Conductivity pS/m	Temp C	Charge Density μC/m3
IV	ASA-3	10	1850	22	-12
	ASA-3	10	1850	22	-32
	ASA-3	10	1850	22	-29
	ASA-3	10	1850	22	-19
	ASA-3	10	1850	22	-18
	None	-	4	22	-252
	None	-	4	22	-185
	None	-	4	22	-217
	None	-	4	22	-198
	None	-	4	22	-179
	None	-	4	22	-167
	None	-	4	22	-164
	None	-	4	22	-158
	None	-	4	22	-145
	None	-	4	22	-139
	None	-	4	22	-127

Table 5 -- Summary of Test Results for Stapleton International Airport Tests

Test # ==>	P1	1	2	3	4	5	6	7
Item								
Additive	None	None	None	ASA-3	ASA-3	ASA-3	ASA-3	ASA-3
Treatment						Commingled	Commingled	Clay Tr'd
Fuel T (F)	34	32	30	45	48	43	43	66
k (pS/m)	2	4	3	65	63	16	15	12
k at 68F	4.1	8.5	6.7	106.5	96.0	27.1	25.4	12.5
Flow Rate (GPM)	900	900	560	870	560	875	550	875
q∞ (μC/m³)	319.9	399.2	353.6	68.2	50.6	215.6	113.1	1319.7
Discharge	Yes	Yes	No	No	No	Yes	No	Yes
Level	High	High				Low		Low
τ (sec)	9.6	4.8	6.4	0.3	0.3	1.2	1.3	1.6
Initial Vol (gal)	595	595	595	595	595	595	595	595
EFS Max.	6.9	11.6	5.8	3.5	4.6	2.3	1.2	16.2
Label	JH-	JH-	JL-	AH-	AL-	AHM	ALM	AHC

Test # ==>	8	9	10	11	12	13	14	15
Item								
Additive	ASA-3	ASA-3	None	None	STS 450	STS 450	STS 450	STS 450
Treatment	Clay Tr'd	Clay Tr'd			Commingled	Commingled	Clay Tr'd	Clay Tr'd
Fuel T (F)	85	84	66	71	74	75	69	70
k (pS/m)	20	25	5	6	24	22	9	13
k at 68F	21.3	27.2	5.2	5.6	21.2	19.0	8.8	12.5
Flow Rate (GPM)	590	875	870	590	880	610	845	610
q∞ (μC/m³)	737	1308.3	442.9	398.9	308.3	211.8	569.2	332.1
Discharge	No	Yes	Yes	No	Yes	No	Yes	No
Level		Low	High		Low		Low	
τ (sec)	0.9	0.8	3.8	3.2	0.8	0.9	2.1	1.5
Initial Vol (gal)	595	595	595	595	595	595	595	595
EFS Max.	8.1	36.2	42.6	50.9	18.5	15.0	9.3	4.6
Label	ALC	AHC	JH-	JL-	SHM	SLM	SHC	SLC

Table 6 -- Residence Time in Hydrant Servicers Using Filter Coalescers

Section	Mode	Median	Average
Piping	2 6	2.7	3.1
Vessel	8 1	8.1	10.1
Total	11 0	11 0	12.8

Time in seconds

Table 7 -- Residence Time in Refuellers Using Filter Coalescers

Section	Mode	Median	Average
Piping	1 3	1 3	2.2
Piping ex 1 User*	2 3	3 8	4.5
Vessel	6 6	8 1	8.5
Total	10.4	13 1	13

* One user with 231 units removed to provide more typical use in field. Vessel residence time was not available for this case

Time in seconds

Table 8 -- Residence Time Distribution in Hydrant Servicers Using Absorbing Media Monitors

Section	Mode	Median	Average
Piping	3.1	4 2	4 5

Time in seconds

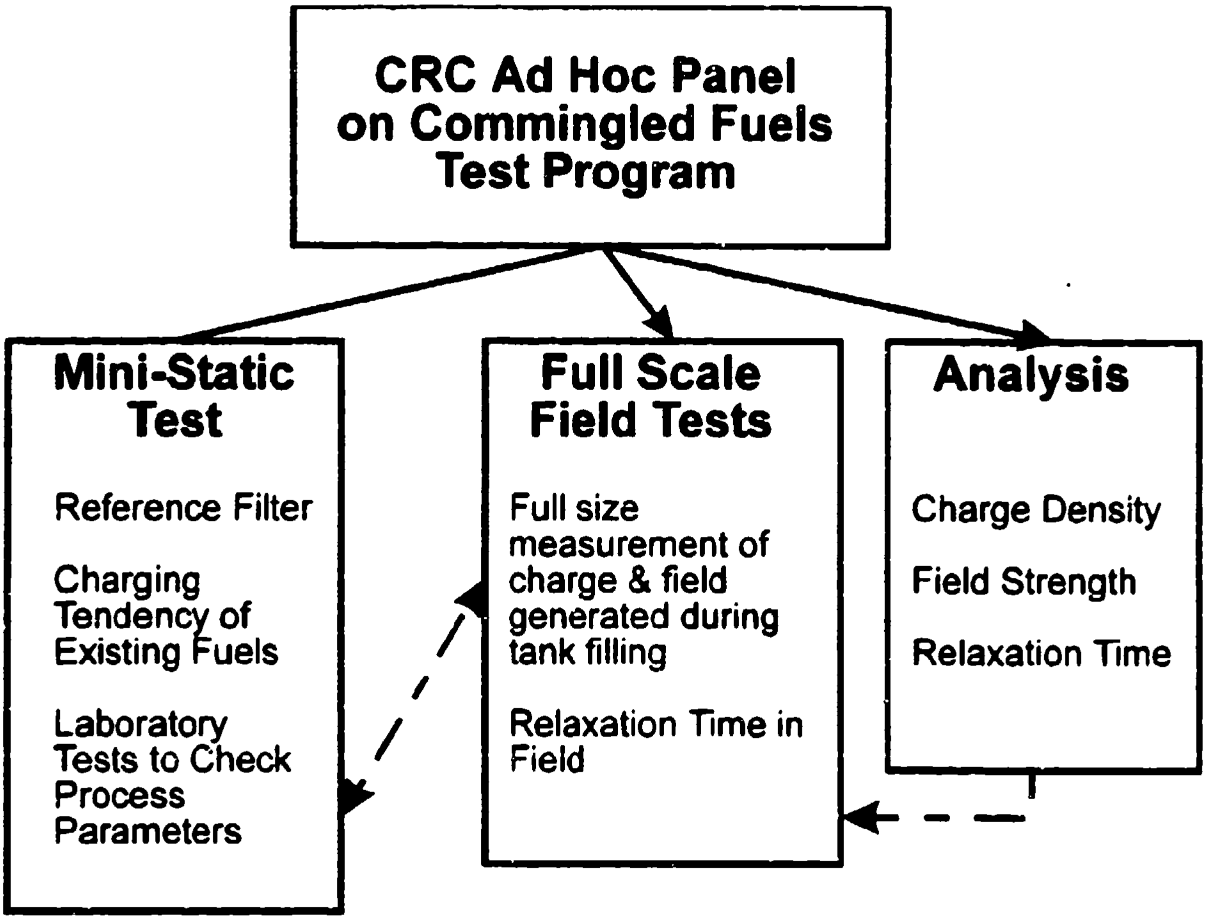
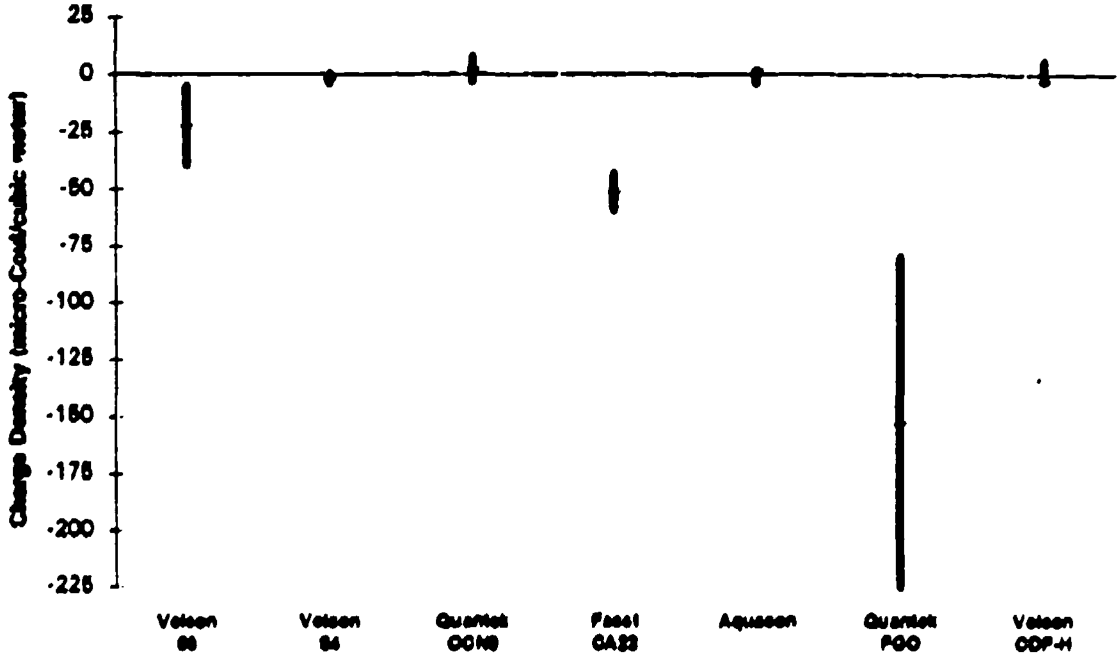
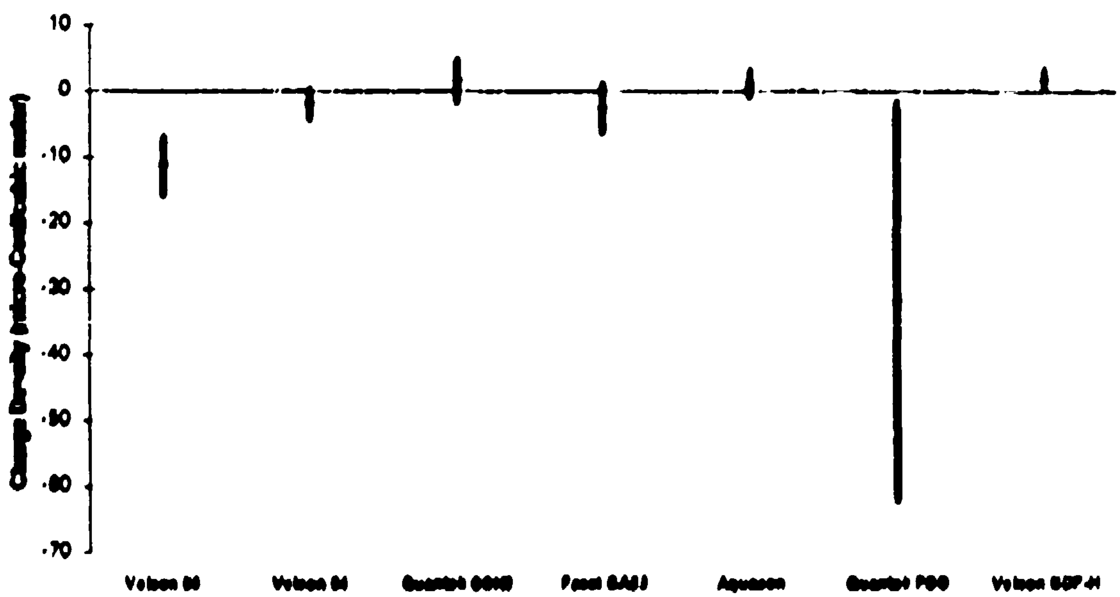


Figure 1 – CRC Ad Hoc Panel on Commingled Fuels Program Elements



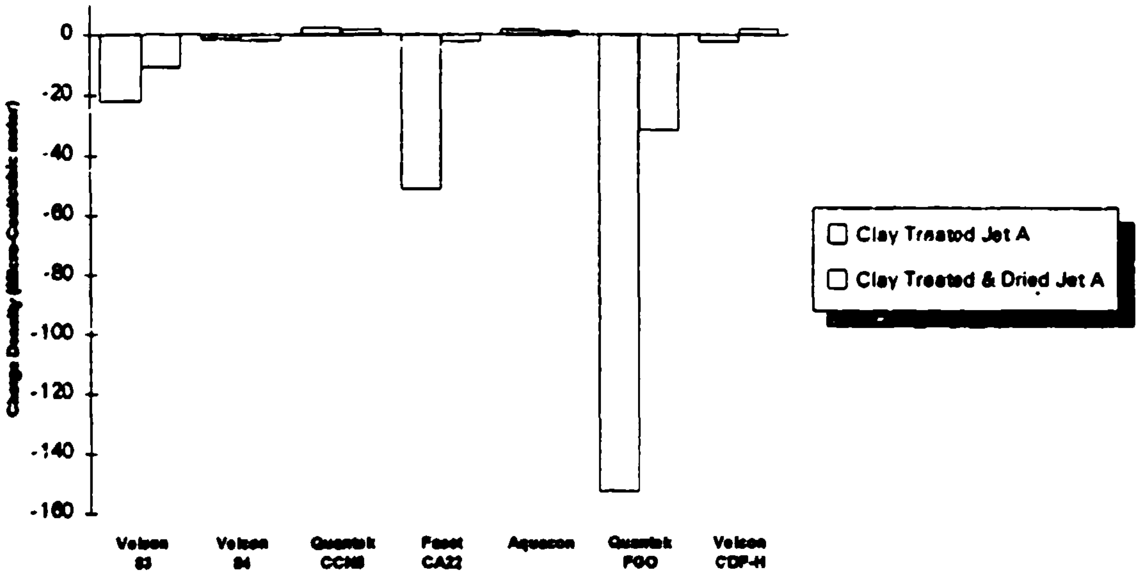
Note: Velcon 83, Velcon 84, Quantek CCN8, Facet CA22 are Filter/Coalescer Elements
Aquacon, Quantek FGO, Velcon CDF-H are Absorbing Media Elements

Figure 2 -- Range of Variability of Charge Density in Clay Treated Jet A



Note Velcon 83, Velcon 84, Quantek CCN8, Facet CA22 are Filter/Coalescer Elements
Aquacon, Quantek FGO, Velcon CDF-H are Absorbing Media Elements

Figure 3 -- Range of Variability of Charge Density in Clay Treated Dry Jet A



Note: Velcon 83, Velcon 84, Quantek CCN8, Facet CA22 are Filter/Coalescer Elements
Aquacon, Quantek FGO, Velcon CDF-H are Absorbing Media Elements

Figure 4 – Average Charge Density for Jet A Fuel

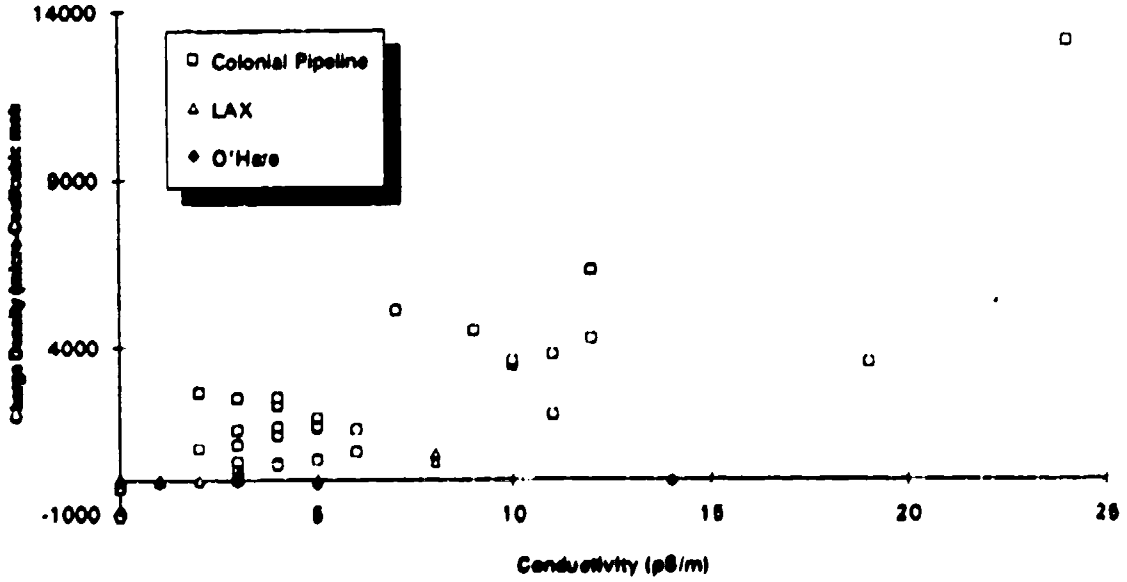


Figure 5 -- Charge Density of Field Samples of Jet A at All Locations

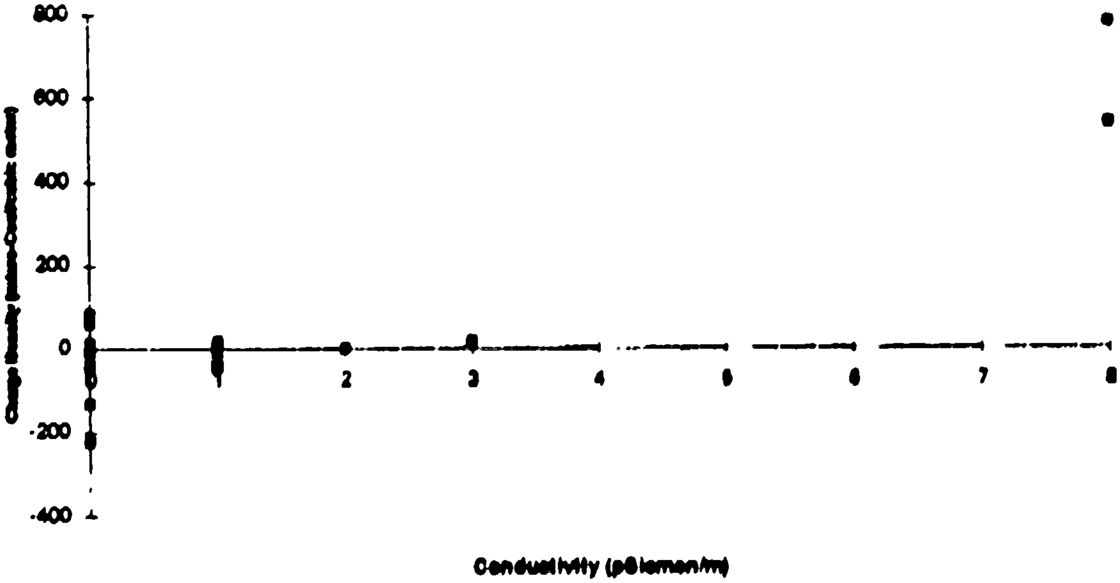


Figure 6 -- Charge Density of Jet A Samples at LAX (Expanded from Fig. 5)

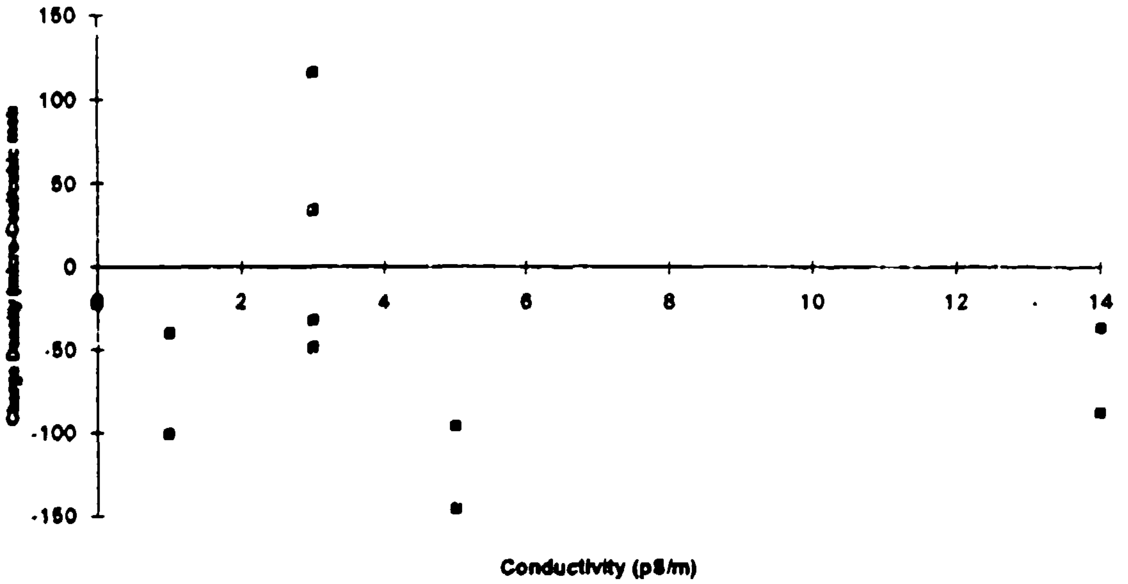


Figure 7 -- Charge Density of Jet A Field Samples at O'Hare (Expanded from Fig. 5)

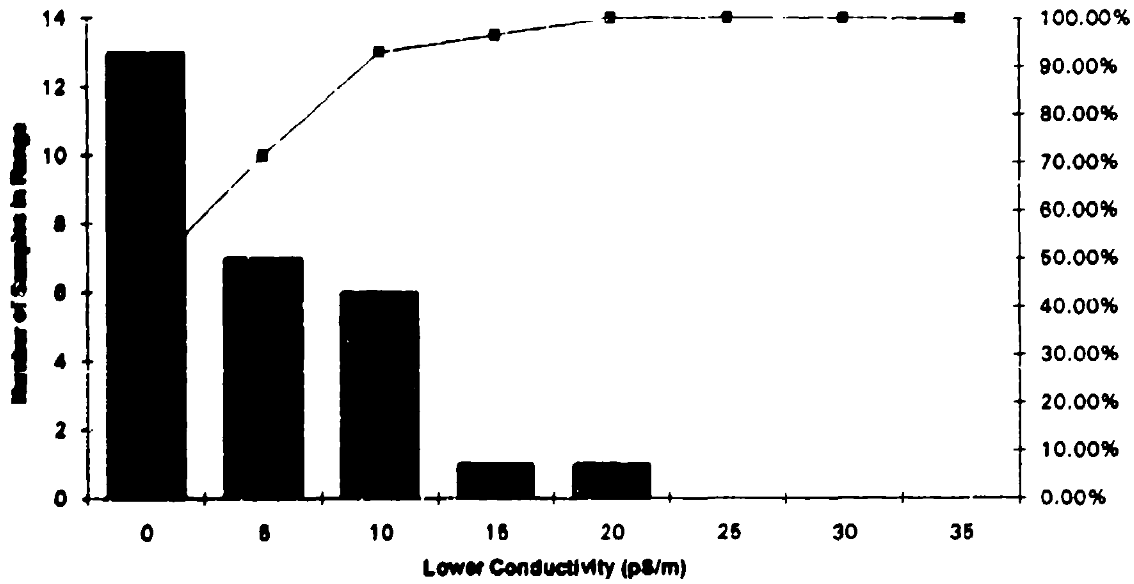


Figure 8 -- Distribution of Conductivity at Colonial Pipeline
(Conductivity under bar is lower limit, e.g., 10 is conductivity between 10 - 15 pS/m)

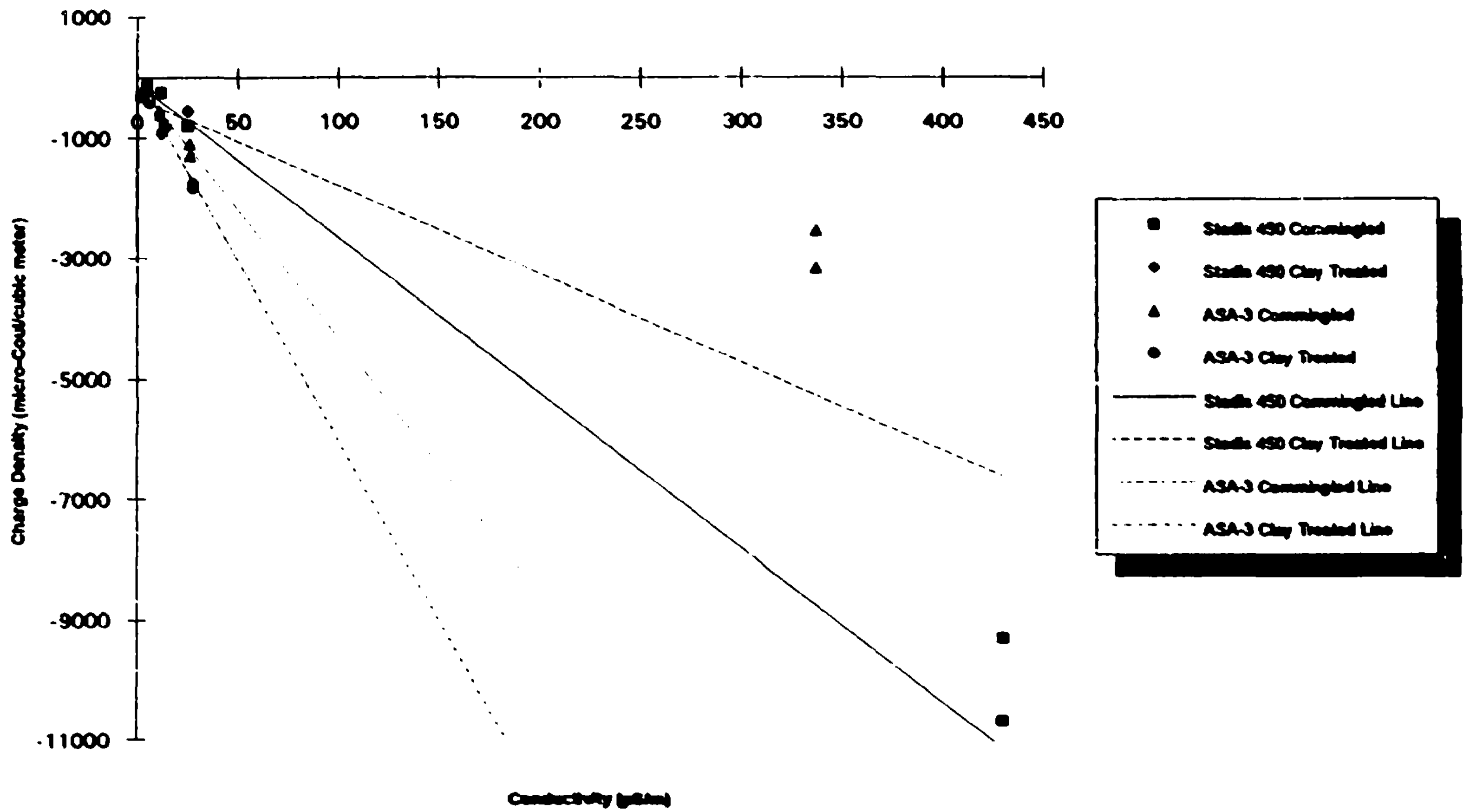


Figure 9 — Effect of Clay Treating & Commingling on Charge Generation Tendency of ASA-3 and Stadis 450 in Jet A

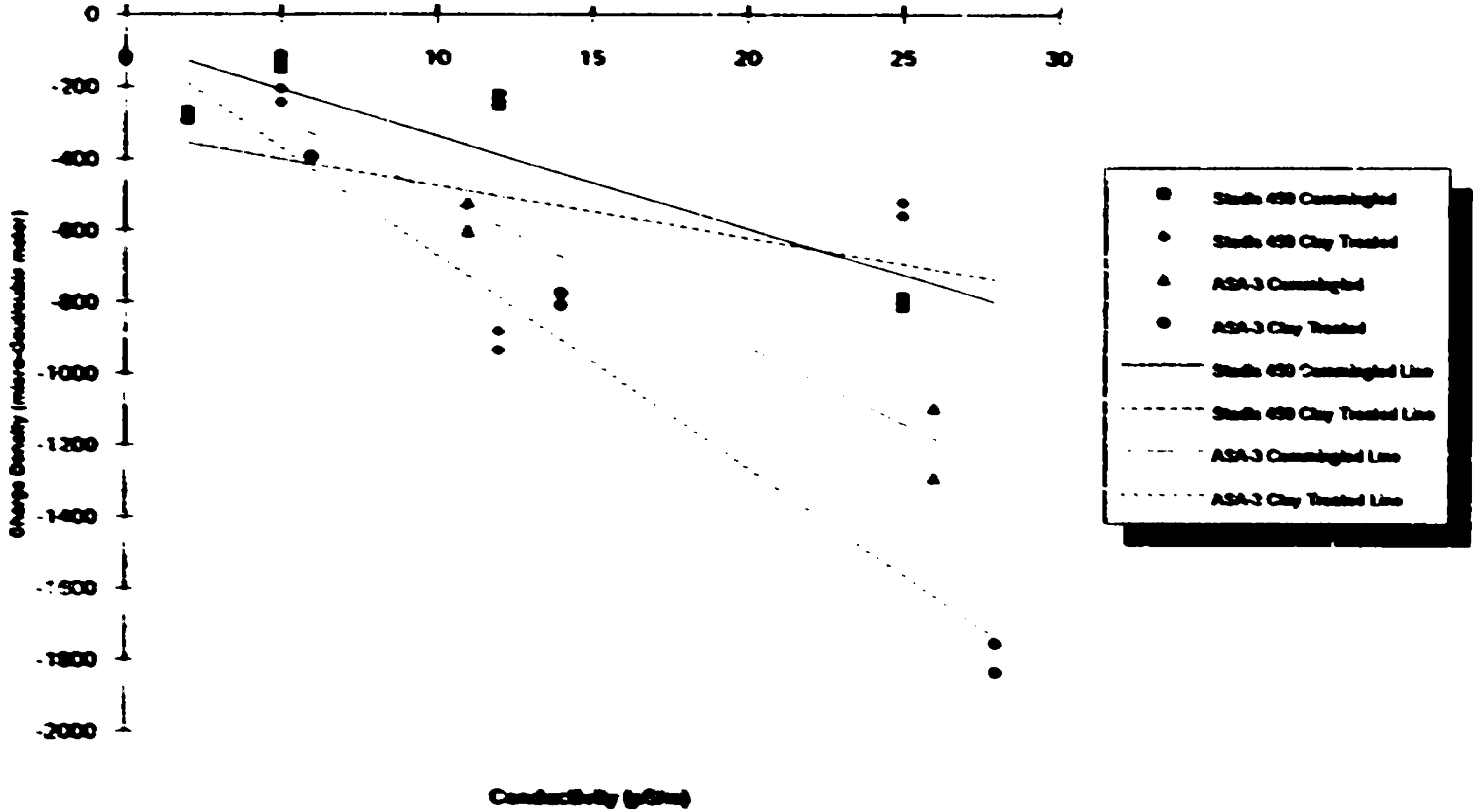


Figure 10 – Effect of Clay Treating & Commingling on Charge Generation Tendency of Jet A Fuel Containing SDA
(Expanded Section for conductivity 0-30 pS/m)

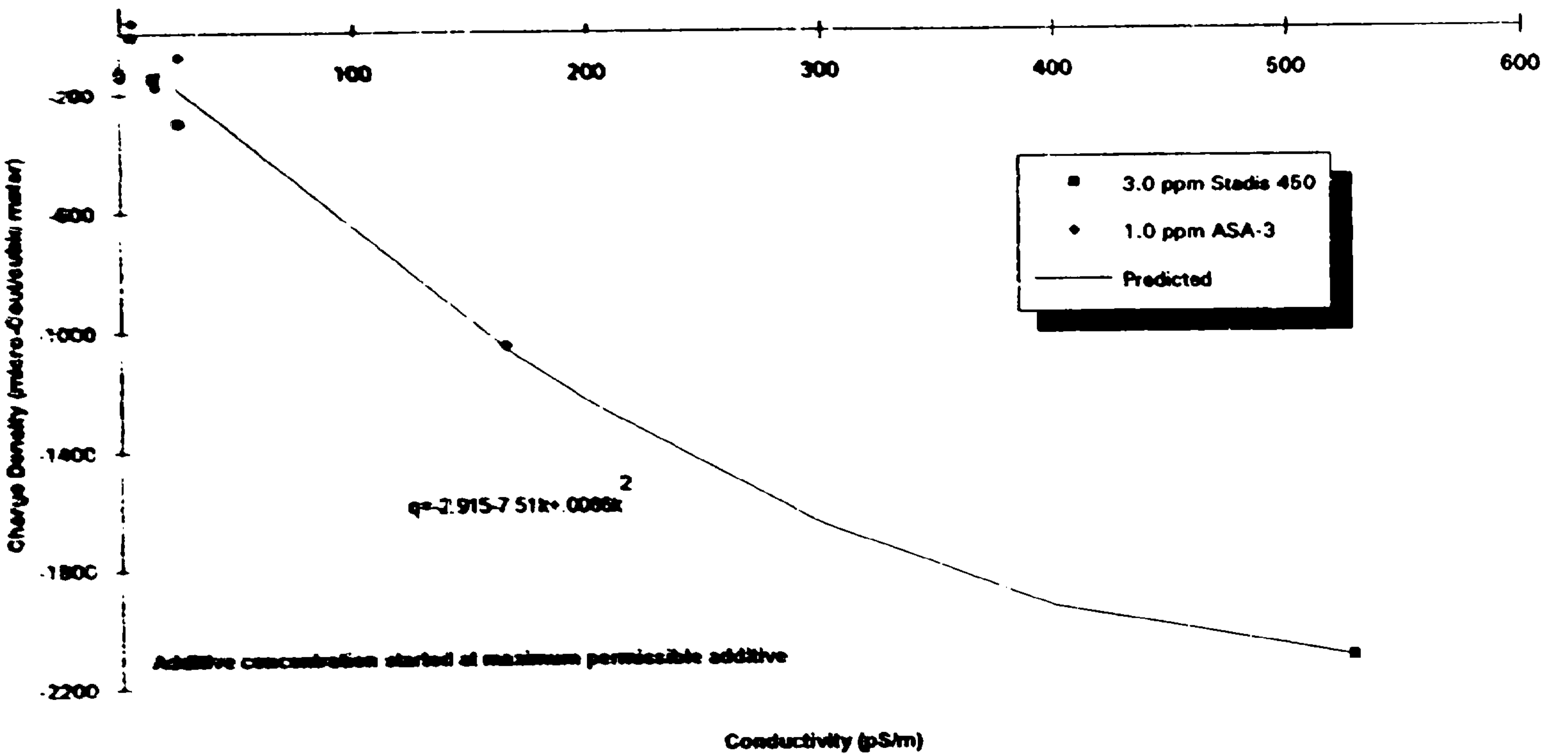


Figure 11 – Effect of Commingling of Jet A Containing ASA-3 or Stadis 450 Using CDF-H as Reference Filter

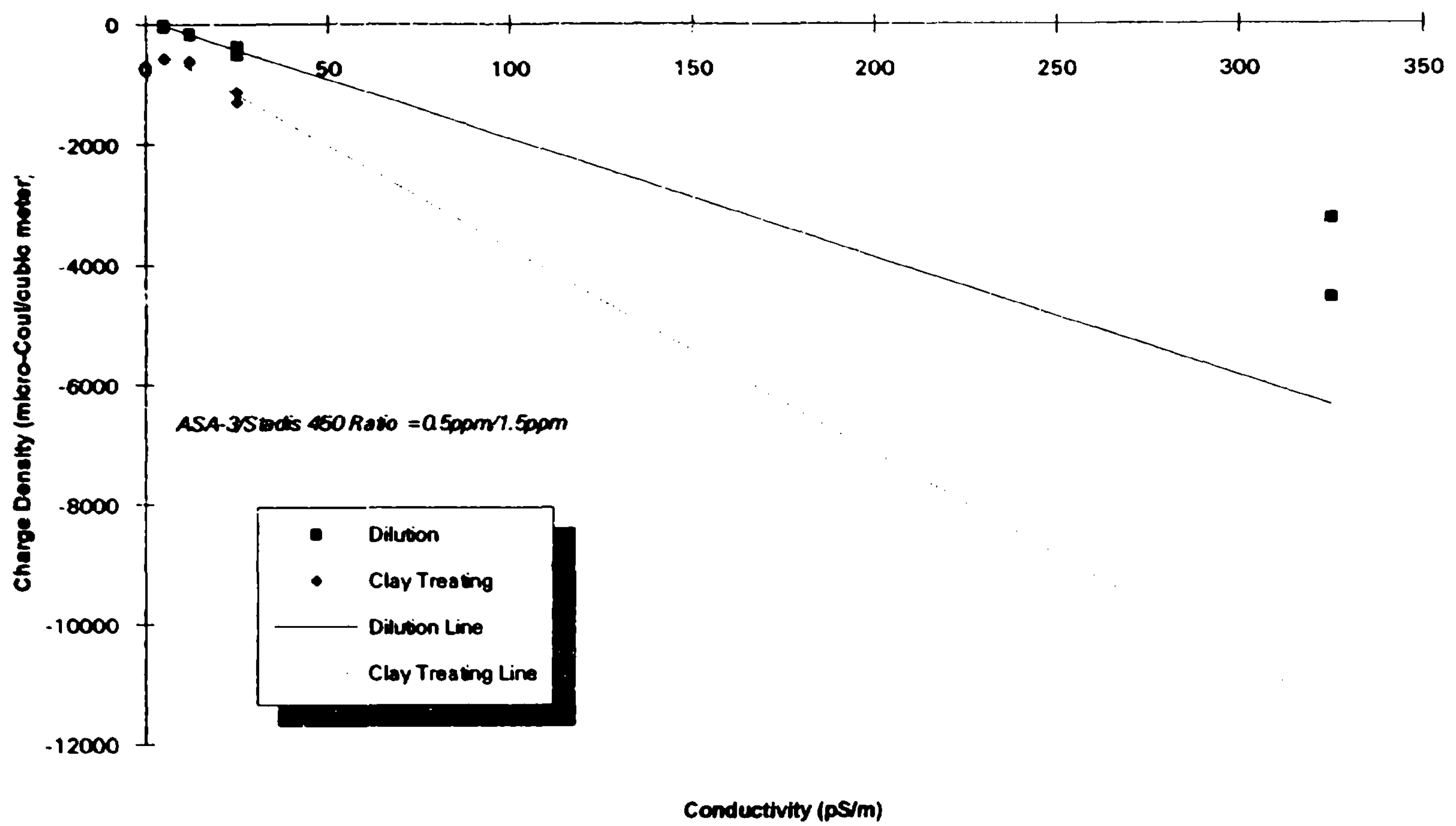


Figure 12-- Effect of Co-Mixtures of ASA-3 and Stadis 450 on Static Charge Generation Tendency in Jet A

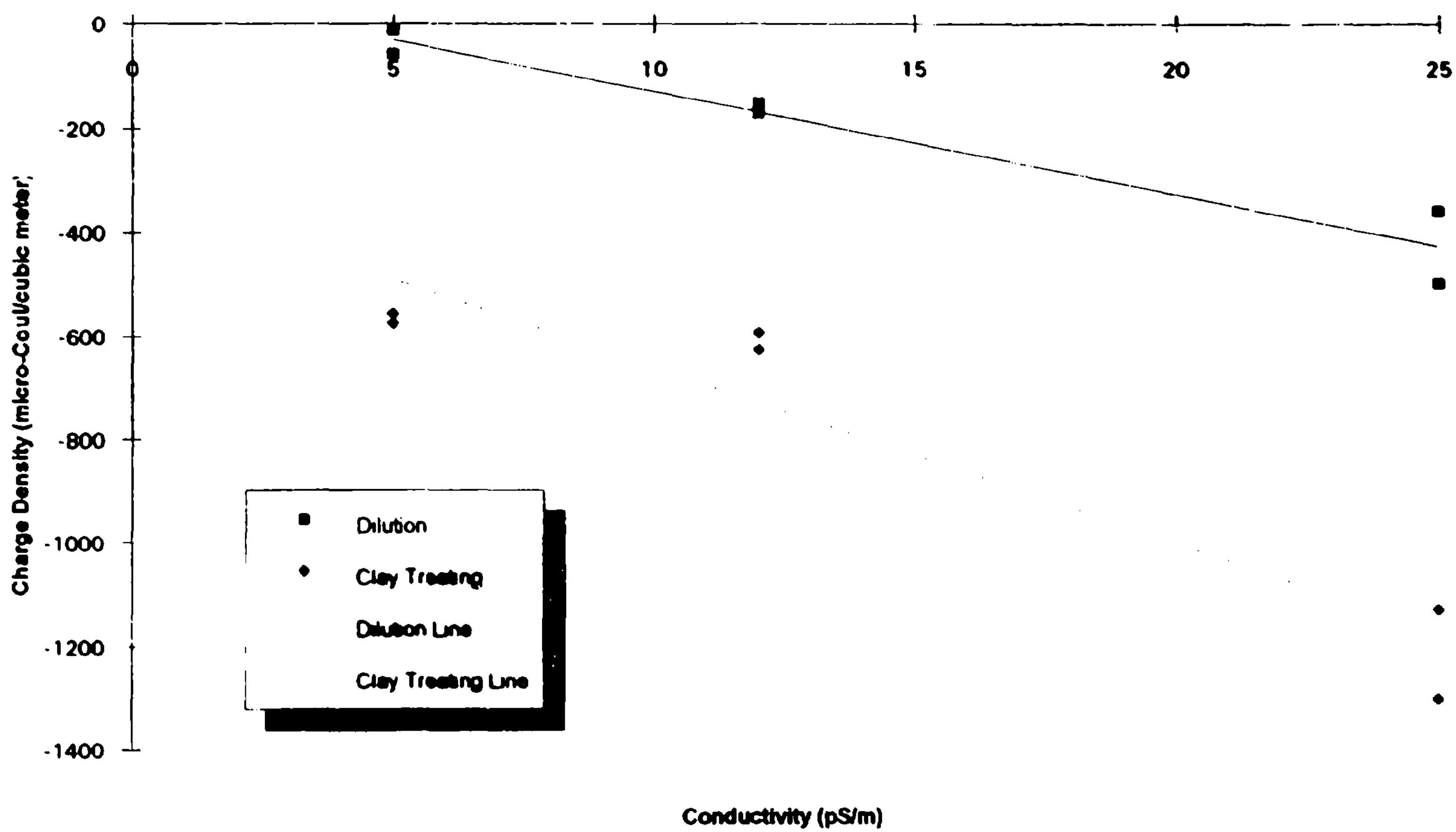


Figure 13-- Effect of Co-Mixtures of ASA-3 and Stadis 450 on Static Charge Generation Tendency in Jet A
(Expanded Region from k=0-25 pS/m)

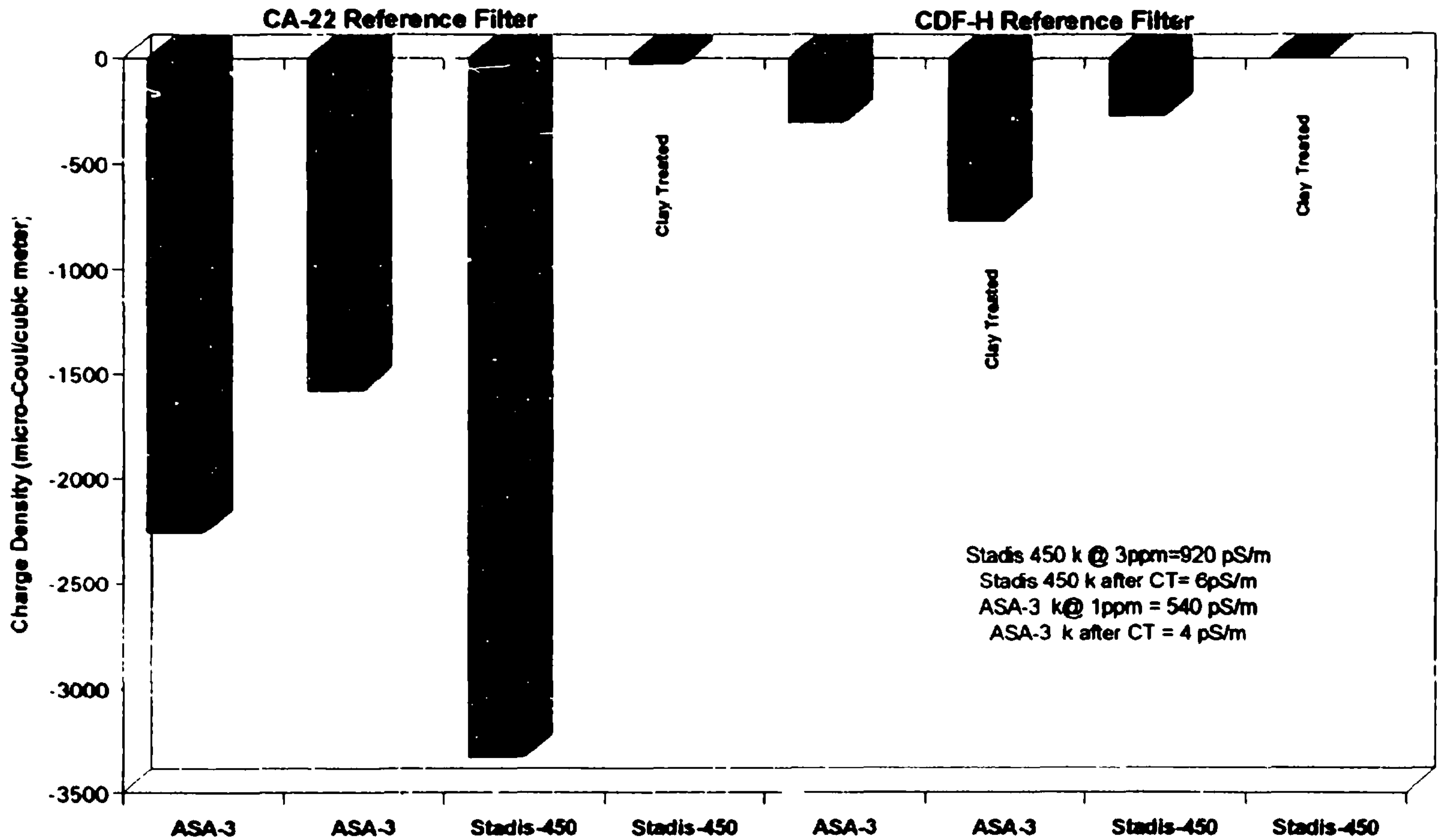


Figure 14 -- Effect of Clay Treating Using Simulated Clay Bag Vessel on Static Charge G^.eration in Jet A Containing SDA

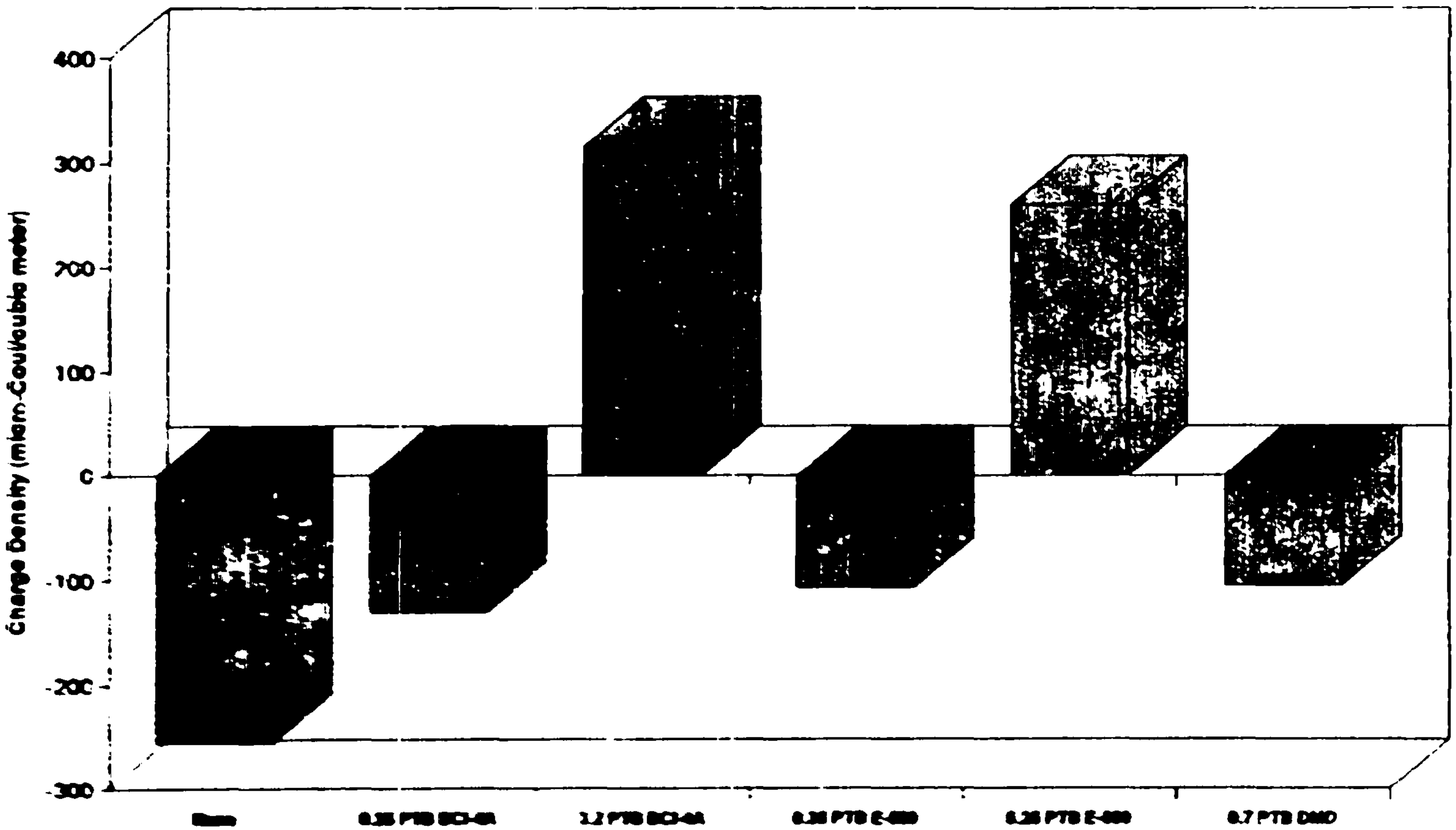


Figure 15 – Effect of Corrosion Inhibitors on Static Charge Generation of Jet A
(Reference Filter CA22)

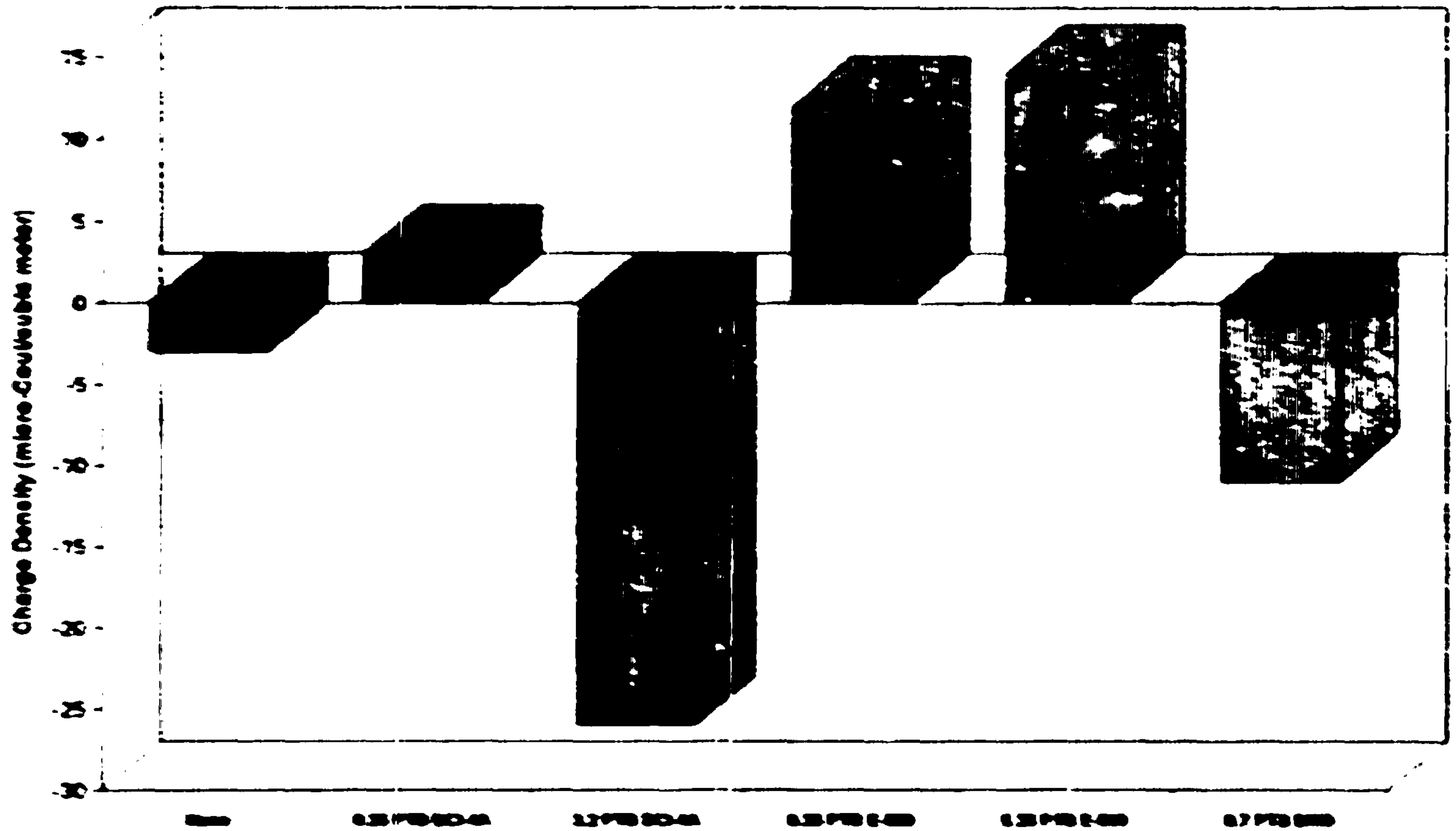


Figure 16 – Effect of Corrosion Inhibitor on Static Charge Generation in Jet A (Reference Filter CDF-H)

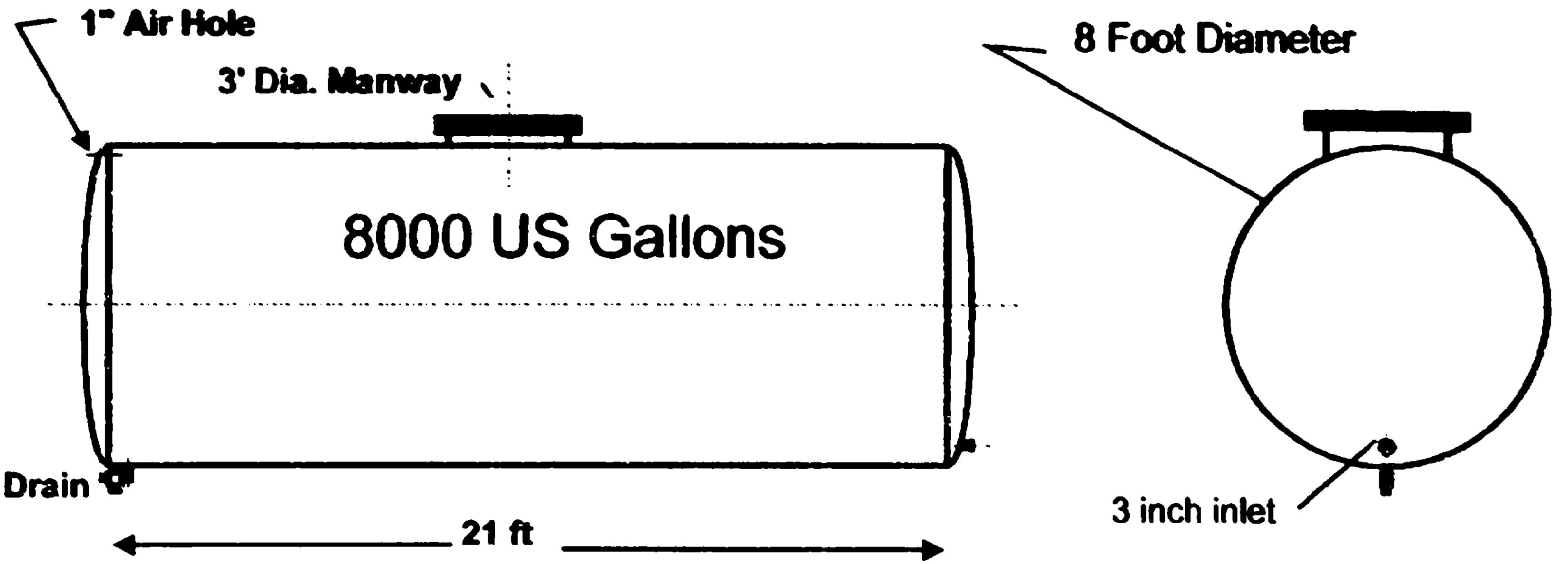


Figure 17 -- Tank Used in Stapleton International Airport Full Scale Tests

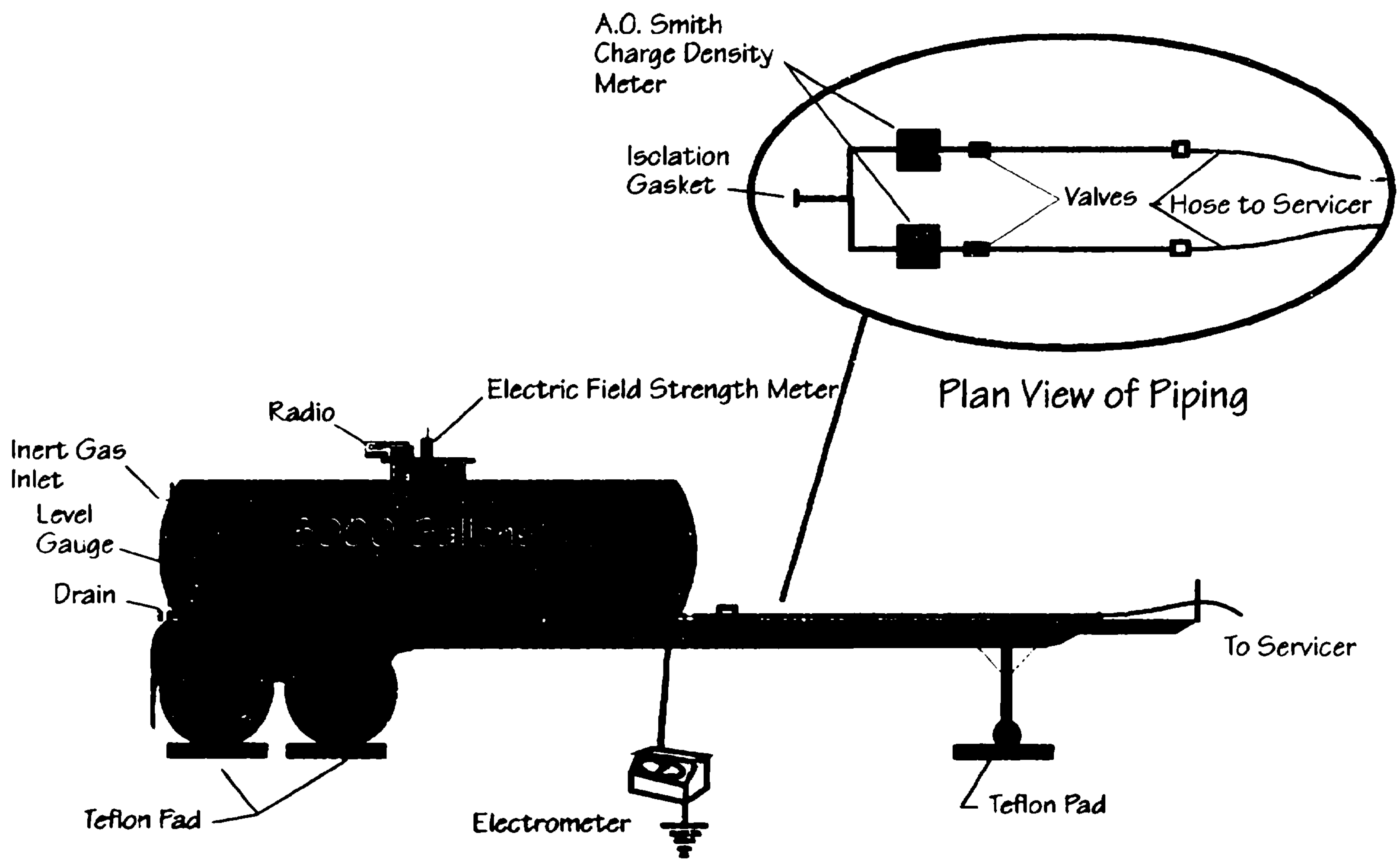


Figure 18 – Schematic of Tank & Instrumentation at Stapleton International Airport

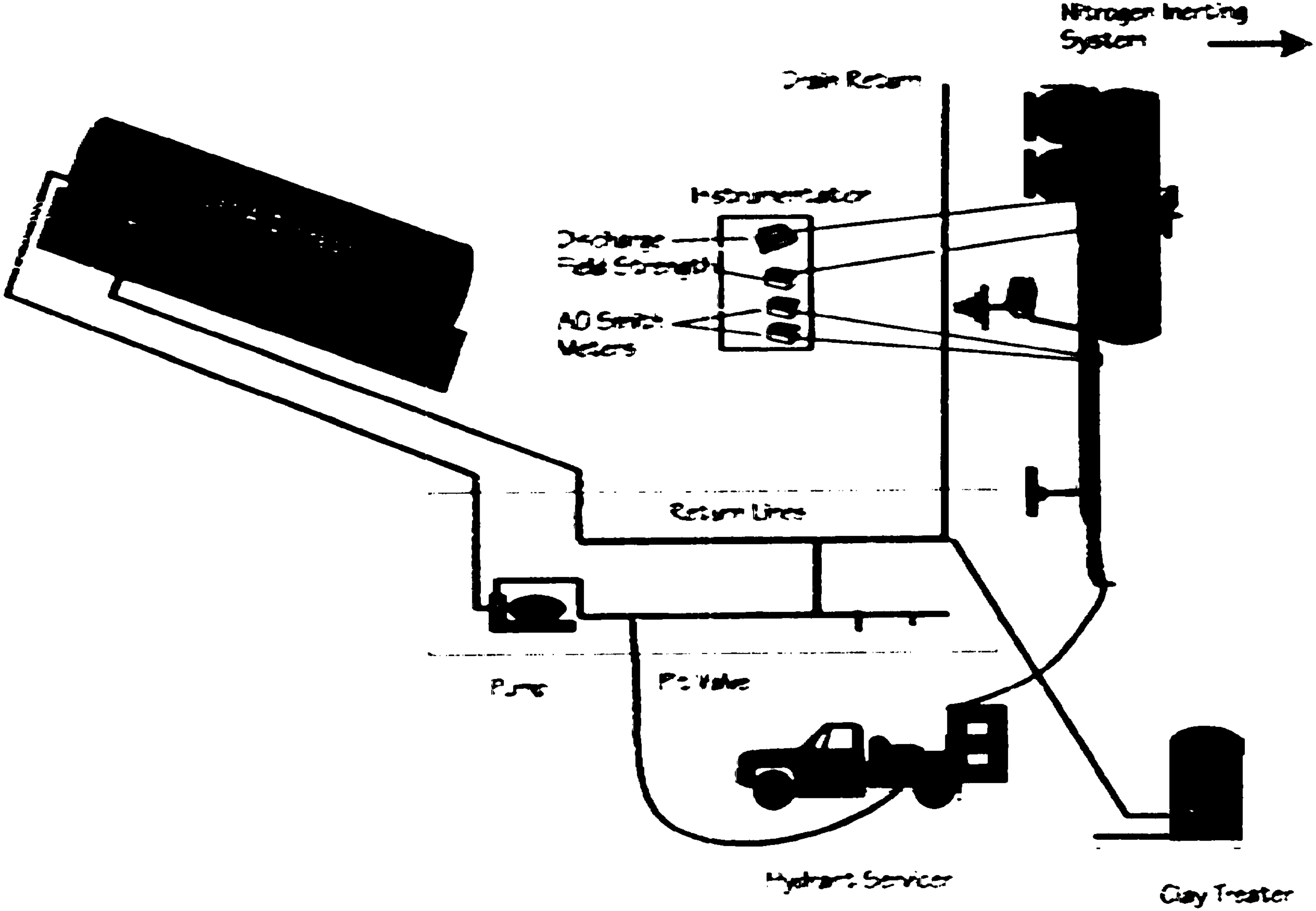


Figure 19— Schematic Layout of Full Scale Test

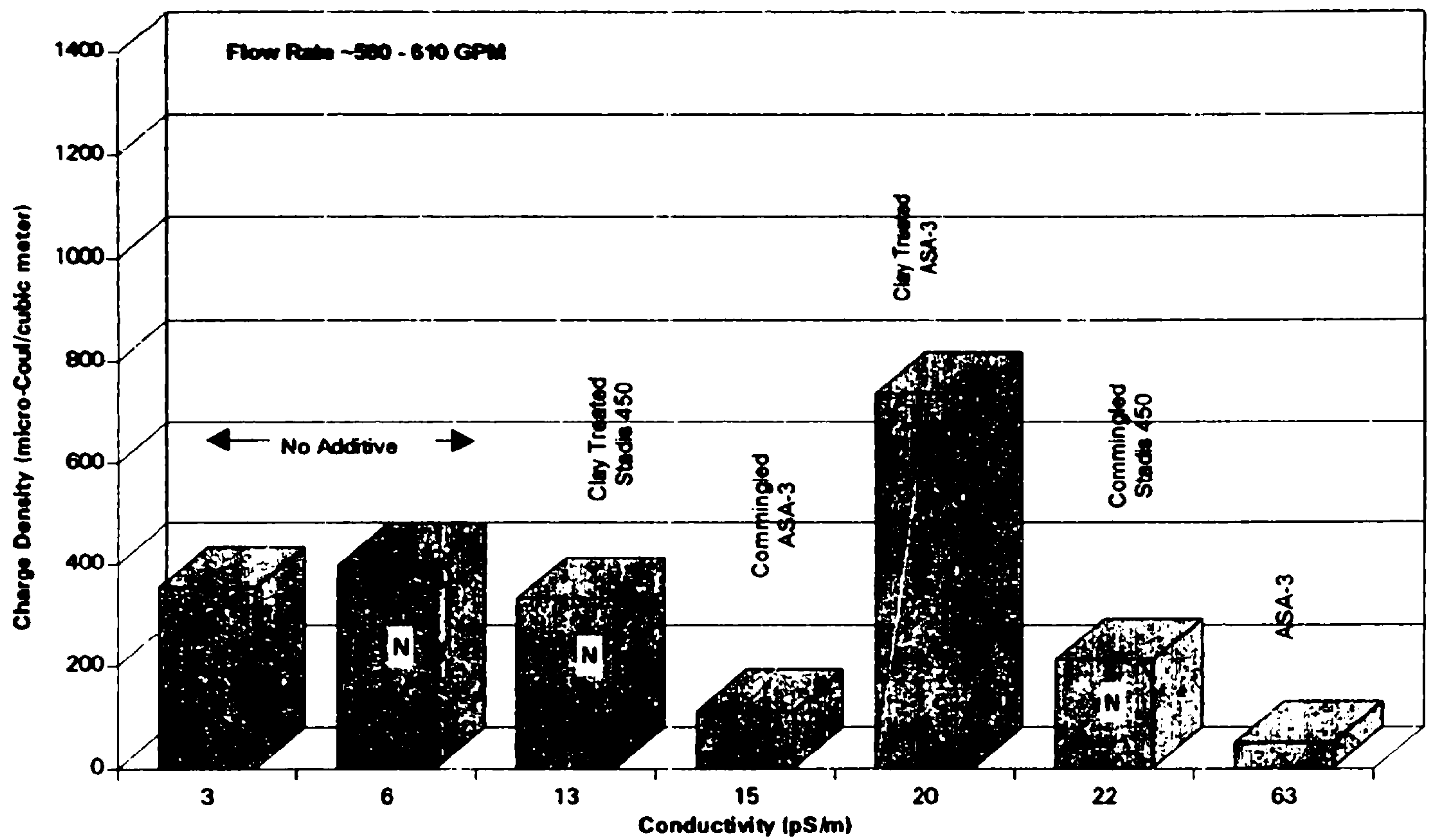


Figure 20 -- Charge Density of Jet A at Tank Inlet During Low Flow Rate Tests

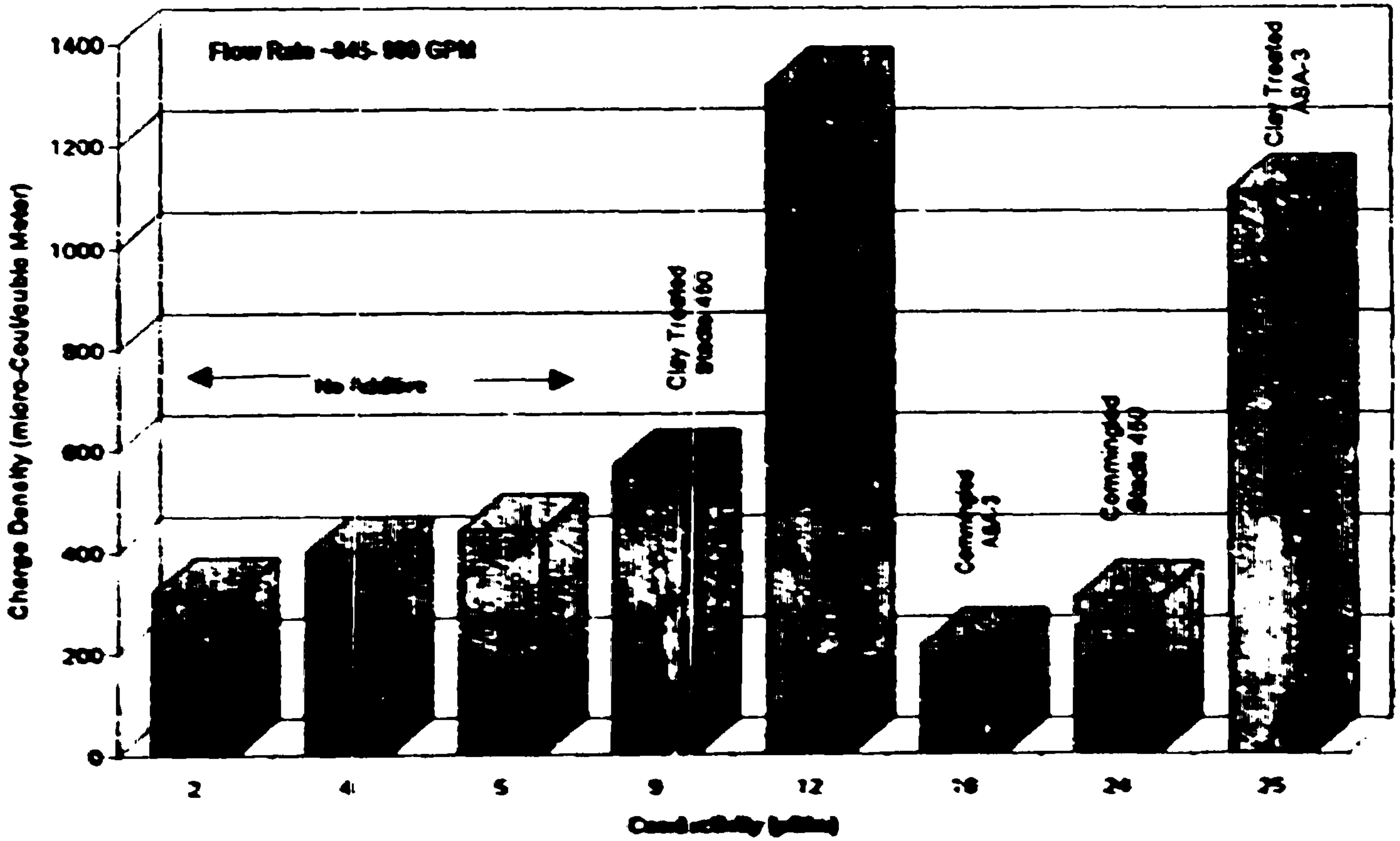


Figure 22 – Charge Density of Jet A at Tank Inlet During High Flow Rate Tests

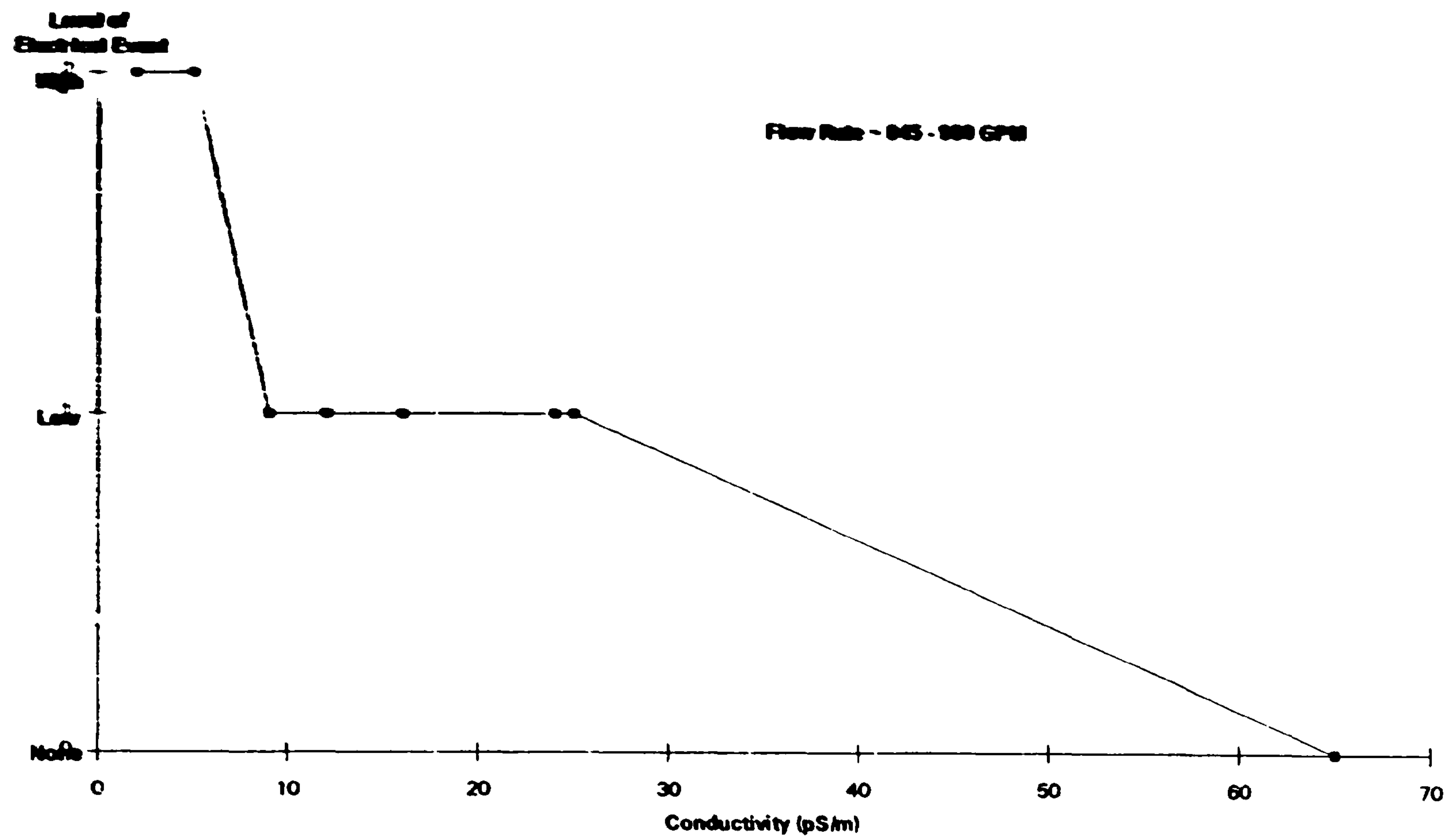


Figure 22 -- Electrical Events As a Function of Conductivity of Jet A During Full Scale Tests

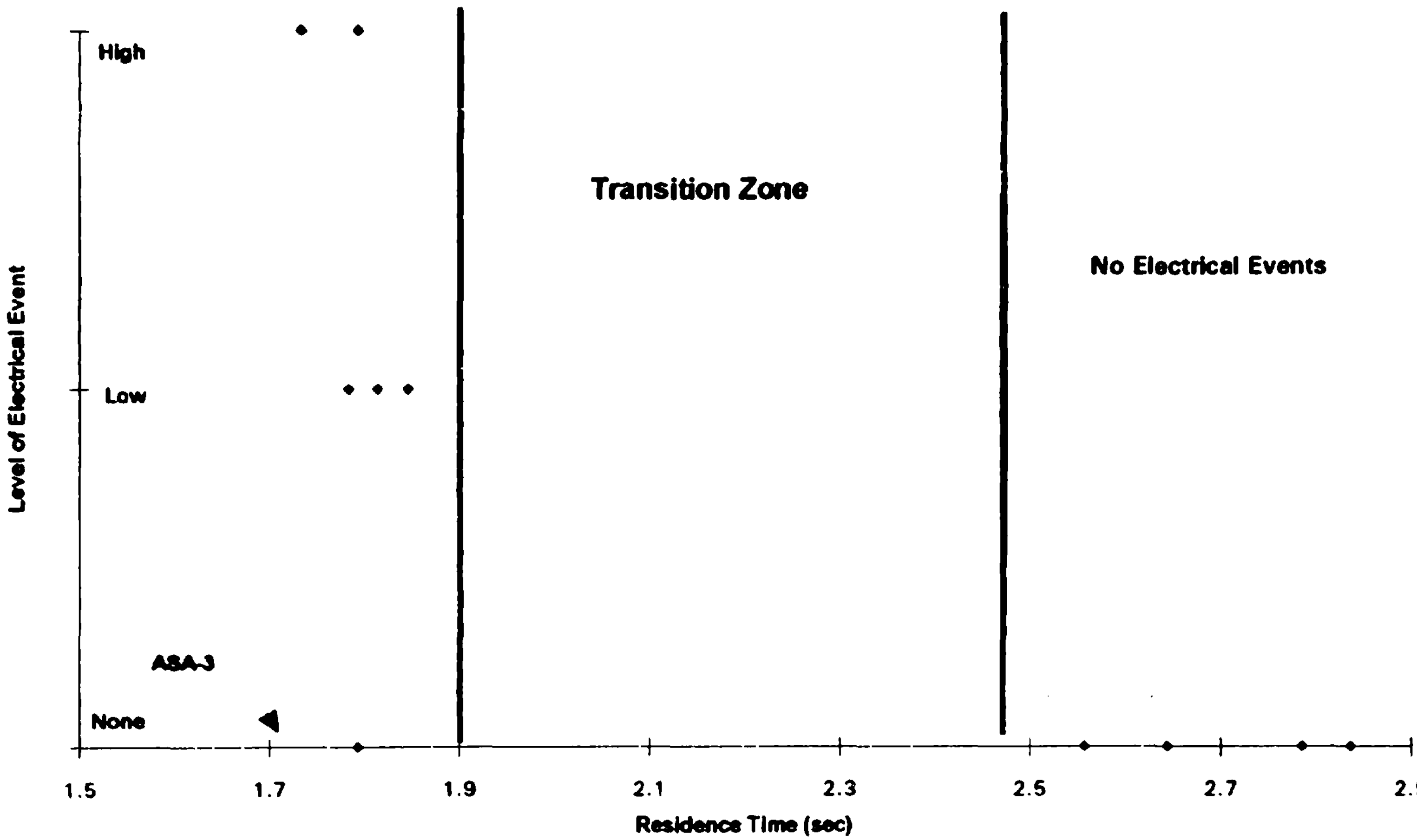


Figure 23 -- Electrical Events as a Function of Residence Time From Monitor to Tank

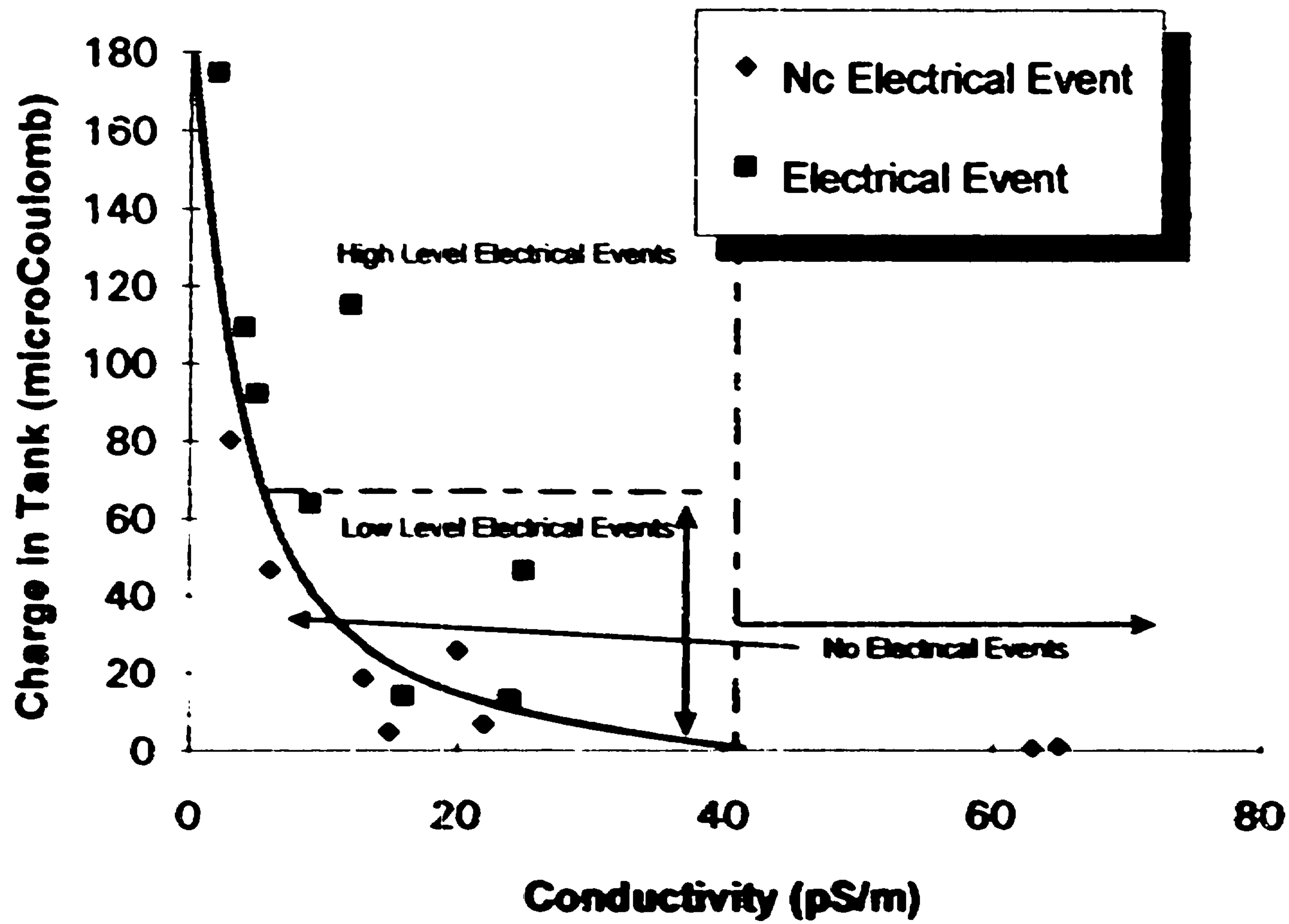


Figure 24 – Electrical Events Related to Conductivity and Charge in Tank

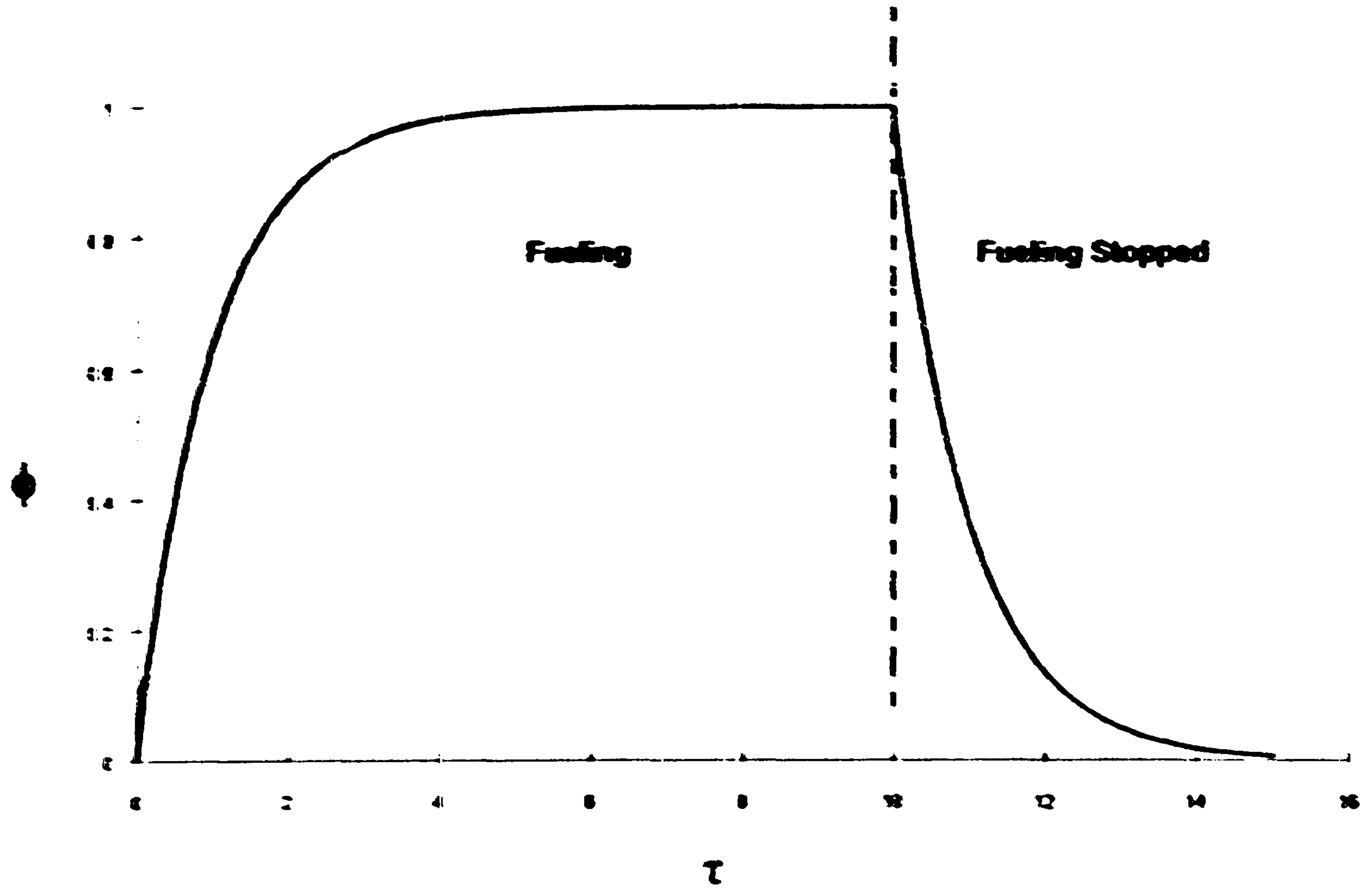


Figure 25 – Total Charge in Tank as a Function of Time During Filling and Rest
(Dimensionless Parameters Defined in Section 9)

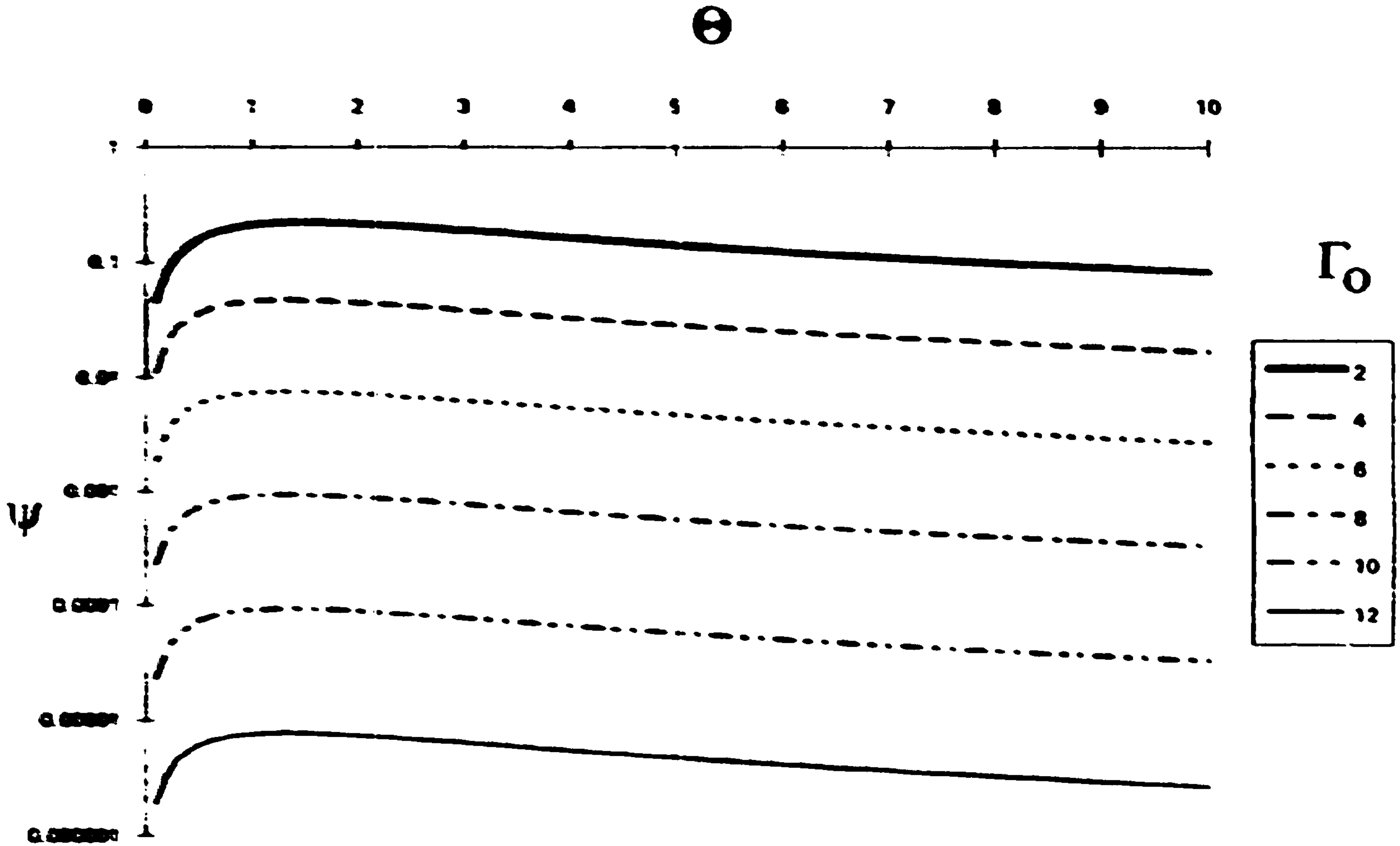


Figure 26 – Charge Density in a Tank as a Function of Time

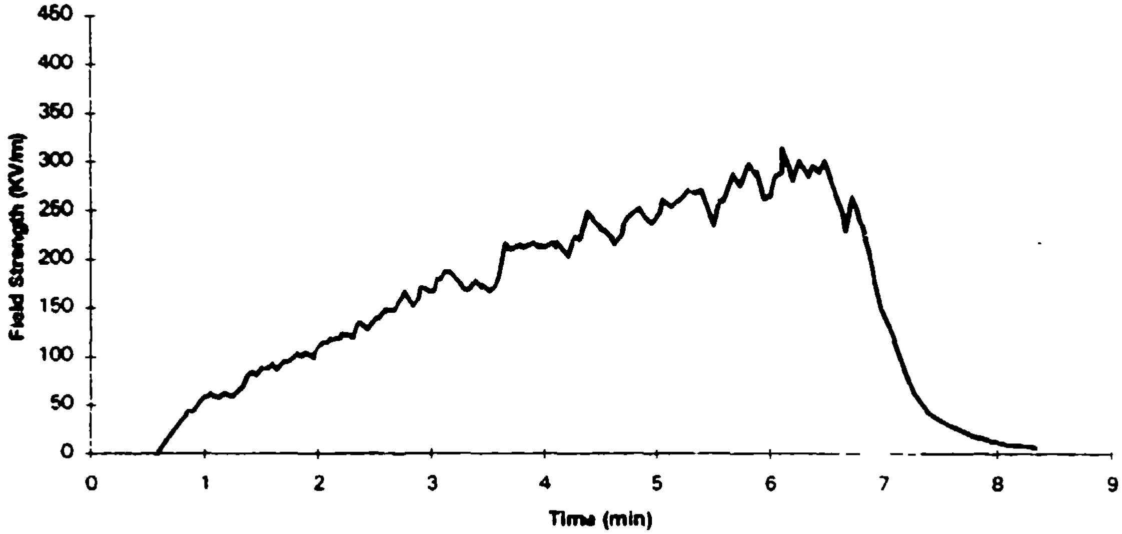


Figure 27 – Typical Field Strength in Tank at Denver Stapleton Airport with Conductivity =2 and Flow rate = 900 GPM[21].

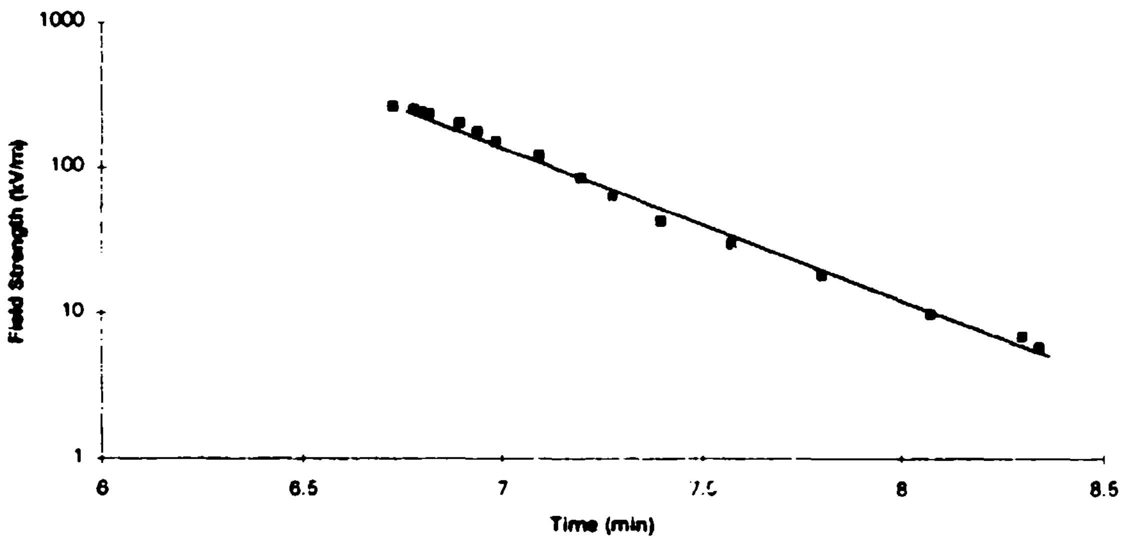


Figure 28 – Relaxation of Field Strength after Filling Stopped (Test in Figure 27)

[21] *Aircraft and Refueler Bonding and Grounding Study* CRC Report 583 (Feb. 1993)

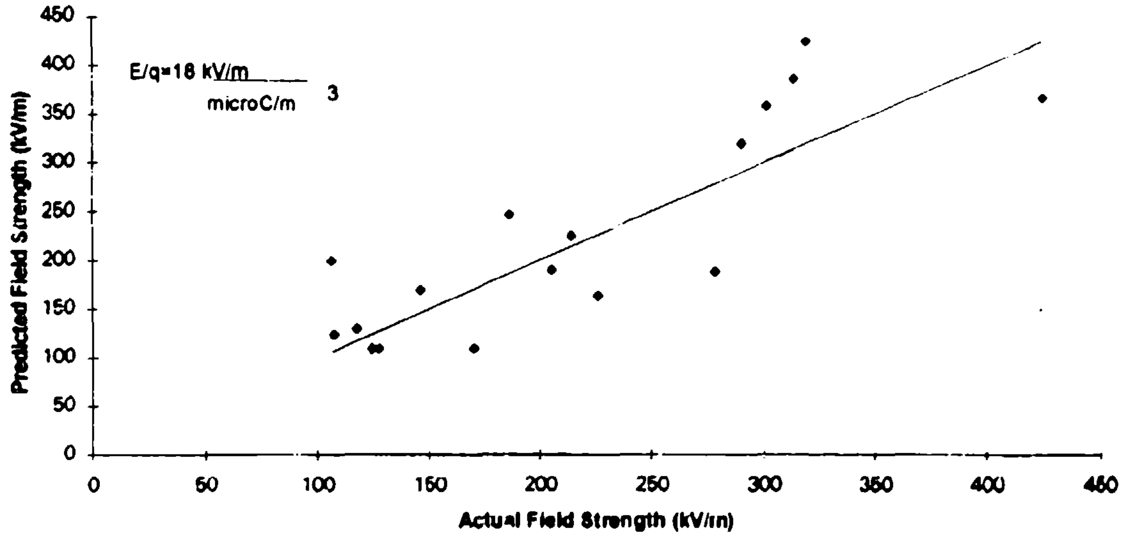
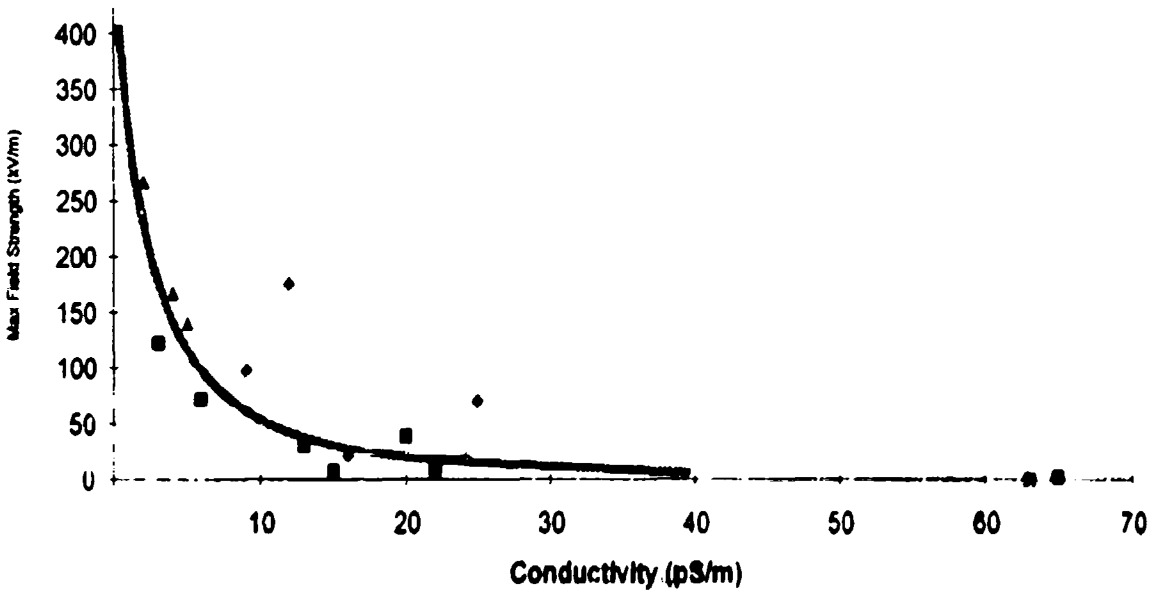


Figure 29– Predicted vs Actual Field Strength in Grounding Tests with k_{eff}= 0.86 pS/m



Fiogure 30 -- Field Strength at 6500 GPM for Test Conditions
(Squares -- No discharge, diamonds -- Low Level Event, triangles - high level discharges)

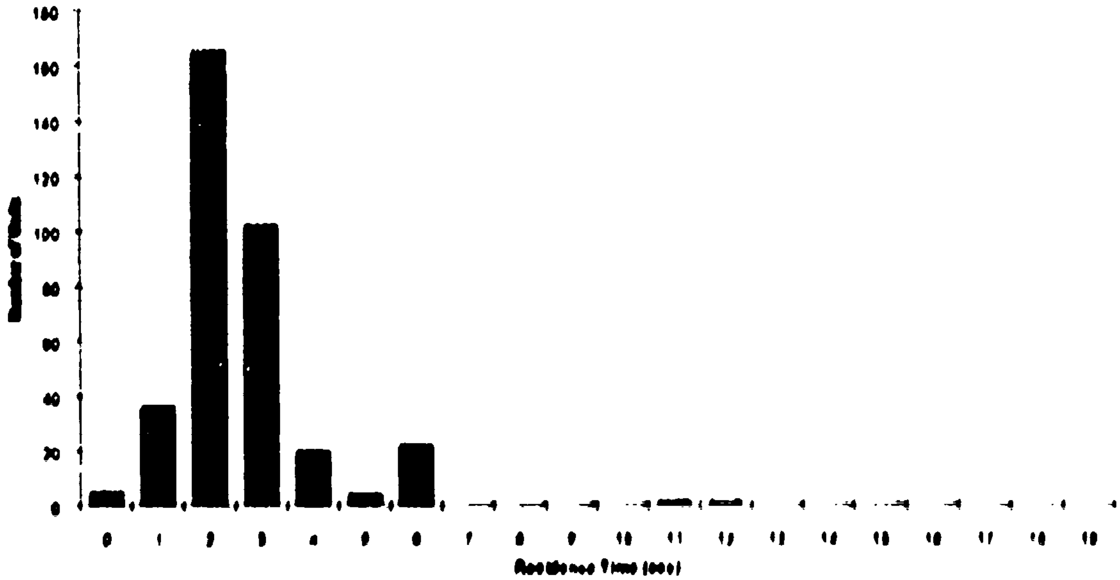


Figure 31 -- Residence Time Distribution in Hydrant Servicers After Filter/Coalescer Vessel

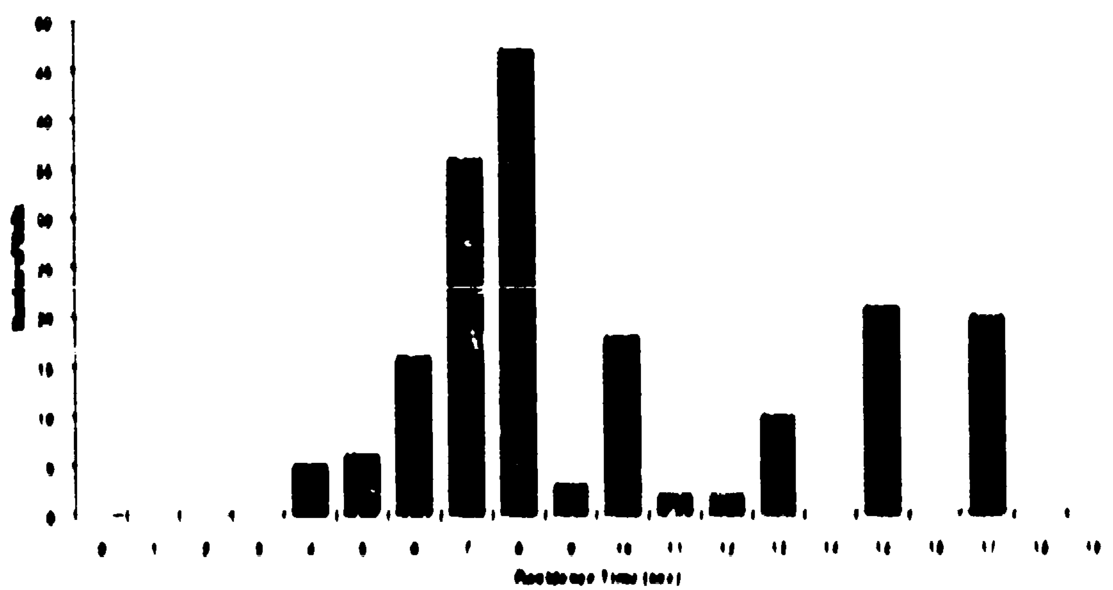


Figure 32 -- Residence Time Distribution at Design Flow Rate Within Filter/Coalescer Vessels on Hydrant Servicers

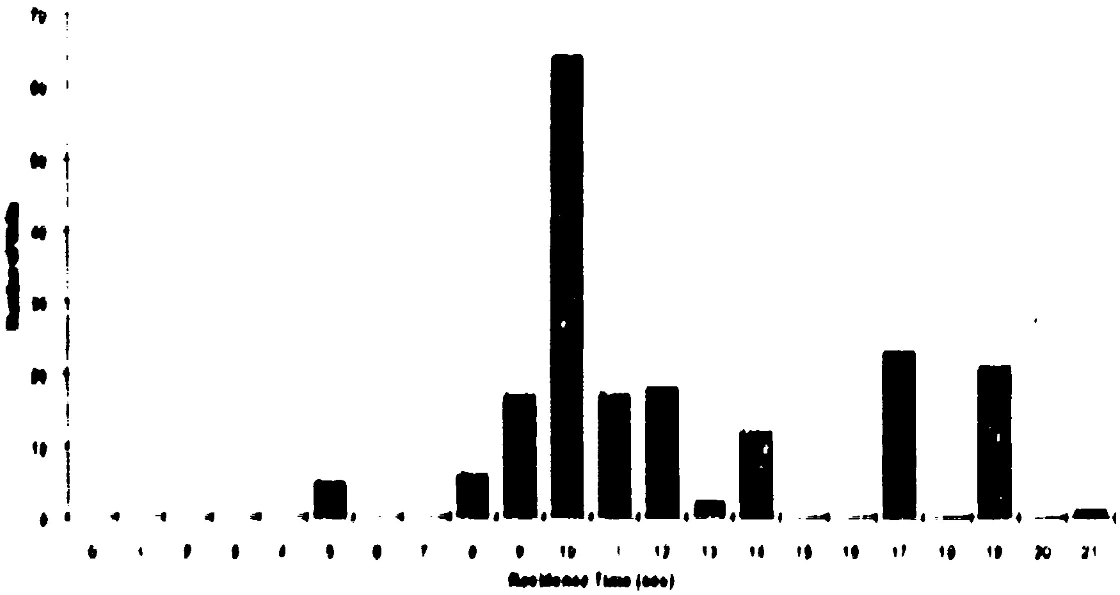


Figure 33 -- Residence Time Distribution for Hydrant Servicers Using Filter/Coalescer Vessels

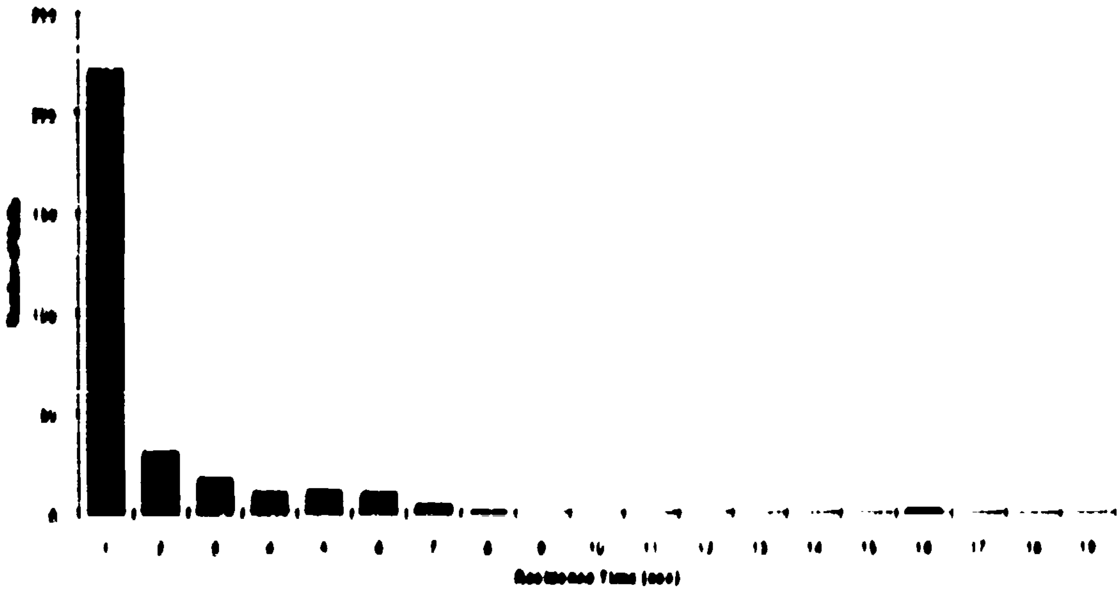


Figure 34 --Residence Time Distribution in Piping of Refueller Trucks Using Filter/Coalescers

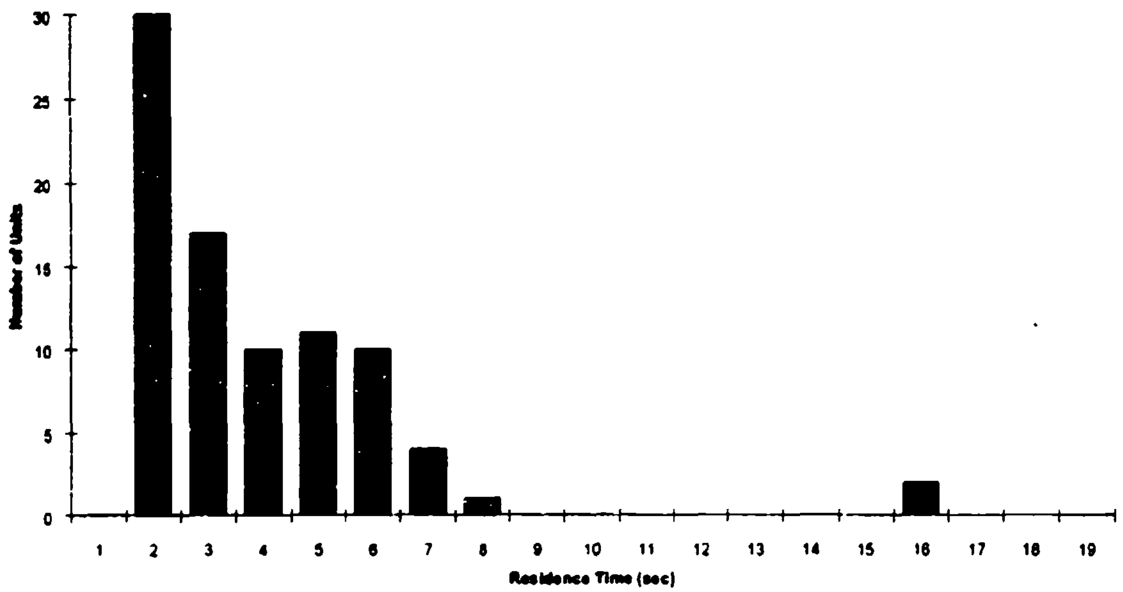


Figure 35 -- Residence Time Distribution In Piping of Refueller Trucks Using Filter/Coalescers Excluding One User

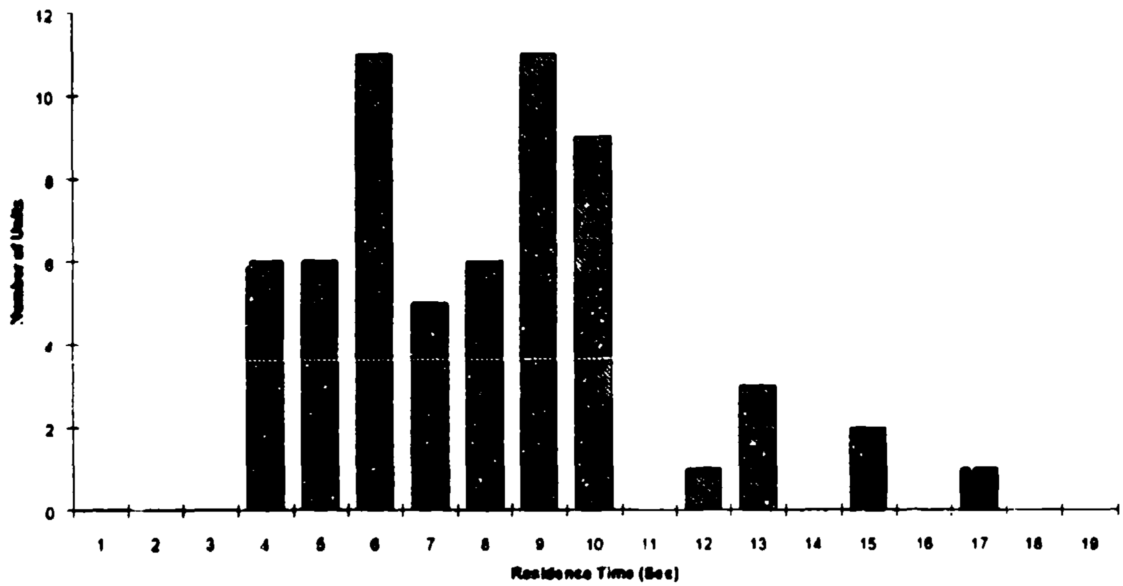


Figure 36 -- Residence Time Distribution Within Filter/Coalescer Vessels of Refueller Trucks

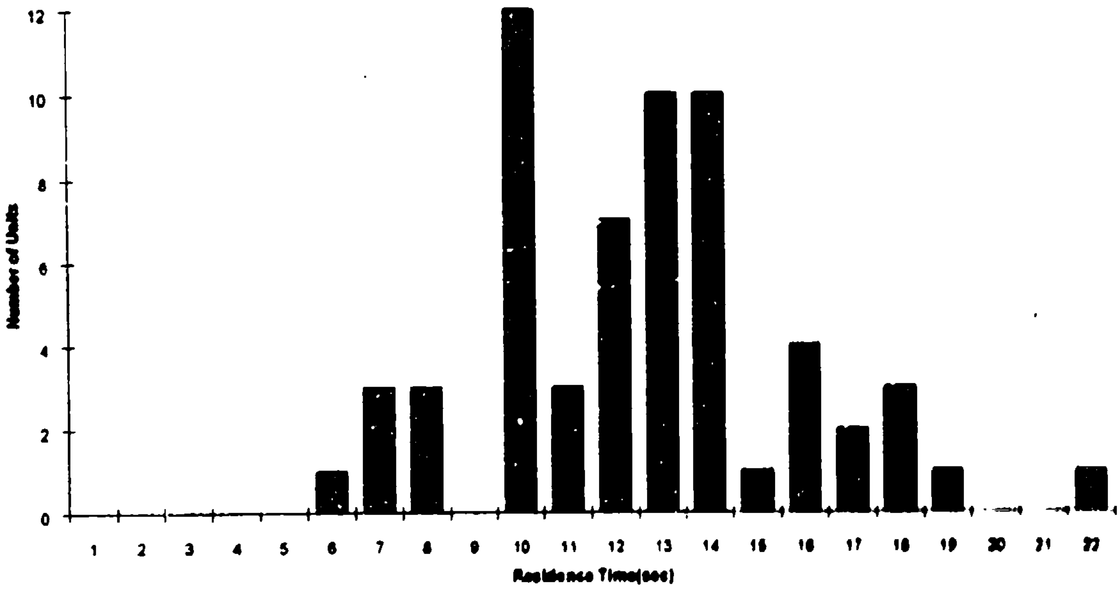


Figure 37 – Total Residence Time Distribution in Refueller Trucks Using Filter/Coalescers

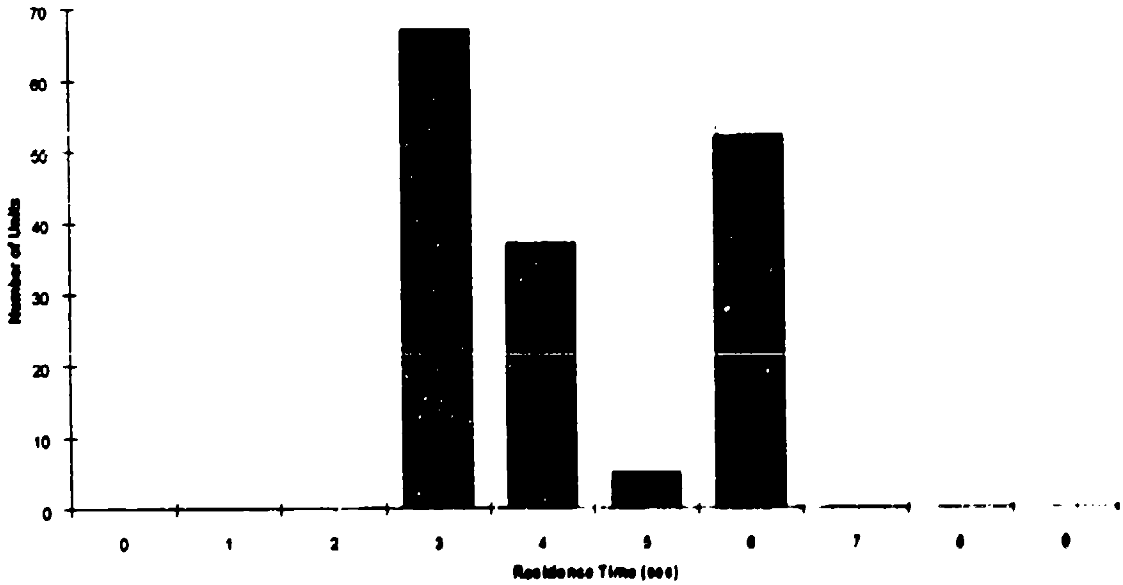


Figure 38 – Residence Time Distribution on Hydrant Servicers Using Absorbing Media Monitors

Appendices

A. Mini-Static Test Procedure

Table of Contents

1. Scope & Significance

1.1. Scope

This test procedure rates the relative static electricity charging tendency of aviation turbine fuels and filter separator media. The test involves the measurement of static electricity generated by the contact and separation of two dissimilar materials - fuel and filter. Ions of one sign are selectively absorbed on the charge separating surface - the filter, while those of opposite sign are separated and carried along with the flowing fluid. Separated charge is observed by measuring the current that flows to ground from the electrically isolated filter. Level of charge is influenced by a number of factors, e.g.

- the filter surface area;
- filter composition;
- flow rate;
- fuel characteristics;
- impurities in the fuel.

By holding the flow rate and filter area constant, current or charge density (charge per unit volume of fuel) becomes an indicator of relative charging tendency

- between fuels when using the same filter composition,

or

- between filter media when using the same fuel.

In this test, a measured sample of fuel is forced by means of a syringe/plunger to flow through a filter at constant flow rate using the mechanical drive of the Minisonic Separometer device, the Microseparometer Mark V, or the Microseparometer Mark V Deluxe. Streaming current from the filter is measured in microamperes (10^{-6} amperes) or nanoamperes (10^{-9} amperes) with a suitable electrometer. (However, for some filter/fuel combinations, the streaming current could be as low as a few picoamperes (10^{-12} amperes))

1.2. Significance

The test provides a measure of the relative static charging tendencies of fuels and/or filter media. The use of a *reference filter media* will provide a relative ranking of charging of different fuels. The use of a *reference fuel* provides a relative ranking of different filter media.

Reference fuels and reference filter media should be selected to provide a broad range of output streaming currents. Experience had shown that charge densities can range from 200 to 12000 microcoulomb/m^3 for different filter media with the same fuel or for different fuels with the same filter media. Correlation between results of this test and pilot equipment or full scale service performance has not been determined.

2. Apparatus

The apparatus for the Mini-Static Tester using the Mini-sonic Separometer drive is shown in Figure 1. The list of equipment along with the legend

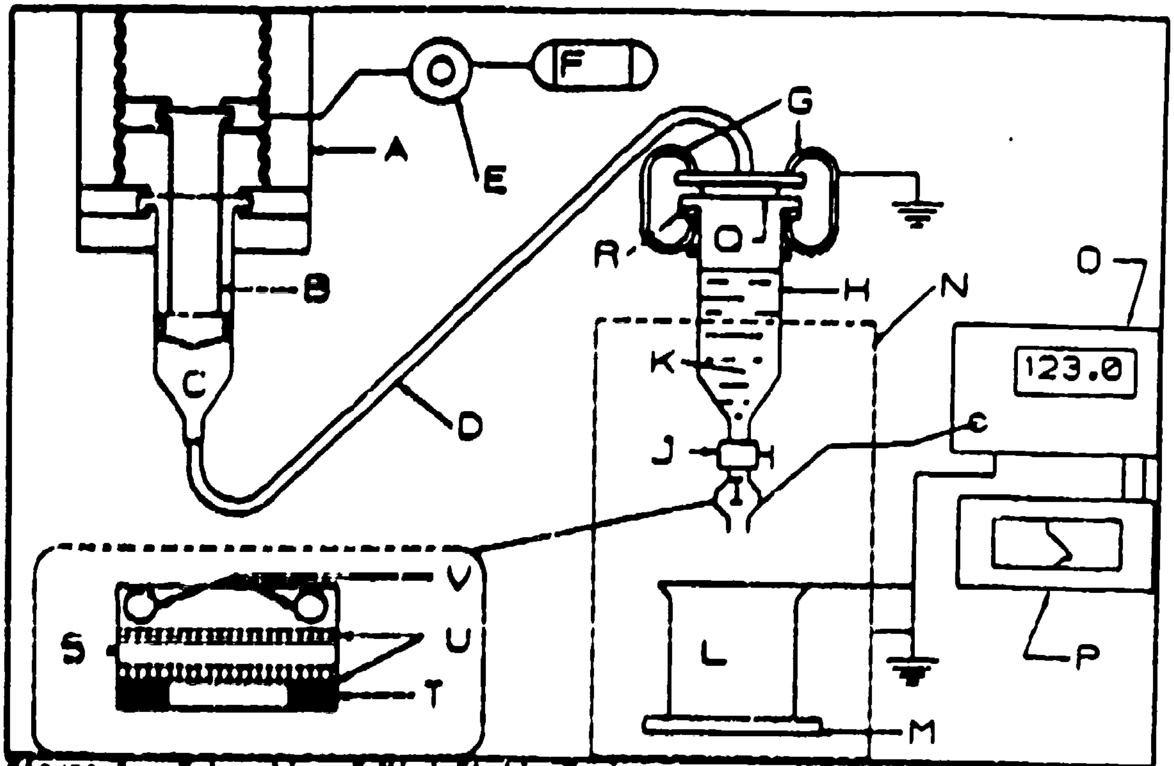


Figure 1 - Schematic of Mini-Static Tester

for Figure 1 is given in Table II. Table I specifies the elements that are part of the filter holder assembly. The actual assembly is shown in the insert of Figure 1. Rather than using the Mini-sonic Separometer drive, the drive from the Microseparometer Mark V or Mark V deluxe can be used following alternative instructions listed.

Table I- Filter Holder Assembly Material

Legend	Item
S	Reference filter paper or test paper
T	Washer
U	Support Screens
V	O-ring

Table I- Equipment List for Mini-Static Test

Legend	Item	Source
A	*Minisonic Separometer Syringe Drive* Note: Only the syringe drive, holder, and variable speed control power supply of the *Minisonic Separator (ASTM-D2550 Appendix 6)* are required for this test.	*Emcee Electronics* Note: *Emcee Microseparometer Mark V* or *Mark V Deluxe* can be substituted.
B	Syringe Plunger, 50cc syringe	*Luer-Loc Plastipak Syringe, 50cc - Becton Dickenson Co.* (Fisher Scientific Cat No. 14-823-20)
C	Syringe body, 50cc	As in B above. To provide air drive for fuel.
D	Hard Plastic or *Teflon* tubing - 1/16" ID approximately 12 to 18" long.	*Eastman Chemical Co.*
E	Switch for running *Minisonic Separometer* drive.	*Emcee Electronics* part of A above.
F	*Minisonic Separator* variable speed drive control	*Emcee Electronics* part of A above.
G	Clamps to hold stopper in syringe body	
H	Syringe body, 50 cc	As in C above. To hold fuel sample
I	Filter Holder - 13mm Diameter stainless steel	*Swinny, Milipore Catalog No. NC/1 XX30 01200*
J	Valve	*Hamilton Valve Co, Part No. 2LF1*
K	Reference Fuel or fuel sample, 50cc	
L	Stainless Steel Beaker, 600 ml	*Ace Chemical Co. Catalog Number 10-3430, EDP-NO-82* or equivalent
M	*Teflon* pad 1/8" or thicker	
N	Six sided *Faraday* cage constructed of 1/4" hardware cloth with approximate dimensions of 6" x 6" x 13" high; entry door provided in front of cage	
O	Electrometer, range from microamperes to nanoamperes	*Keithley Electrometer - Model 600B* or equivalent
P	Strip Chart recorder - full scale to match output of electrometer or appropriate data acquisition system	E.g., *Hewlett-Packard 7100 Model* for Keithley Model 600B above.
Q	One hole rubber stopper which fits snugly into syringe body	
R	Syringe holder - suitable arrangement to hold syringe securely; steel.	

Additional equipment and material required for performing the *Mini-Static Test* is given in Table III. The apparatus is assembled as shown in Figure 1. When assembling the equipment the following precautions should be followed:

Table III- Additional Equipment for Mini-Static Test

Punch - 1/2" diameter e.g., *Arch Punch (gasket Cutter) C.S. Osborne Co.*
Tweezers - suitable clean, dry tweezers for use at all times when handling the filter specimens.
Stop watch or timer capable of handling elapsed time in seconds.

1. The electrical leads to the electrometer should be kept as short as possible to minimize the possibility of stray current noise.
2. The *Teflon* tubing should be kept as short as possible to minimize flow rate changes over the test period.
3. Electrical ground should be made as shown in Figure 1. If the syringe holder is non-metallic, both clamps should be separately grounded.
4. The apparatus should be kept away from areas where stray currents may be present. E.g., areas near electrical motors, fluorescent lamps, high traffic areas can cause noise in measurements.

The suggested sources of material are recommendations only. However, the filter holder assembly should be as specified to maintain reproducibility between different labs. Also, the syringes should be of polyethylene or other insulating material to prevent false readings.

3. Procedures to Prepare Filter and Equipment

3.1. Preparation of Filter Media

3.1.1. Suitable filter media may be selected for any type of filter paper stock. Specimens may be prepared from new or used coalescer or separator paper type elements - either of the pleated or cylindrical form. When using the filter media to test fuels, the filter media should be prepared from the same st[illegible] and handled in the same manner for all tests.

3.1.2. When using commercial paper elements, cut open the element to be tested using knife, scissors, saw, and snips. Remove a 4 to 5 inch square of the media. Store in a large evaporating dish covered tightly with foil. Caution: Handle all media by the edges only. Do not use any part of the media that has been soiled or contacted by the hands.

3.1.3. Punch out about 20 (1/2" diameter) disks of each material to be tested. Place in Petri dish (one dish for each element media type). Keep dish covered except in the act of transferring disks.

3.2. Preparation of the Test Apparatus

3.2.1. Cleaning of Fuel Systems and Filter Holders. Between each test, thoroughly wash the fuel syringe body and entire filter holder with a solvent such as M-50 (John B. Moore Products), followed by rinsing with methanol or acetone. Dry in a stream of dry nitrogen. Caution: Let parts equilibrate to room temperature before reusing.

3.2.2. Filter Load the filter holder base (lower portion) in the following order:

1. Flat Teflon washer (" in Figure 1)
2. Support screen (U)
3. Sample filter media (S)
4. Support screen (U) (optional - use when voidage of fiberglass must be controlled, for example)
5. Teflon O-ring (V)

Tape threads of the top half using about 2 1/2" of 1/4" Teflon tape. Join halves together, finger tight.

3.2.3. <u>Apparatus</u>

Check that the fuel syringe holder and electrometer are well grounded. Allow the electrometer sufficient time to warm-up.

3.2.3.1. Case 1. Using Mini-Sonic Separometer Drive

Adjust the *Minisonic Separometer* drive potentiometer to obtain a fuel flow rate of 100 ml/min (It should take 30 sec. /50 ml during the test). Leave the drive in the UP position.

3.2.3.2. Case 2. Using the Micro-Separometer Mark V

Turn the Micro-Separometer mark V power switch ON.

Preset the UP/AUTO/DOWN switch to AUTO.

Preset the syringe drive gear to low by lifting the release knob.

Prepare a fuel sample in a syringe and attach to the Emulsion Mixing Unit bracket. (This fuel prevents damage to the emulsifier due to over speeding) This syringe should be left in place during the entire test.

Depress CLEAN switch

3.2.3.3. Case 3. Using the Micro-Separometer Mark V Deluxe

Momentarily depress the ON switch. The annunciator lamps located on switches A through G in the TEST SELECT section will start scanning for your selection.

Depress G switch. This will initiate the MINISTATIC TEST PROGRAM.

The annunciator lamps in the SYRINGE section will indicate that manual control can be used for the syringe drive mechanism. Depress UP pushbutton. This will move the syringe mechanism to the upper limit. (Ignore PROGRAM section annunciator indicating that turbidity meter can be used)

3.2.4. <u>Drive Syringe</u>

Make sure that the syringe plunger moves smoothly by applying silicone lubricant as necessary.

Pull the plunger up in the syringe to the 50 ml mark.

Attach the syringe to the syringe drive mechanism.

3.2.5. Syringe

Attach valve to the fuel syringe body. Turn the valve off. Fill with test fuel to slightly above the 50 ml mark. Insert stopper with tubing and place assembled syringe in holder. Clamp stopper to holder.

Attach filter and connect electrometer input to the base (lower portion) of the filter, avoiding strain on the connection.

Center the receiver under the filter and connect to ground.

OPEN THE VALVE.

4. Test Procedure

4.1. Zero the electrometer. If electrometer is auto-ranging follow the instructions with the device. If it is not auto-ranging zero the electrometer on the 0.01 multiplier, then set at 0.1 multiplier and the 10^{-6} amp range or other settings if known. Turn electrometer on for test.

4.2. Drive Instructions

4.2.1. Case 1. Using Mini-Sonic Separometer Drive
Turn the drive direction switch DOWN. Turn drive ON. Start timer when fuel passes 50 ml mark.

4.2.2. Case 2. Using the Micro-Separometer Mark V
Depress the RESET switch. (This will start the drive - It will travel the 50 ml volume in approximately 30 sec.)

4.2.3. Case 3. Using the Micro-Separometer Mark V Deluxe
Momentarily depress the DOWN pushbutton. (This will start the drive - It will travel the 50 ml volume in approximately 30 sec.)

4.3. After approximately 5 seconds, adjust electrometer to best reading range. To prevent making readings insensitive use only the 0.1 or 0.3 multiplier in non-auto-ranging electrometers.

4.4. Caution: Once adjustments have been made, remove hands and body away from the vicinity of the filter holder, Faraday cage, and avoid motion.

4.5. Mark the strip recording or note time on data acquisition system when the plunger is between the 25 to 20ml mark on the syringe.

4.6. When the plunger reaches the bottom of the syringe, turn off the drive and timer.

4.7. Measure the temperature in the receiver.

4.8. Disassemble the syringe and filter holder as soon as possible after recording the data.

4.9. Obtain a repeat measurement by redoing <u>all</u> steps given in Sections 3 & 4.

5. Data Recording

For each test record the following information:

5.1. The average value of streaming current, in microamperes, between the time period calculated in Section 7.2.
5.2. The electrometer settings, e.g., the Multiplier & current range if electrometer is non-auto-ranging.
5.3. The time for 50 ml of fuel to flow through the filter
5.4. The amount of fuel left after the plunger hit bottom of the syringe.
5.5. The sample temperature in the receiver
5.6. The fuel and filter paper used.

6. Calculations and Report

6.1. Calculations

Calculate the relative charging tendency of the filter media and/or fuel for each determination as follows:

$$Q = i/V$$

where

Q = Charge density (microcoulomb/meter^3)
i = Streaming current (microamperes)
V = Volumetric flow rate (meter^3/second)

6.2. Report

Report the average charge density of the two determinations and the average sample temperature. Also, report the percent deviation between readings, i.e.,

$$\% \text{ Deviation} = (Q_1 - Q_2)/(Q_1 + Q_2) \times 100$$

where

Q_1 and Q_2 are the charge density of the first and second measurement respectively.

7. Miscellaneous

7.1. Decay Rate Measurements

By connecting the metal receiver to a second electrometer and recorder, it may be possible to observe the rate at which the charge on the bulk fuel accumulates and decays during flow and after flow ceases. This rate of charge decay is related to the conductivity of the fuel. It could be useful in interpreting the results of the streaming current measurements.

7.2. Flow Validity Check

7.2.1. Need for Flow Check

An air drive is used to send the fuel sample through the filter in order to

* Minimize the amount of fuel sample required;
* Minimize the potential of contaminating fuel samples;
* Minimize the potential of electrical noise from the electrical drive affecting results, especially when highly conductive fuels are used.

However, significant error can be introduced in the flow rate under some circumstances. This can affect the calculation of the charge density as well as the magnitude of the streaming current. It is necessary to ensure that the measurement is taken when the flow rate is within ?5 to 100 ml/min. The following procedure is used to assess whether the apparatus can be used for measuring the charge density for a particular filter.

7.2.2. Volume Measurement for System

Assemble the syringe as in Section 3.2.5. However, do not fill with fuel. Also, do not attach the filter. Clamp the syringe, stopper and tubing to the syringe holder upside down. Using another syringe fill the stoppered syringe and tubing with fuel. (Keep the valve open during this procedure).

Clamp the stoppered syringe to the holder in the proper position (Section 3.2.5), taking care not to spill any fuel.

Using a 100ml graduated cylinder measure the total amount of fuel contained in the tubing and stoppered syringe. Record the volume measured.

Repeat the procedure two more times. Reject readings if variation is greater than +/- 3ml. Average the three valid readings and record as V_{gas}.

Calculate the ratio of piston volume to total gas volume, using the following equation:

$$t_m = 50/V_{gas}$$

7.2.3. Residual Fuel Measurement

Carry out all steps given in Sections 3 and 4 using the filter media to be tested. Note: The electrometer readings do not have to be taken for this portion of the experiment. Measure the fuel remaining in the syringe after the plunger in the drive syringe reaches the bottom. Repeat this portion of the experiment three times. (Unless the fuel is dirty, the same filter can be used). Reject the readings if the variation is greater than +/-3 ml. Subtract the average of the three readings from 50 and divide by 50 ml. Record this value as Q.

7.2.4. Calculation of Pressure Drop Factor

Using Figure 2, find the value of B for the value of Q and t_m from above. Record this value (B).

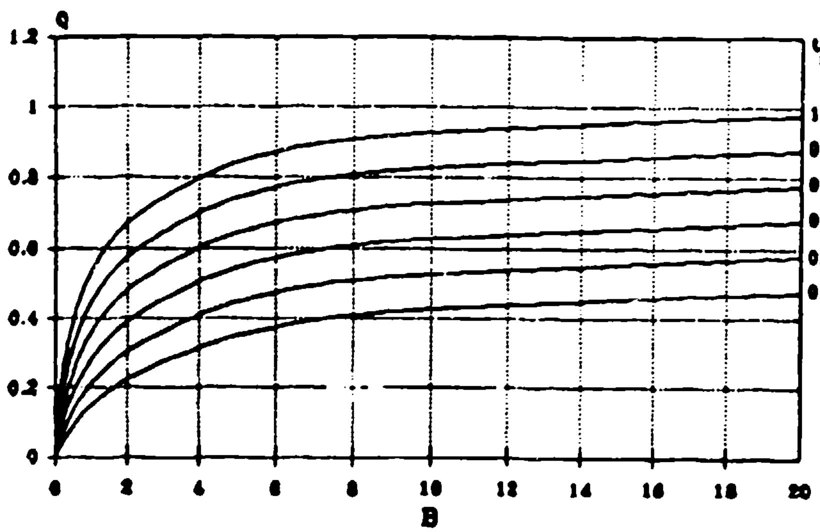


Figure 2-Pressure Factor Correlation

7.2.5.Calculation of Minimum Time to Steady State Flow

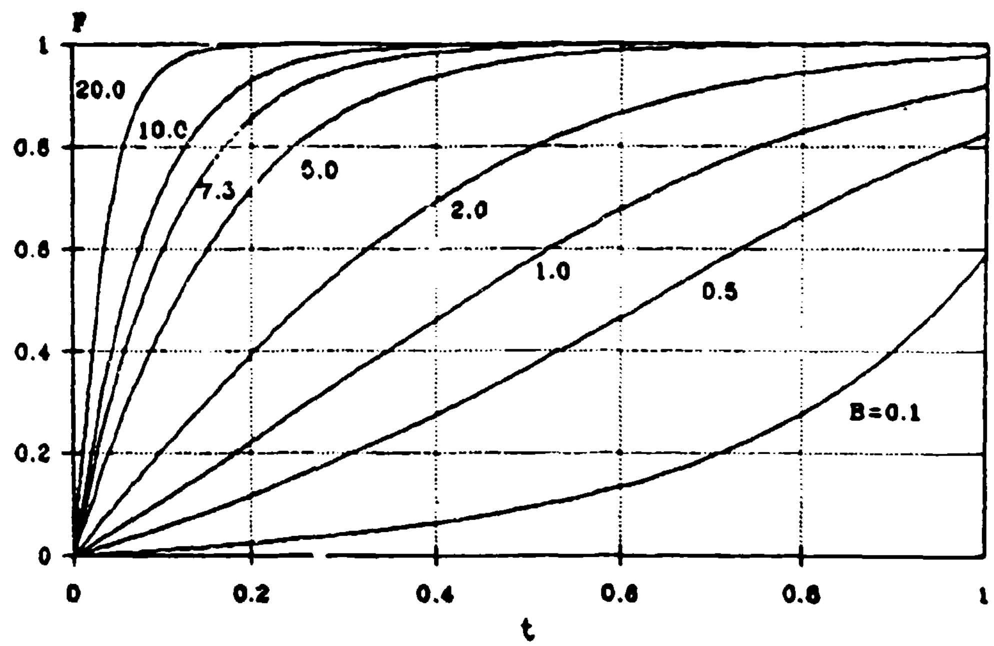


Figure 3- Flow Rate Correlation

Select the minimum acceptable flow rate relative to the drive flow rate, F. For standard tests, a value of 0.95 or better should be used. Using Figure 3, F and B calculated from above, find t_{min}, the minimum time ratio that can be used to obtain streaming current readings at constant flow rate.

7.2.6.Drive Flow Rate

Measure the time it takes it takes for the plunger to move from the 50 ml mark to the bottom of the syringe. Record the average of 3 readings as t_s. The drive flow rate, R, is

$$R = 50/t_s$$

The value of R should be approx 1.67ml/sec +/- 0.17 ml/sec.

7.2.7. Steady State Portion of the Experiment

Calculate the minimum start time for reading the streaming current by using the following equation:

$$t_{start} = t_{min} \times V_{gas} / R$$

t_{start} is the time that the fuel flow rate reaches 95% of R or the steady state flow rate.

7.2.8. Time to Start Selection

Select the time to start averaging readings as follows:

* If t_{start} is less than 5 secs away from t_s, the time for the plunger in the syringe to reach bottom, then the Ministatic test is not suited for the filter being used. Abandon the test.

* If t_{start} is 5 to 15 seconds less than t_s, then average the streaming current results from t_{start} to t_{start} + 5 seconds.

* If t_{start} is shorter than t_s by more than 15 seconds, the average the streaming current between, 15 seconds and 20 seconds into the run.

7.2.9. Example

The volume of fuel measured by the procedure in Section 7.2.2, was 64, 65, 64 ml. Thus, the average volume, V_{gas} = 64.3 ml.

From this, t_m = 50/64.3 = 0.78.

Following the procedure outlined in Section 7.2.3, a filter paper from a Velcon 83 series element leaves, 17, 17, 15 ml fuel in the syringe at the time the plunger in the drive syringe reaches the bottom. The average was 16.33 ml. From this, the value of Q = (50-16.33)/50 = 0.67.

Using Figure 2, one can extrapolate for Q = 0.67, and t_m = 0.78, a value for B of 6.8.

Using Figure 3, one can find for F = 0.95 and B = 6.8, that t_{min} = 0.38.

The three times for the plunger to reach bottom from 50 ml were 30, 30, 30 sec. The average is 30 sec. Thus R = 50/30 = 1.67 ml/sec.

Using these values, t_{start} = 0.38 x 64.3 / 1.67 = 14.6 sec.

Using the criteria in Section 7.2.8, the streaming current measurements should be taken over the range from 15 to 20 seconds.

7.3. Information

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B. Mini-Static Data

B.1 Lab Program

Table B.1.1 -- Mini-Static Charge Tests on Stapleton International Airport Fuel Samples

CRC Sample Test #	Treatment	Cond., pS/m	Temp., C	MSEP	Charge Density μC/m³	
1 Base Fuel	As Rec.	4	23	76	-91	-77
3 ASA-3 Inlet	As Rec.	54	23	84	-702	-834
	Clay Filt.	10	26		-559	-449
	Clay Filt.*	4	26		-78	-93
3 ASA-3 Outlet	As Rec.	8	23	85	13	196
5 ASA-3 Comm. Inlet	As Rec.	7	24	88	-82	-41
5 ASA-3 Comm. Outlet	As Rec.	5	24	84	565	539
7 ASA-3 Clay-Treat. Inlet	As Rec.	6	24	99	-694	-745
10 Base Fuel	As Rec.	3	25	86	-41	-32
12 S-450 Comm.	As Rec.	14	26	90	-1882	-2370
14 S-450	As Rec.	4	26	100	-853,	-896

Notes
Fuel samples from Stapleton International Airport Full Size Test Program -- Test # refers to test number (see Section 6)
Commingled fuel inlet is before hydrant servicer; outlet is after servicer
Reference filter used: CA-22
* Multiple Clay-Filtration

Table B.1.2 -- Mini-Static Charge Tests on Stapleton International Airport Fuel Samples

CRC SAMPLE, TEST #	TREATMENT	k pS/m	T C	MSEP	Charge Density μC/m³*	
1 Base Fuel	As Rec.	4	23,24	76	-90	-86
3 ASA-3 Inlet	As Rec.	54	23,24	84	-334	-315
3 ASA-3 Outlet	As Rec.	8	23,24	85	-146	-150
5 ASA-3 Comm. Inlet	As Rec.	7	23,24	88	-153	-130
5 ASA-3 Comm. Outlet	As Rec.	5	23,25	84	-119	-103
7 ASA-3 Clay-Filt. Inlet	As Rec.	6	23,25	99	-182	-283
10 Base Fuel	As Rec.	3	24,25	86	-49	-49
12 S-450 Comm. Inlet	As Rec.	14	24,25	90	-1032	-1074
14 S-450 Clay-Filt. Inlet	As Rec.	4	24,25	100	-325	-327

Notes

Fuel samples from Stapleton International Airport Full Size Test Program -- Test # refers to test number (see Section 6)

Commingled fuel inlet is before hydrant servicer; outlet is after servicer

Reference filter used: CDF-H

*Duplicates on Different Days

Table B.1.3 -- Mini-Static Tests on Reference Fuel Studying the Effect Clay Treating and Commingling

Type	Conc ppm	Treatment	k pS/m	T C	Charge Density µCoulomb/m³		
None	-	As Received	2	24	-291	-270	-132
None	-	Clay Filtered	0	24	12	30	
S-450	3.0	None	430	23	-10730	-9348	
		Dilution	5	23	-152	-122	
		Dilution	12	23	-252	-223	
		Dilution	25	23	-790	-813	
S-450	3.0	Clay Filtered	5	23	-245	-206	
		Clay Filtered	12	23	-882	-937	
		Clay Filtered	25	23	-560	-524	
ASA-3	1.0	None	337	25	-2553	-3181	-2261
		Dilution	5	26	-137	-147	
		Dilution	11	26	-522	-602	
		Dilution	26	27	-1097	-1292	
ASA-3	1.0	Clay Filtered*	6	26	-396	-395	
		Clay Filtered*	14	23	-809	-777	
		Clay Filtered*	28	23	-1838	-1759	

Reference Filter CA22
*Multiple Clay Filtration.

Table B.1.4 -- Mini-Static Tests Studying Effect of Mixed Additives on Static Charge Tendency of Reference Fuel

Type	Conc PPM	Treatment	k pS/m	T C	Charge Density μCoulomb/m³	
ASA-3 / S-450	0.5/ 1.5	None	325	22	-3239	-4545
ASA-3 / S-450	0.5/ 1/5	Dilution	5	22	-58	-12
			12	22	-153	-172
			25	23	-498	-358
ASA-3 / S-450	0.5/ 1.5	Clay Filtered	5	20	-575	-556
			12	25	-594	-626
			25	24	-1128	-1301

Table B.1.5 -- Effect of Clay Treating and Commingling of Stadis 450 in CRC Fuel from Test # 10

Type	Conc PPM	Treatment	k pS/m	T C	Charge Density μCoulomb/m³	
None	-	None	4	22	129	202
None	-	Clay Filtered	0	26	-16	-21
S-450	3.0	None	560	24	-4273	-4430
		Diluted	5	23	310	319
		Diluted	12	24	30	63
		Diluted	25	24	-420	-305
S-450	3.0	Clay Filtered	6	22	-63	-91
		Clay Filtered	12	26	-377	-417
		Clay Filtered	24	23	-250	-253

Table B.1.6 -- Mini-Static Tests Using Reference Filter CDF-H & Reference Fuel Effects of Commingling & Clay Treatment

Type	Conc PPM	Treatment	k pS/m	T C	Charge Density µCoulomb/m^3
S-450	3.0	None	528	25	-2114
		Diluted	5	24	-12
		Diluted	14	24	-148
		Diluted	25	24	-303
ASA-3	1.0	None	165	25	-1050
		Diluted	5	25	37
		Diluted	15	24	-178
		Diluted	25	24	-80

Table B.1.7 -- Effect of Clay Treatment Through Simulated Bag Clay Treater

Type	Conc., mg/L	Clay Filtered	Conductivity, pS/m @ 19-22C	MST Filter	Charge Density µC/m3	
S-450	3.0	No	920	CA-22	-3414	-3255
S-450	3.0	Yes	6	CA-22	-37	-26
S-450	3.0	No	920	CDF-H	-416	-143
S-450	3.0	Yes	6	CDF-H	-10	-3
ASA-3	1.0	No	540	CA-22	-2716	-1811
ASA-3	1.0	Yes	4	CA-22	-1596	-1566
ASA-3	1.0	No	540	CDF-H	-290	-333
ASA-3	1.0	Yes	4	CDF-H	-786	-756

Table B.1.8 – Effect of Corrosion Inhibitors on Charge Generation Tendency

Type	Conc PPM	Treatment	k pS/m	T C	Charge Density µCoulomb/m^3	
Denver #10	None	-	CDF-H	24	-66	
	DCI-4A	0.35	CDF-H	25	-68	
	DCI-4A	3.2	CDF-H	25	-298	
	E-580	0.35	CDF-H	25	-45	
	E-580	5.25	CDF-H	25	-58	
	DMD	0.7	CDF-H	25	-43	
Reference	None	-	CDF-H	22	-3	
	DCI-4A	0.35	CDF-H	22	3	
	DCI-4A	3.2	CDF-H	22	-26	
	E-580	0.35	CDF-H	22	12	
	E-580	5.25	CDF-H	22	14	
	DMD	0.7	CDF-H	23	-11	
Denver #10	None	-	CA-22	24	-364	-354
	DCI-4A	0.35	CA-22	24	-366	-355
	DCI-4A	3.2	CA-22	24	-373	-403
	E-580	0.35	CA-22	24	-262	-300
	E-580	5.25	CA-22	24	-429	-451
	DMD	0.7	CA-22	24	-245	-330
Reference	None	-	CA-22	24	-159	-352
	DCI-4A	0.35	CA-22	24	-7	-253
	DCI-4A	3.2	CA-22	24	339	293
	E-580	0.35	CA-22	24	-73	-141
	E-580	5.25	CA-22	24	215	306
	DMD	0.7	CA-22	24	14	-224

B.2 Mini Static Field Tests

Table B.2.1 -- Mini Static Test Results from Field Samples

Colonial		LAX		O"Hare	
k pS/m	q microC/m3	k pS/m	q microC/m3	k pS/m	q microC/m3
3	1046	0	-48	4	-16
5	581	1	-43	5	-136
6	1508	0	-10	5	-84
6	842	0	61	3	-28
19	3523	0	-132	2	-23
9	4488	0	13	14	-34
11	3768	1	9	14	-89
3	1493	1	3	7	-129
7	5092	1	17	0	-23
4	2245	1	-26	0	-19
4	1353	1	-46	3	-49
3	2464	0	-21	3	-31
12	6286	0	-222	3	33
4	2481	2	0	3	115
10	3454	8	540	1	-100
2	2630	3	15	1	-103
5	1550	8	780	5	-98
10	3586	0	85	5	-150
5	1856			14	-40
3	534			14	-90
4	482				
2	949				
3	193				
11	1947				
4	440				
24	13156				
4	1582				
12	4258				

C. Stapleton International Airport Field Data

Enclosed is the raw data from the tests at Stapleton International Airport.

Summary		
Test #	P1	
SDA type	None	
Conc(ppm)		
κ (CU)		2
T(F)		34
F (GPM)		900
q/r(μC/m3)		319.9
Discharge	Yes	
Level	High	

Fill Rate Data

Flow Rate (GPM): 900

Act.Time sec	Time sec	Level in	Volume Gal	Rise Rate in/sec
	0	12.0	595	12.4
	27	17.2	1000	10.7
	94	28.0	2000	9.0
	160	37.6	3000	8.4
	227	46.8	4000	8.2
	294	56.0	5000	8.3
	361	65.5	6000	8.8
	394	70.6	6500	9.3

Notes:

1. Actual time measured from level measurement
2. Time calculated from flow rate
3. Level calculated from regression of volume vs. height measurements

Streaming Current Data

Time secs	Streaming Current μamps	Calc'd i μamps
0		
10	0.60	11.49
20	0.58	15.71
30	0.60	17.26
40	6.54	17.83
50	9.45	18.04
60	9.87	18.12
70	10.16	18.15
80	10.39	18.15
90	10.47	18.16
100	10.64	18.16
120	10.76	18.16
140	10.89	18.16
160	11.04	18.16
180	11.06	18.16
200	11.18	18.16
250	11.24	18.16
300	11.31	18.16
350	11.42	18.16
380	11.12	18.16
400	11.04	18.16
430	11.33	18.16
440	1.40	18.15
450	0.62	18.16
480	0.59	18.16
500	0.55	18.16
510	0.52	18.16
520	0.55	18.16

Field Strength Measurements

Time Sec	Field μamps	Field St kV/m	Field Str Max kV/m
0	9		
15	9	-6.1	2.1
30	50	3.4	11.6
45	50	3.4	11.5
60	40	1.1	9.3
75	30	-1.3	6.9
90	30	-1.3	6.9
105	30	-1.3	6.9
120	30	-1.3	6.9
135	30	-1.3	6.9
150	30	-1.3	6.9
165	30	-1.3	6.9
180	30	-1.3	6.9
195	30	-1.3	6.9
210	30	-1.3	6.9
225	30	-1.3	6.9
240	30	-1.3	6.9
255	30	-1.3	6.9
270	30	-1.3	6.9
285	30	-1.3	6.9
300	30	-1.3	6.9
315	30	-1.3	6.9
330	30	-1.3	6.9
345	30	-1.3	6.9
360	30	-1.3	6.9

Summary		
Test #		1
SDA type	None	
Conc(ppm)		
k (CU)		4
T(F)		32
F (GPM)		900
qin(μC/m3)		399.2
Discharge	Yes	
Level	High	

Fill Rate Data

Flow Rate (GPM): 900

Act.Time sec	Time sec	Level in	Volume Gal	Rise Rate in/sec
0	0	12.0	595	12.4
30	27	17.2	1000	10.7
108	94	28.0	2000	9.0
160	160	37.6	3000	8.4
224	227	46.8	4000	8.2
304	294	56.0	5000	8.3
374	361	65.5	6000	8.8
422	394	70.6	6500	9.3

Notes:

1. Actual time measured from level measurement
2. Time calculated from flow rate
3. Level calculated from regression of volume vs. height measurements

Streaming Current Data

Time secs	Streaming Current μamps	Calc'd i μamps
0		
10	0.36	19.60
20	0.36	22.25
30	1.46	22.61
40	9.10	22.66
50	9.24	22.67
60	9.44	22.67
70	9.53	22.57
80	9.73	22.57
90	9.73	22.67
100	9.75	22.67
110	9.78	22.67
120	9.73	22.67
130	9.78	22.67
140	9.73	22.67
150	9.75	22.67
160	9.67	22.67
170	9.50	22.67
180	9.46	22.67
190	9.03	22.67
200	8.94	22.67
210	9.03	22.67
220	8.81	22.67
230	3.63	22.67
240	0.20	22.67
250	0.23	22.67
260	0.24	22.67

Field Strength Measurements

Time Sec	Field μamps	Field St KV/m	Field Str Max KV/m
0			
15	10.0	-5.9	2.3
30	30.0	-1.3	6.9
45	50.0	3.4	11.6
60	40.0	1.1	9.3
75	45.0	2.2	10.4
90	50.0	3.4	11.6
105	50.0	3.4	11.6
120	50.0	3.4	11.5
135	50.0	3.4	11.6
150	50.0	3.4	11.6
165	50.0	3.4	11.6
150	50.0	3.4	11.6
195	50.0	3.4	11.6
210	50.0	3.4	11.6
225	50.0	3.4	11.6
240	50.0	3.4	11.6
255	50.0	3.4	11.6
270	50.0	3.4	11.6
285	50.0	3.4	11.6
300	50.0	3.4	11.6
315	50.0	3.4	11.6
330	50.0	3.4	11.6
345	50.0	3.4	11.6
380	50.0	3.4	11.6
375	50.0	3.4	11.6
390	50.0	3.4	11.6
405	50.0	3.4	11.6
420	50.0	3.4	11.6

Summary		
Test #		2
SDA type	None	
Conc(ppm)		
k (CU)		3
T(F)		30
F (GPM)		560
qi(μC/m3)		353.6
Discharge	No	
Level		

Fill Rate Data

Flow Rate (GPM): 560

Act. Time sec	Time sec	Level in	Volume Gal	Rise Rate in/sec
0	0	12.0	595	7.7
29	44	17.2	1000	6.7
160	150	29.0	2000	5.6
247	258	37.6	3000	5.2
357	365	46.8	4000	5.1
473	472	55.0	5000	5.2
590	580	65.5	6000	5.5
657	634	70.6	6500	5.8

Notes:

1. Actual time measured from level measurement
2. Time calculated from flow rate
3. Level calculated from regression of volume vs. height measurements

Streaming Current Data

Time secs	Streaming Current μamps	Calc'd i μamps
0	0.24	
60	5.44	12.49
120	5.45	12.49
180	5.37	12.49
240	5.23	12.49
300	5.18	12.49
360	5.13	12.49
420	5.07	12.49
480	5.06	12.49
540	5.05	12.49
600	0.23	12.49
660	5.04	12.49

Field Strength Measurements

Time Sec	Field μamps	Field Str KV/m	Field Str Max KV/m
0	20.0000	-3.6	
15	20.0000	-3.6	4.6
30	40.0000	1.1	9.3
45	25.0000	-2.4	5.8
60	25.0000	-2.4	5.8
75	25.0000	-2.4	5.8
90	25.0000	-2.4	5.8
105	25.0000	-2.4	5.8
120	25.0000	-2.4	5.8
135	25.0000	-2.4	5.8
150	25.0000	-2.4	5.8
165	25.0000	-2.4	5.8
180	25.0000	-2.4	5.8
195	25.0000	-2.4	5.8
210	25.0000	-2.4	5.8
225	25.0000	-2.4	5.8
240	25.0000	-2.4	5.8
255	25.0000	-2.4	5.8
270	25.0000	-2.4	5.8
285	25.0000	-2.4	5.8
300	25.0000	-2.4	5.8
315	25.0000	-2.4	5.8
330	25.0000	-2.4	5.8
345	25.0000	-2.4	5.8
360	25.0000	-2.4	5.8
375	25.0000	-2.4	5.8
390	25.0000	-2.4	5.8
405	25.0000	-2.4	5.8
420	25.0000	-2.4	5.8
435	25.0000	-2.4	5.8
450	25.0000	-2.4	5.8
465	25.0000	-2.4	5.8
480	20.0000	-3.6	4.6
495	25.0000	-2.4	5.8
510	25.0000	-2.4	5.8
525	25.0000	-2.4	5.8
540	25.0000	-2.4	5.8
555	25.0000	-2.4	5.8

Summary

Test #		3
SDA type	ASA-3	
Cond(pom)		0.45
k (CU)		65
T(°F)		45
F (GPM)		870
qin(μC/m3)		68.2
Discharge	No	
Level		

Fill Rate Data

Flow Rate (GPM): 870

Act.Time sec	Time sec	Level in	Volume Gal	Rise Rate in/sec
0	0	12.0	595	12.0
30	28	17.2	1000	10.3
105	97	28.0	2000	8.7
180	166	37.6	3000	8.1
225	235	46.8	4000	7.9
298	304	56.0	5000	8.0
370	373	65.5	6000	8.5
407	408	70.6	6500	9.0

Notes:

1. Actual time measured from level measurement
2. Time calculated from flow rate
3. Level calculated from regression of volume vs. height measurements

Streaming Current Data

Time secs	Streaming Current μamps	Calc'd I μamps
0		
10	1.69	3.74
20	1.71	3.74
30	1.66	3.74
40	1.02	3.74
50	0.60	3.74
60	0.46	3.74
70	0.41	3.74
80	0.42	3.74
90	0.38	3.74
100	0.38	3.74
110	0.37	3.74
120	0.41	3.74
130	0.43	3.74
140	0.41	3.74
150	0.43	3.74
170	0.43	3.74
190	0.45	3.74
200	0.45	3.74
250	0.49	3.74
300	0.98	3.74
350	0.97	3.74
400	0.97	3.74
450	2.18	3.74

Field Strength Measurements

Time Sec	Field μamps	Field St KV/m	Field Str Max KV/m
0	15.0	-4.7	
15	15.0	-4.7	3.5
30	15.0	-4.7	3.5
45	15.0	-4.7	3.5
60	15.0	-4.7	3.5
75	15.0	-4.7	3.5
90	15.0	-4.7	3.5
105	15.0	-4.7	3.5
120	15.0	-4.7	3.5
135	15.0	-4.7	3.5
150	15.0	-4.7	3.5
165	15.0	-4.7	3.5
180	15.0	-4.7	3.5
195	15.0	-4.7	3.5
210	15.0	-4.7	3.5
225	15.0	-4.7	3.5
240	15.0	-4.7	3.5
255	15.0	-4.7	3.5
270	15.0	-4.7	3.5
285	15.0	-4.7	3.5
300	15.0	-4.7	3.5
315	15.0	-4.7	3.5
330	15.0	-4.7	3.5
345	15.0	-4.7	3.5

Summary		
Test #		4
SDA type	ASA-3	
Cond(ppm)		0.45
k (CU)		63
T(F)		48
F (GPM)		560
qin(µC/m3)		50.6
Discharge	No	
Level		

Fill Rate Data

Flow Rate (GPM): 585

Act.Time secs	Time secs	Level in	Volume Gal	Rise Rate in/sec
0	0	12.0	595	7.7
26	44	17.2	1000	6.7
152	150	28.0	2000	5.6
240	238	37.6	3000	5.2
347	365	46.8	4000	5.1
453	472	56.0	5000	5.2
570	580	65.5	6000	5.5
636	634	70.6	6500	5.8

Notes:
1. Actual time measured from level measurement
2. Time calculated from flow rate
3. Level calculated from regression of volume vs. height measurements

Streaming Current Data

Time secs	Streaming Current µamps	Calc'd I µamps
0		
10	1.40	1.79
20	1.39	1.79
30	1.29	1.79
40	0.88	1.79
50	0.80	1.79
60	0.83	1.79
70	0.80	1.79
80	0.81	1.79
90	0.79	1.79
100	0.78	1.79
110	0.77	1.79
120	0.79	1.79
130	0.76	1.79
140	0.79	1.79
150	0.78	1.79
200	0.79	1.79
250	0.79	1.79
300	0.77	1.79
350	0.73	1.79
400	0.78	1.79
450	0.77	1.79
500	0.76	1.79
550	0.81	1.79
600	0.82	1.79
650	0.79	1.79
660	0.78	1.79
670	0.79	1.79
700	0.76	1.79

Field Strength Measurements

Time Sec	Field µamps	Field St KV/m	Field Str Max KV/m
0	20.0	-3.6	
15	20.0	-3.6	4.6
30	20.0	-3.6	4.6
45	20.0	-3.6	4.5
60	20.0	-3.6	4.6
75	20.0	-3.6	4.6
90	20.0	-3.6	4.6
105	20.0	-3.6	4.6
120	20.0	-3.6	4.6
135	20.0	-3.6	4.5
150	20.0	-3.6	4.6
165	20.0	-3.6	4.6
180	20.0	-3.6	4.6
195	20.0	-3.6	4.6
210	20.0	-3.6	4.6
225	20.0	-3.6	4.6
240	20.0	-3.6	4.6
255	20.0	-3.6	4.6
270	20.0	-3.6	4.6
285	20.0	-3.6	4.6
300	20.0	-3.6	4.6
315	20.0	-3.6	4.6
330	20.0	-3.6	4.6
345	20.0	-3.6	4.6
360	20.0	-3.6	4.6
375	20.0	-3.6	4.6
390	20.0	-3.6	4.6
405	20.0	-3.6	4.6
420	20.0	-3.6	4.6
435	20.0	-3.6	4.6
450	20.0	-3.6	4.6
465	20.0	-3.6	4.6
480	20.0	-3.6	4.6
495	20.0	-3.6	4.6
510	20.0	-3.6	4.6
525	20.0	-3.6	4.6
540	20.0	-3.6	4.6
555	20.0	-3.6	4.6

Test #	5
SDA type	ASA-3
Cond(ppm)	—
k (CU)	16
T(F)	43
F (GPM)	875
qin(μC/m3)	215.6
Discharge	Yes
Level	low

Flow Rate Data

Flow Rate (GPM): 875

Act. Time sec	Time sec	Level in	Volume Gal	Rise Rate in/sec
0	0	12.0	595	12.1
23	28	17.2	1000	10.4
99	96	28.0	2000	8.8
160	165	37.6	3000	8.2
224	233	46.8	4000	8.0
295	302	56.0	5000	8.1
380	371	65.5	6000	8.6
422	406	70.6	6500	9.0

Notes:
1. Actual time measured from level measurement
2. Time calculated from flow rate
3. Level calculated from regression of volume vs. height measurements

Streaming Current Data

Time secs	Streaming Current μamps	Calc'd i μamps
0		
10	0.23	11.90
20	0.26	11.90
30	0.20	11.90
40	2.35	11.90
50	4.31	11.90
60	4.52	11.90
70	4.79	11.90
80	4.52	11.90
90	4.91	11.90
100	4.77	11.90
110	4.76	11.90
120	4.83	11.90
130	4.80	11.90
140	4.70	11.90
150	4.63	11.90
200	4.22	11.90
250	4.11	11.90
300	4.02	11.90
350	4.18	11.90
400	4.10	11.90
410	4.08	11.90
420	4.16	11.90
430	4.05	11.90
440	0.83	11.90

Field Strength Measurements

Time Sec	Field μamps	Field St KV/m	Field Str Max KV/m
0	5.0	-7.0	
15	5.0	-7.0	1.2
30	5.0	-7.0	1.2
45	5.0	-7.0	1.2
60	5.0	-7.0	1.2
75	10.0	-5.9	2.3
90	5.0	-7.0	1.2
105	5.0	-7.0	1.2
120	10.0	-5.9	2.3
135	10.0	-5.9	2.3
150	10.0	-5.9	2.3
165	10.0	-5.9	2.3
180	10.0	-5.9	2.3
195	10.0	-5.9	2.3
210	10.0	-5.9	2.3
225	10.0	-5.9	2.3
240	10.0	-5.9	2.3
255	10.0	-5.9	2.3
270	10.0	-5.9	2.3
285	10.0	-5.9	2.3
300	10.0	-5.9	2.3
315	10.0	-5.9	2.3
330	10.0	-5.9	2.3
345	10.0	-5.9	2.3
360	10.0	-5.9	2.3
375	10.0	-5.9	2.3
390	10.0	-5.9	2.3

Test #		6
SDA type	ASA-3	
Conc(ppm)		
κ (CU)		15
T(F)		43
F (GPM)		550
qin(μC/m3)		113.1
Discharge	No	
Level		

Fill Rate Data

Flow Rate (GPM): 550

Act.Time secs	Time secs	Level in	Volume Gal	Rise Rate in/sec
0	0	12.0	595	7.6
29	45	17.2	1000	6.5
159	153	28.0	2000	5.5
247	262	37.6	3000	5.1
357	371	46.8	4000	5.0
477	481	56.0	5000	5.1
590	591	65.5	6000	5.4
646	645	70.6	6500	5.7

Notes:

1. Actual time measured from level measurement
2. Time calculated from flow rate
3. Level calculated from regression of volume vs. height measurements

Streaming Current Data

Time secs	Streaming Current μamps	Calc'd I μamps
0		
10	0.01	3.92
20	0.01	3.93
30	0.00	3.93
40	0.87	3.93
50	1.09	3.93
60	1.07	3.93
70	1.09	3.93
80	1.11	3.93
90	1.12	3.93
100	1.12	3.93
110	1.15	3.93
120	1.11	3.93
130	1.13	3.93
140	1.10	3.93
150	1.09	3.93
200	1.11	3.93
250	1.10	3.93
300	1.13	3.93
350	1.18	3.93
400	1.29	3.93
450	1.28	3.93
500	1.28	3.93
550	1.24	3.93
600	1.26	3.93
650	1.15	3.93
660	0.07	3.93
670	0.09	3.93
680	0.09	3.93

Field Strength Measurements

Time Sec	Field μamps	Field St KV/m	Field Str Max KV/m
0			
15	5.0	-7.0	1.2
30	10.0	-5.9	2.3
45	10.0	-5.9	2.3
60	10.0	-5.9	2.3
75	10.0	-5.9	2.3
90	10.0	-5.9	2.3
105	10.0	-5.9	2.3
120	10.0	-5.9	2.3
135	5.0	-7.0	1.2
150	5.0	-7.0	1.2
165	5.0	-7.0	1.2
180	5.0	-7.0	1.2
195	5.0	-7.0	1.2
210	5.0	-7.0	1.2
225	5.0	-7.0	1.2
240	5.0	-7.0	1.2
255	5.0	-7.0	1.2
270	5.0	-7.0	1.2
285	5.0	-7.0	1.2
300	5.0	-7.0	1.2
315	5.0	-7.0	1.2
330	5.0	-7.0	1.2
345	5.0	-7.0	1.2
360	5.0	-7.0	1.2
375	5.0	-7.0	1.2
390	5.0	-7.0	1.2
405	5.0	-7.0	1.2
420	5.0	-7.0	1.2
435	5.0	-7.0	1.2
450	5.0	-7.0	1.2
465	5.0	-7.0	1.2
480	5.0	-7.0	1.2
495	5.0	-7.0	1.2
510	5.0	-7.0	1.2
525	5.0	-7.0	1.2
540	5.0	-7.0	1.2
555	5.0	-7.0	1.2

Test #		7
SDA type	ASA-3	
Conc(ppm)		
κ (CU)		12
T(°F)		66
F (GPM)		875
qin(μC/m3)		1319.7
Discharge	Yes	
Level	Low	

Fill Rate Data

Flow Rate (GPM): 875

Act.Time sec	Time sec	Level in	Volume Gal	Rise Rate in/sec
0	0	12.0	595	12.1
29	28	17.2	1000	10.4
102	96	28.0	2000	8.8
158	165	37.6	3000	8.2
228	233	46.8	4000	8.0
306	302	56.0	5000	8.1
382	371	65.5	6000	8.6
422	406	70.6	6500	9.0

Notes:
1. Actual time measured from level measurement
2. Time calculated from flow rate
3. Level calculated from regression of volume vs. height measurements

Streaming Current Data

Time secs	Streaming Current μamps	Calc'd i μamps
0		
10	0.00	72.66
20	0.00	72.84
30	0.78	72.84
40	17.42	72.84
50	30.62	72.84
60	33.37	72.84
70	35.22	72.84
80	35.41	72.84
90	35.95	72.84
100	36.56	72.84
110	36.70	72.84
120	37.16	72.84
130	36.82	72.84
140	36.73	72.84
150	37.30	72.84
200	36.73	72.84
250	36.39	72.84
300	35.32	72.84
350	34.85	72.84
400	34.31	72.84
410	33.98	72.84
420	33.85	72.84
430	4.22	72.84
440	0.09	72.84
450	0.09	72.84

Field Strength Measurements

Time Sec	Field μamps	Field St KV/m	Field Str Max KV/m
0			
15	15.0	-4.7	3.5
30	20.0	-3.6	4.6
45	50.0	3.4	11.6
60	40.0	1.1	9.3
75	50.0	3.4	11.6
90	60.0	5.7	13.9
105	100.0	14.9	23.2
120	100.0	14.9	23.2
135	80.0	10.3	18.5
150	70.0	8.0	16.2
165	80.0	10.3	18.5
180	80.0	10.3	18.5
195	70.0	8.0	16.2
210	70.0	8.0	16.2
225	100.0	14.9	23.2
240	80.0	10.3	18.5
255	80.0	10.3	18.5
270	90.0	12.6	20.8
285	50.0	3.4	11.6
300	60.0	5.7	13.9
315	70.0	8.0	16.2
330	60.0	5.7	13.9
345	80.0	10.3	18.5
360	60.0	5.7	13.9
375	100.0	14.9	23.2
390	100.0	14.9	23.2

Note Large variation in Field Strength
Variation 50 - 100 with spikes to 150
micro-amperes

Test #		8
SDA type	ASA-3	
Conc(ppm)		
k (CU)		20
T(F)		65
f (GPM)		590
qi(μC/m3)		737.0
Discharge	No	
Level		

Fill Rate Data

Flow Rate (GPM): 590

Act. Time sec	Time sec	Level in	Volume Gal	Rise Rate in/sec
0	0	12.0	595	8.1
24	42	17.2	1000	7.0
143	143	28.0	2000	5.9
224	245	37.6	3000	5.5
329	346	46.8	4000	5.4
436	448	56.0	5000	5.5
552	551	65.5	6000	5.8
604	601	70.6	6500	6.1

Notes:

1. Actual time measured from level measurement
2. Time calculated from flow rate
3. Level calculated from regression of volume vs. height measurements

Streaming Current Data

Time secs	Streaming Current μamps	Calc'd i μamps
0		
10	0.07	27.43
20	0.07	27.43
30	0.95	27.43
40	9.92	27.43
50	13.06	27.43
60	11.70	27.43
70	11.97	27.43
80	12.27	27.43
90	12.40	27.43
100	12.68	27.43
110	12.74	27.43
120	12.80	27.43
130	12.69	27.43
140	13.09	27.43
150	13.08	27.43
200	13.20	27.43
250	12.99	27.43
300	13.32	27.43
350	13.26	27.43
400	13.06	27.43
450	13.00	27.43
500	13.02	27.43
550	12.92	27.43
600	13.05	27.43
610	13.09	27.43
620	0.06	27.43
630	0.09	27.43
640	0.09	27.43

Field Strength Measurements

Time Sec	Field μamps	Field St KV/m	Field Str Max KV/m
0			
15	25.0	-2.4	5.8
30	25.0	-2.4	5.8
45	25.0	-2.4	5.8
60	30.0	-1.3	6.9
75	30.0	-1.3	6.9
90	35.0	-0.1	8.1
105	30.0	-1.3	6.9
120	35.0	-0.1	8.1
135	40.0	1.1	9.3
150	30.0	-1.3	6.9
165	30.0	-1.3	6.9
180	30.0	-1.3	6.9
195	30.0	-1.3	6.9
210	35.0	-0.1	8.1
225	35.0	-0.1	8.1
240	35.0	-0.1	8.1
255	30.0	-1.3	6.9
270	35.0	-0.1	8.1
285	40.0	1.1	9.3
300	40.0	1.1	9.3
315	35.0	-0.1	8.1
330	40.0	1.1	9.3
345	30.0	-1.3	6.9
360	40.0	1.1	9.3
375	40.0	1.1	9.3
390	35.0	-0.1	8.1
405	40.0	1.1	9.3
420	40.0	1.1	9.3
435	35.0	-0.1	8.1
450	35.0	-0.1	8.1
465	30.0	-1.3	6.9
480	35.0	-0.1	8.1
495	45.0	2.2	10.4
510	45.0	2.2	10.4
525	35.0	-0.1	8.1
540	35.0	-0.1	8.1
555	35.0	-0.1	8.1

Test #		9
SDA type	ASA-3	
Conc(ppm)		
σ (C/J)		25
T(F)		64
F (GPM)		875
qi(μC/m3)		1108.3
Discharge	Yes	
Level	Low	

Fill Rate Data

Flow Rate (GPM): 875

Act. Time sec	Time sec	Level in	Volume Gal	Rise Rate in/sec
	0	12.0	595	12.1
	28	17.2	1000	10.4
	96	28.0	2000	8.8
	165	37.6	3000	8.2
	233	46.8	4000	8.0
	302	56.0	5000	8.1
	371	65.5	6000	8.6
	406	70.6	6500	9.0

Notes:
1. Actual time measured from level measurement
2. Time calculated from flow rate
3. Level calculated from regression of volume vs. height measurements

Streaming Current Data

Time secs	Streaming Current μamps	Calc'd i μamps
0		
10	0.00	61.18
20	0.07	61.18
30	0.63	61.18
40	13.70	61.18
50	24.27	61.18
60	26.84	61.18
70	29.35	61.18
80	28.88	61.18
90	30.01	61.18
100	30.38	61.18
110	30.02	61.18
120	30.49	61.18
130	30.51	61.18
140	30.48	61.18
150	30.64	61.18
200	30.24	61.18
250	29.86	61.18
300	29.33	61.18
350	28.89	61.18
400	27.97	61.18
410	28.22	61.18
420	28.75	61.18
430	11.93	61.18
440	0.08	61.18
450	0.08	61.18

Field Strength Measurements

Time Sec	Field μamps	Field St KV/m	Field Str Max KV/m
0			
15	20.0	-3.6	4.6
30	25.0	-2.4	5.8
45	30.0	-1.3	6.9
60	50.0	3.4	11.6
75	70.0	8.0	16.2
90	90.0	12.6	20.8
105	60.0	5.7	13.9
120	100.0	14.9	23.2
135	90.0	12.6	20.8
150	100.0	14.9	23.2
165	70.0	8.0	16.2
180	70.0	8.0	16.2
195	80.0	10.3	18.5
210	100.0	14.9	23.2
225	70.0	8.0	16.2
240	100.0	14.9	23.2
255	50.0	3.4	11.6
270	70.0	8.0	16.2
285	100.0	14.9	23.2
300	90.0	12.6	20.8
315	60.0	5.7	13.9
330	90.0	12.6	20.8
345	80.0	10.3	18.5
360	110.0	17.3	25.5
375	90.0	12.6	20.8
390	70.0	8.0	16.2
405	60.0	5.7	13.9
420	70.0	8.0	16.2

Test #		10
SDA type		
Cond(ppm)		
κ (CU)		5
T(F)		66
F (GPM)		870
qin(μC/m3)		442.9
Discharge	Yes	
Level	High	

Fill Rate Data

Flow Rate (GPM): 870

Act.Time sec	Time sec	Level in	Volume Gal	Rise Rate in/sec
0	0	12.0	595	12.0
28	28	17.2	1000	10.3
104	97	28.0	2000	8.7
158	166	37.6	3000	8.1
224	235	46.8	4000	7.9
304	304	56.0	5000	8.0
380	373	65.5	6000	8.5
421	408	70.6	6500	9.0

Notes:
1. Actual time measured from level measurement
2. Time calculated from flow rate
3. Level calculated from regression of volume vs. height measurements

Streaming Current Data

Time secs	Streaming Current μamps	Calc'd I μamps
0		
10	0.01	22.31
20	0.01	24.14
30	7.55	24.29
40	12.29	24.31
50	12.79	24.31
60	12.92	24.31
70	12.97	24.31
80	12.80	24.31
90	12.8[illegible]	24.31
100	12.92	24.31
110	12.70	24.31
120	12.68	24.31
130	12.75	24.31
140	12.44	24.31
150	12.55	24.31
200	12.22	24.31
250	12.05	24.31
300	11.72	24.31
350	11.13	24.31
400	11.14	24.31
410	11.13	24.31
420	11.25	24.31
430	0.07	24.31
440	0.08	24.31

Field Strength Measurements

Time Sec	Field μamps	Field St KV/m	Field St Max KV/m
0			
15	35.0	-0.1	8.1
30	60.0	5.7	13.9
45	190.0	35.8	44.0
60	200.0	38.1	46.3
75	200.0	38.1	46.3
90	250.0	49.7	57.9
105	205.0	39.3	47.5
120	205.0	39.3	47.5
135	210.0	40.4	48.6
150	210.0	40.4	48.6
165	210.0	40.4	48.6
180	210.0	40.4	48.6
195	210.0	40.4	48.6
210	210.0	40.4	48.6
225	210.0	40.4	48.6
240	210.0	40.4	48.6
255	210.0	40.4	48.6
270	210.0	40.4	48.6
285	215.0	41.6	49.8
300	215.0	41.6	49.8
315	215.0	41.6	49.8
330	215.0	41.6	49.8
345	215.0	41.6	49.8
360	215.0	41.6	49.8
375	220.0	42.7	50.9
390	220.0	42.7	50.9
405	220.0	42.7	50.9
455	60.0	5.7	13.9
470	50.0	3.4	11.6
525	45.0	2.2	10.4

Test #	11
SDA type	
Conc(ppm)	
k (CU)	6
T(F)	71
F (GPM)	590
qin(µC/m3)	398.9
Discharge	No
Level	

Fill Rate Data

Flow Rate (GPM): 590

Act. Time sec	Time sec	Level in	Volume Gal	Rise Rate in/sec
0	0	12.0	595	8.1
25	42	17.2	1000	7.0
144	143	28.0	2000	5.9
226	245	37.8	3000	5.5
333	346	46.8	4000	5.4
442	448	56.0	5000	5.5
550	551	65.5	6000	5.8
604	601	70.6	6500	8.1

Notes:

1. Actual time measured from level measurement
2. Time calculated from flow rate
3. Level calculated from regression of volume vs. height measurements

Streaming Current Data

Time secs	Streaming Current µamps	Calc'd i µamps
0		
10	0.08	14.11
20	0.08	14.81
30	0.09	14.85
40	0.36	14.85
50	6.82	14.85
60	7.55	14.85
70	7.53	14.85
80	7.61	14.85
90	7.62	14.85
100	7.55	14.85
110	7.52	14.85
120	7.52	14.85
130	7.48	14.85
140	7.43	14.85
150	7.42	14.85
200	7.32	14.85
250	7.17	14.85
300	7.16	14.85
350	7.13	14.85
400	7.09	14.85
450	7.01	14.85
500	7.02	14.85
550	6.97	14.85
600	6.90	14.85
610	6.93	14.85
620	6.88	14.85
630	1.01	14.85
640	0.08	14.85
650	0.08	14.85

Field Strength Measurements

Time Sec	Field µamps	Field Str KV/m	Field Str Max KV/m
0			
15	35.0	-0.1	8.1
30	35.0	-0.1	8.1
45	80.0	10.3	18.5
60	100.0	14.9	23.2
75	160.0	28.8	37.0
90	190.0	35.8	44.0
105	190.0	35.8	44.0
120	215.0	41.6	49.5
135	210.0	40.4	48.6
150	215.0	41.6	49.8
165	215.0	41.6	49.5
180	220.0	42.7	50.9
195	220.0	42.7	50.9
210	215.0	41.6	49.8
225	215.0	41.6	49.8
240	230.0	45.0	53.2
255	220.0	42.7	50.9
270	220.0	42.7	50.9
285	220.0	42.7	50.9
300	220.0	42.7	50.9
315	220.0	42.7	50.9
330	220.0	42.7	50.9
345	220.0	42.7	50.9
360	220.0	42.7	50.9
375	220.0	42.7	50.9
390	220.0	42.7	50.9
405	220.0	42.7	50.9
420	220.0	42.7	50.9
435	220.0	42.7	50.9
450	220.0	42.7	50.9
465	220.0	42.7	50.9
480	220.0	42.7	50.9
495	220.0	42.7	50.9
510	220.0	42.7	50.9
525	220.0	42.7	50.9
540	220.0	42.7	50.9
555	220.0	42.7	50.9

Test #	12
SDA type	Stadis 450
Conc(ppm)	
k (CU)	24
T(F)	74
F (GPM)	860
qin(μC/m3)	308.3
Discharge	Yes
Level	Low

Fill Rate Data

Flow Rate (GPM): 860

Act. Time sec	Time sec	Level in	Volume Gal	Rise Rate in/sec
	0	12.0	595	11.9
29	29	17.2	1000	10.2
106	98	28.0	2000	8.6
162	168	37.6	3000	8.0
229	237	46.8	4000	7.8
309	307	56.0	5000	8.0
389	378	65.5	6000	8.4
426	413	70.6	6500	8.9

Notes:

1. Actual time measured from level measurement
2. Time calculated from flow rate
3. Level calculated from regression of volume vs. height measurements

Streaming Current Data

Time secs	Streaming Current μamps	Calc'd i μamps
0		
10	0.09	16.73
20	0.09	16.73
30	0.48	16.73
40	4.98	16.73
50	7.72	16.73
60	8.05	16.73
70	8.33	15.73
80	8.67	16.73
90	8.56	16.73
100	8.72	16.73
110	8.42	16.73
120	8.55	16.73
130	8.50	16.73
140	8.35	16.73
150	8.07	16.73
200	8.39	16.73
250	8.38	16.73
300	8.00	16.73
350	7.84	16.73
400	7.96	16.73
410	8.02	16.73
420	7.28	16.73
430	7.85	16.73
440	0.06	16.73

Field Strength Measurements

Time Sec	Field μamps	Field St KV/m	Field St Max KV/m
0			
15	50.0	3.4	11.6
30	60.0	5.7	13.9
45	75.0	9.2	17.4
60	80.0	10.3	18.5
75	80.0	10.3	18.5
90	90.0	12.6	20.8
105	100.0	14.9	23.2
120	80.0	10.3	18.5
135	80.0	10.3	18.5
150	100.0	14.9	23.2
165	95.0	13.8	22.0
180	80.0	10.3	18.5
195	90.0	12.8	20.8
210	80.0	10.3	18.5
225	70.0	8.0	16.2
240	80.0	10.3	18.5
255	80.0	10.3	18.5
270	90.0	12.6	20.8
285	90.0	12.6	20.8
300	85.0	11.5	19.7
315	80.0	10.3	18.5
330	80.0	10.3	18.5
345	80.0	10.3	18.5
360	75.0	9.2	17.4
375	85.0	11.5	19.7
390	80.0	10.3	18.5
405	95.0	13.8	22.0

Fill Rate Data

Test #	13
SDA type	Stadis 450
Conc(ppm)	
k (CU)	22
T(F)	75
F (GPM)	610
qin(µC/m3)	211.8
Discharge	No
Level	

Flow Rate (GPM): 610

Act.Time sec	Time sec	Level in	Volume Gal	Rise Rate in/sec
0	0	12.0	595	8.4
19	40	17.2	1000	7.3
145	138	28.0	2000	6.1
220	237	37.6	3000	5.7
325	335	46.8	4000	5.6
430	433	56.0	5000	5.6
535	533	65.5	6000	6.0
585	582	70.6	6500	6.3

Notes:

1. Actual time measured from level measurement
2. Time calculated from flow rate
3. Level calculated from regression of volume vs. height measurements

Streaming Current Data

Time secs	Streaming Current µamps	Calc'd i µamps
0		
10	0.09	8.15
20	0.09	8.15
30	0.20	8.15
40	2.66	8.15
50	3.49	8.15
60	3.47	8.15
70	3.54	5.15
80	3.54	8.15
90	3.81	8.15
100	3.73	8.15
110	3.79	8.15
120	3.81	8.15
130	3.76	8.15
140	3.76	8.15
150	3.77	8.15
200	3.90	8.15
250	3.77	8.15
310	3.70	8.15
350	3.87	8.15
400	3.87	8.15
450	3.97	8.15
500	3.92	8.15
550	3.81	8.15
570	3.86	8.15
580	3.86	8.15
590	3.77	8.15
600	0.08	8.15

Field Strength Measurements

Time Sec	Field µamps	Field St KV/m	Field Str Max KV/m
0			
15	55.0	4.5	12.7
30	55.0	4.5	12.7
45	60.0	5.7	13.9
60	60.0	5.7	13.9
75	65.0	6.8	15.0
90	65.0	6.8	15.0
105	65.0	6.5	15.0
120	55.0	6.5	15.0
135	70.0	8.0	16.2
150	65.0	6.8	15.0
165	70.0	8.0	16.2
180	65.0	6.8	15.0
195	70.0	8.0	16.2
210	70.0	8.0	16.2
225	70.0	8.0	16.2
240	70.0	8.0	16.2
255	70.0	8.0	16.2
270	70.0	8.0	16.2
285	70.0	8.0	16.2
300	70.0	8.0	16.2
315	70.0	8.0	16.2
330	65.0	6.8	15.0
345	65.0	6.8	15.0
360	65.0	6.8	15.0
375	65.0	6.8	15.0
390	65.0	6.8	15.0
405	65.0	6.8	15.0
420	70.0	8.0	16.2
435	70.0	8.0	16.2
450	70.0	8.0	16.2
465	70.0	8.0	16.2
480	70.0	8.0	16.2
495	70.0	8.0	16.2
510	70.0	8.0	16.2
525	70.0	8.0	16.2
540	70.0	8.0	16.2
555	70.0	8.0	16.2

Fill Rate Data

Test #		14
SDA type	Stadis 450	
Cond(pom)		
κ (CU)		9
T(F)		69
F (GPM)		845
qr(μC/m3)		569.2
Discharge	Yes	
Level	Low	

Flow Rate (GPM): 845

Act.Time sec	Time sec	Level in	Volume Gal	Rise Rate in/sec
	0	12.0	585	11.7
	29	17.2	1000	10.0
	100	28.0	2000	8.5
	171	37.6	3000	7.9
	242	46.8	4000	7.7
	313	56.0	5000	7.8
	384	65.5	6000	8.3
	420	70.6	6500	8.7

Notes:
1. Actual time measured from level measurement
2. Time calculated from flow rate
3. Level calculated from regression of volume vs. height measurements
4. Actual time not measured

Streaming Current Data

Time secs	Streaming Current μamps	Calc'd i μamps
0		
10	0.00	30.01
20	0.00	30.34
30	0.52	30.34
40	10.49	30.34
50	13.90	30.34
60	14.94	30.34
70	14.79	30.34
80	14.84	30.34
90	14.34	30.34
100	13.92	30.34
110	14.32	30.34
120	13.99	30.34
130	14.11	30.34
140	13.94	30.34
150	14.02	30.34
160	13.69	30.34
170	13.08	30.34
180	12.5C	30.34
190	12.67	30.34
200	12.7:	30.34
210	12.82	30.34
220	12.68	30.34
230	12.88	30.34
240	7.72	30.34
250	0.05	30.34
260	0.05	30.34

Field Strength Measurements

Time Sec	Field μamps	Field Str KV/m	Field Str Mag KV/m
0			
15	5.0	-7.0	1.2
30	10.0	-5.9	2.3
45	40.0	1.1	9.3
60	30.0	-1.3	6.9
75	50.0	3.4	11.6
90	30.0	-1.3	6.9
105	40.0	1.1	9.3
120	50.0	3.4	11.6
135	30.0	-1.3	6.9
150	20.0	-3.6	4.6
165	40.0	1.1	9.3
180	40.0	1.1	9.3
195	50.0	3.4	11.6
210	0.0	-8.2	0.0
225	40.0	1.1	9.3
240	50.0	3.4	11.6
255	30.0	-1.3	6.9
270	50.0	3.4	11.6
285	30.0	-1.3	6.9
300	30.0	-1.3	6.9
315	30.0	-1.3	6.9
330	40.0	1.1	9.3
345	40.0	1.1	9.3
360	30.0	-1.3	6.9
375	40.0	1.1	9.3
390	50.0	3.4	11.6
405	30.0	-1.3	6.9

D. Residence Time Study Data

The appendix contains the raw daw for residence time available in various equipment. The data is coded with reference number in the event future retrieval is necessary.

Table D.1 -- Residence Times for Hydrant Servicers with Filter/Coalescers

Reference	No of Units	Flow Rate	Volume After Vessel	Vessel Volume After Elements	Residence Time (sec)		
		USGPM	*cubic inch*	*Gallons*	*After Vessel*	*In Vessel*	*Total*
101	71	500	5047		2.62	NA	N/A
102	29	500	6223		3.23	NA	N/A
103	10	350	4447		3.3	NA	N/A
104	4	500	9791		5.09	NA	N/A
105	2	500	12380	95.2	6.43	11.42	17.85
106	5	575	5881	79.3	2.66	8.27	10.93
107	5	475	8434		4.61	NA	N/A
108	6	500	4588	64.9	2.38	7.79	10.17
109	20	450	1066	2	6.15	NA	N/A
110	31	550	5975	74.6	2.82	8.14	10.96
111	10	550	3433	119.5	1.62	13.04	14.66
112	2	800	1028	5	3.34	NA	N/A
113	7	750	6234		2.16	NA	N/A
114	4	750	6755	127.1	2.34	10.17	12.51
115	19	500	4572	127.1	2.38	15.25	17.63
116	14	740	4951	127.1	1.74	10.31	12.05
117	5	300	2274	88.4	1.97	17.68	19.65
118	15	300	2576	88.4	2.23	17.68	19.91
119	4	810	3923		1.26	NA	N/A
120	13	420	8006		4.95	NA	N/A
121	1	375	16028	54.2	11.1	8.67	19.77
122	10	450	5938	55.2	3.43	7.36	10.79
123	5	450	6861	55.2	3.96	7.36	11.32
124	1	600	3859		1.67	NA	N/A
125	1	500	4491	62.8	2.33	7.54	9.87
126	2	500	3718	127.1	1.93	15.25	17.18
127	2	600	5504	122.2	2.38	12.22	14.6
128	6	600	7672	62.6	3.32	6.26	9.58
129	6	600	7031	55.2	3.04	5.52	8.56
130	1	100	4750	15.1	12.34	9.06	21.4
131	3	500	5777	74	3	8.88	11.88
132	2	470	6041	55.2	3.34	7.05	10.39
133	7	470	5806	55.2	3.21	7.06	10.27
134	2	400	6239	64.9	4.05	9.74	13.79
135	4	600	7630		3.3	NA	N/A
136	9	600	7365	62.8	3.19	6.28	9.47
137	5	1000	2813	72.5	0.73	4.35	5.08
138	7	480	6008	64.9	3.25	8.11	11.30
139	1	600	6638	64.9	2.87	6.49	9.36
140	3	600	6009	74.6	2.6	7.46	10.06
141	2	600	8395	74.6	3.63	7.46	11.09

Table D.2 – Residence Times for Refuelers with Filter/Coalescers

Reference	No of Units	Flow Rate	Volume After Vessel	Vessel Volume After Elements	Residence (sec)		Time
		USGPM	*cubic inch*	*Gallons*	*After Vessel*	*In Vessel*	*Total*
201	2	250	3216	22.6	3.34	5.42	8.76
202	2	550	7956	95.2	3.76	10.39	14.15
203	2	100	2509	7.5	6.52	4.5	11.02
204	3	600	5292	54.2	2.29	5.42	7.71
205	9	500	7474	54.2	3.88	6.5	10.38
206	5	500	5690		2.96	NA	N/A
207	7	650	7210	115.1	2.86	10.62	13.5
208	1	320	5919	95.2	4.8	17.85	22.65
209	10	450	4023		2.32	NA	N/A
210	3	225	4434		5.12	NA	N/A
211	2	70	4360		16.18	NA	N/A
212	1	200	4834	20.5	6.28	6.15	12.43
213	2	300	6857	20.5	5.94	4.1	10.04
214	1	200	6291	20.5	8.17	6.15	14.32
215	4	400	11630	59.6	7.55	8.94	16.49
216	1	500	12960		6.73	NA	N/A
217	1	100	2502	13.3	6.5	7.98	14.48
218	1	200	4439	16.7	5.77	5.01	10.78
219	1	600	5754	95.7	2.49	9.57	12.06
220	1	600	479	95.2	2 06	9.52	11.58
221	1	100	2465		6 4	NA	N/A
222	1	300	2804	21.1	2 43	4.22	6.65
223	1	300	4863	20.5	4 21	4.1	8.31
224	1	450	8383	57.2	4 84	7.63	12.47
225	2	400	6021	54.2	3 91	8.13	12.04
226	2	400	9241		6	NA	N/A
227	2	400	6199	93.1	4 03	13.97	18
228	221	270	1359		1 31	NA	N/A
229	1	100	2658	20.5	6 9	12.3	19.2
230	3	600	13205	74	5 72	7.4	13.12
231	1	600	15278	93.1	6 61	9.31	15.92
232	2	600	5910	154	2 56	15.4	17.96
233	2	600	7010	95.7	3 03	9.57	12.6
234	2	600	11619	95.7	5 03	9.57	14.6
235	4	600	11097	95.7	4 8	9.57	14.37
236	1	600	11352	135	4 91	13.5	18.41

Table D.3 -- Residence Times for Hydrant Servicers with Absorbing Media Monitors

Reference Number	No. of Units	Flow Rate *GPM*	Volume *Gallon*	esidence Time *Sec*
301	21	900	10573	3.05
302	12	900	10163	3.11
304	21	900	10831	3.13
303	13	900	11541	3.33
305	5	900	14338	4.14
407	12	100	1610	4.18
402	20	550	9778	4.62
404	5	180	3765	5.43
406	15	450	10490	6.05
401	15	550	12846	6.07
405	12	600	14321	6.2
403	10	550	14764	6.97

E. ASTM Request to the Coordinating Research Council

CRC Letter Answering Research Request from ASTM

Max Kurowski, Chairman
ASTM D.02.J Sub-Committee on Aviation Fuels

In your March 14, 1989 letter to A. E. Zengel, ASTM Sub-Committee J on Aviation Fuels requested CRC to undertake research to define the electrostatic risks of handling commingled jet fuels containing static dissipater additive (SDA) and having a conductivity less than 50 pS/m. The work has been completed and a report of the findings is being prepared. The answer to the three specific questions posed in your 1989 letter are:

- *Do fuels containing SDA with a conductivity less than 50 pS/m present an electrostatic risk in U. S. handling systems?*

  Commingled fuels that combine fuels with static dissipater additive (SDA) with non-additized fuel do not exhibit unusual static charging behavior. These can be handled as safely as non-additized fuels.

- *If fuels containing SDA are clay filtered to a conductivity of less than 10 pS/m can they be considered additive-free?*

  Fuels that contain SDA and are clay filtered cannot be considered additive-free because the clay changes the relative proportion of components of the SDA remaining in the fuel. This can cause unexpected static effects in handling. For this reason, fuels containing SDA should not be clay filtered to low conductivity levels.

- *Do likely changes in aircraft fueling systems lead to any changes in the assessment that SDA is not needed to protect facilities during aircraft fueling?*

  If changes in future aircraft systems approach or exceed the low residence times in the CRC program, SDA to a minimum of 50 pS/m may be needed to protect the aircraft and facilities. SDA would not be needed if adequate residence times are maintained.

CRC is preparing recommendations to incorporate these replies to your specific questions, to suggest the need for a better test for assessing charging tendencies of additives and equipment, and to define the appropriate design and operating parameters of aircraft fueling systems.

END

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DATE: 6-94

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