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EVALUATION OF THE HAZARDS OF STATIC ELECTRICITY IN POL SYSTEMS

EXXON RESEARCH AND ENGINEERING COMPANY
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Tests were conducted at air bases and in a full-scale rig to evaluate the hazards of static electricity in POL systems. Field testing at two air bases revealed a low level of charge in JP-4 fuel delivered to aircraft through DOD filter-separators. The low levels result from the high conductivity of JP-4 due to the presence of approved DOD corrosion inhibitor and the design of filter-separators which provide considerable residence time

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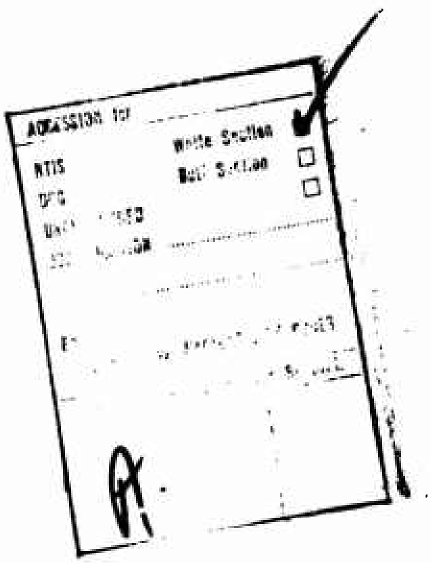
for charge relaxation. Single stage filter separator units were shown to generate less charge than older two-stage units. Teflon® screens charged at about half the level of paper separators. Aluminum hydrant systems were found to have a lower charging tendency than carbon steel systems.

Tests in a full-scale rig showed that the surface voltage generated in tank truck filling is determined by the inlet charge regardless of the use of a Static Charge Reducer. Spark discharges were observed at very low surface voltage levels if charge collectors were present. Tests with JP-4 in FRP pipe showed that charge relaxation rates are the same as in steel pipe, a result contrary to tests with non-additive fuel. Tests in epoxy coated drums indicated that surface voltage relaxes at a rate equal to or greater than bare metal.



PREFACE

This report documents work performed during the period from June 1974 to December 1975 by Exxon Research and Engineering Company, P. O. Box 51, Linden, New Jersey 07036, under contract F29601-74-C-0126 with the Air Force Weapons Laboratory (AFWL), Kirtland Air Force Base, New Mexico. In March 1975 the responsibility for the work unit was transferred to the Air Force Civil Engineering Center (AFCEC), Tyndall Air Force Base, Florida. Lt William J. Bierck, Jr., was the AFWL project officer and Captain Larry W. Strother was the AFCEC project officer for the program.

This report has been reviewed by the Information Officer (IO) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

1. BACKGROUND AND PRIOR WORK

Static electricity has been recognized as a serious hazard in military POL systems, particularly when pumping JP-4 fuel, a volatile hydrocarbon which produces flammable mixtures with air in the temperature range from -30°C to +20°C. Electric charges separate on filters and pipe-walls as the fuel moves and can then accumulate in an aircraft tank or truck. If a sufficiently high potential develops, the accumulated charge can discharge to a grounded object of different electrical potential with sufficient spark energy to ignite fuel vapors. This ignition source has been identified with accidents to tank trucks, storage tanks, filter-separators and actual aircraft.

Charge accumulation is particularly apt to occur in military fuels because they are inherently low in conductivity and yet contain ionic species as additives or contaminants that enhance static charge separation. The filter-separators which are used in POL systems to safeguard against the introduction of water and particulate are potent charge generators due to their large surface areas. Prior to the present study, the extent to which JP-4 fuels pumped through DOD type filter-separators in the field deliver charges into aircraft was unknown but was expected to vary with both fuels and filters. To answer this question for the Federal Aviation Administration(Reference 1), a survey of commercial fuels pumped through filter-separators had been conducted at six airports by the Coordinating Research Council (CRC). A further survey of fuels by the CRC(Reference 2) had included JP-4 samples from two Air Force bases; these tests showed that JP-4 fuels covered a wide range in conductivity and charging tendency and in these respects were similar to commercial fuels. The question about DOD filter-separators remained to be answered.

A device to relax the charge on fuel being pumped through a filter-separator [called the Static Charge Reducer (SCR)] had been installed for test purposes at Kelly Air Force Base. Evaluation of this device by numerous investigators(Reference 3) had disclosed some serious deficiencies with respect to efficiency, tendency to deactivate and turn-on time, i.e., elapsed interval to initiate charge relaxation. There were also indications that an apparently functioning SCR could still deliver high charge in fuel(Reference 4). The last finding had been verified with commercial Jet A rather than JP-4 fuel.

References:

1. "Electrostatic Charging Survey of Airport Fueling Systems" Coordinating Research Council, Report No. 473, December 1974
2. "A Survey of Electrical Conductivity and Charging Tendency Characteristics of Aircraft Turbine Fuels 1973/74" Coordinating Research Council, Report No. 478, April 1975
3. Martel, C.R. "An Evaluation of the Static Charge Reducer for Reducing Electrostatic Hazards in the Handling of Hydrocarbon Fuels" AFAPL-TR-70-22, July 1970
4. Bachman, K. C., and Munday, J. C., "Evaluation of the Hazards of Static Electricity in Non-Metallic POL Systems" - AFWL-TR-72-90

Elimination of final filter-separators in order to reduce the static hazard when fueling aircraft is one of the benefits of the use of fiberglass reinforced pipe (FRP), stainless steel or aluminum instead of uncoated carbon steel for underground hydrant systems. There was concern about the effects of non-conductive FRP pipe on static charge. A previous study (Reference 4) had revealed that FRP pipe would require a somewhat greater volume to relax charge than the steel pipe it would replace. This finding needed confirmation with JP-4 fuel containing the required additives.

The concern about FRP pipe was related to the electrical properties of the plastic binder which is generally a dielectric material like wire insulation. Similar materials are used to internally coat tanks and marking devices. There is some question as to the effect of such coatings on the rate at which static charges relax. In turn, this relaxation rate would influence surface voltages and the degree of hazard in terms of static discharge from bulk fluid to ground.

2. APPROACH TO RESEARCH ON ELECTROSTATIC HAZARDS

The questions concerning electrostatic hazards in military POL systems appear to fall into two categories: (1) those that reflect the actual static charging tendencies of JP-4 fuels and DOD filter-separators in field use and (2) those best investigated by experimental work in a properly designed facility. Accordingly, a multi-task investigation was made. This report discusses the results of each of these tasks.

The individual tasks and the specific requirements each is intended to answer are as follows:

a. Field Testing of JP-4 Fuels and DOD Filter-Separators

The questions raised were these:

(1) The relationship between JP-4 conductivity and its charging characteristics.

(2) The charging parameters of DOD filter-separators over a time period to assess aging effects.

(3) The static charge generated in Air Force POL systems with JP-4 and standard DOD filter-separators using the latest DOD elements.

It was logical to develop the answers to these questions by field testing at certain Air Force bases; the questions seemed an appropriate follow-on to the program conducted by the CRC at six commercial airports (Reference 1). The Boeing Test Rig used by the CRC was available and proposed for use for this task.

JP-4 fuels were shown by another CRC fuel survey program (Reference 2) to exhibit a wide range of both conductivity and laboratory charging tendency. The reasons for this are probably the different corrosion inhibitors that are required by Military Specification MIL-T-5624J (different materials qualified to MIL-I-25017 affect conductivity differently).

Their charging tendency is related to their ionic properties. The charge output from filters in the field is related to the particular corrosion inhibitors in fuel which have not been depleted as fuels are pumped through pipelines and storage tanks.

DOD type filter-separators, like their commercial counterparts, would be expected to change in charging characteristics as they age. The contaminants removed by filter elements generally contribute to a filter's charge output although the pattern is unknown. No aging effect was found to be statistically significant in the CRC airport survey(Reference 1). On the other hand, a batch of high charging fuel can promote charging by filter elements regardless of their age.

Filter elements qualified to MIL-F-8901C are different in design than commercial elements. In the case of the CRC programs involving commercial two-stage filter-separators, the second stage separator was found to be the important charging factor and significant differences were found between paper separators and coated screens. DOD filter-separators utilize combination filters which suggests that the coalescer element, as well as the separator element, would be factors in charging tendency.

Another question concerned the relationship between field strength exhibited by charged fuel in a storage vessel and input charge. This measurement had been made by a limited number of runs in the CRC airport survey(Reference 1). It was shown that surface voltage was related to charge entering the tank of the fueler but that the geometry of each tank affected the level of field strength measurement.

It was recognized that all military fueler vehicles of the R-5 and R-9 type are identical in tank geometry. Hence, it seemed possible to make field strength measurements in the field to answer this question. A field meter installed in the fueler tank to record the field produced by charged fuel filling the tank should permit surface voltage to be measured.

b. Surface Voltage Tests in the Exxon Facility

The question regarding the relationship between surface voltage and charge on input fuel that had been reduced through a static charge reducer could best be investigated in the Exxon full-scale facility where close control is possible on all charging parameters. Prior work under F29601-71-C-0071 had shown that fuel delivered into FRP pipe through the SCR with an apparent charge density close to zero could still produce high voltages on the wall of the pipe.

The facility at Exxon Research is designed to permit fuel to be charged through either a filter-separator or a filter-monitor when pumped through an SCR into a tank truck in which a field meter, radio detector and depth gage are installed. A surface voltage comparison between fuel charged and SCR-relaxed versus fuel which bypasses this filter-SCR array is possible to settle the question.

c. Electrical Effects of FRP Pipe With JP-4 Fuel

The question with regard to the relaxation time needed in systems made with FRP pipe had derived from the earlier work under F29601-71-C-0071. That work was done with Jet A fuel and showed that fuel of positive polarity required 30 per cent more time to relax to the same level in FRP pipe versus steel pipe. Fuel of negative polarity behaved about the same in both systems. The question of whether JP-4 fuel would behave the same way as Jet A fuel could only be settled by experimental work in the original facility.

d. Effect of Tank Coatings on Charge Relaxation

These questions concerned the effect of 8-mil epoxy coatings and a rod or cable on the behavior of charged fuel in a storage vessel. Because the technique for answering this question required close control over fuel charge level and polarity and measurements of both streaming current and field strength, it seemed most appropriate to design the experiments for the Exxon facility.

e. Effect of Deposits on SCR Performance

These questions were all related to the tendency of fuels in service to form deposits on the liner of the SCR and thus reduce its effectiveness. This result had been demonstrated in earlier work in the Exxon facility but never with JP-4 fuel. Inasmuch as SCR's were in a test installation on JP-4 at Kelly Air Force Base, it seemed possible to measure their efficiency and also recover deposits for analysis.

SECTION II

SIGNIFICANCE OF TEST RESULTS

This section assesses details of the individual test programs that were carried out in fulfillment of contractual requirements. The results of each program are summarized and interpreted in terms of overall significance with respect to the electrostatic hazard of POL systems when handling JP-4 fuel into aircraft.

1. FIELD TESTS OF FUELS AND GROUND EQUIPMENT

In order to survey the amount of static charge being generated when fueling aircraft with JP-4, the Air Force selected two air bases for field testing. These bases represented different POL systems separated by geography and climate and supplied by JP-4 from completely different sources. In some ways this survey was a logical extension of the CRC program conducted on six major airports to assess static charge in commercial Jet A fuel(Reference 1). Accordingly, the test rig used by the CRC to simulate the aircraft manifold to measure charge densities into aircraft was borrowed for this survey. A total of 63 test runs were made during four different periods with results described in detail in Section III.

The most striking result of all of these tests was the relatively low level of static charge measured from a variety of hose carts and fuelers. The low level of charge is explained by the relatively high level of JP-4 conductivity observed and by the relatively large internal volumes of DOD filter-speartors that permit charge to relax. A comparison with the CRC program using commercial Jet A in six airports (Table I) illustrates the differences in fuels and filter-separator design. It should be noted that much higher charge levels were observed in commercial systems.

The importance of residence time and fuel conductivity in charge relaxation is apparent from the well-known charge decay equation

$$\ln \frac{Q_t}{Q_o} = - \frac{tK}{\varepsilon\varepsilon_o}$$

where
Q_t = charge at time t
Q_o = initial charge
t = residence time in the system, sec
K = conductivity of fuel siemens/m
$\varepsilon\varepsilon_o$ = 17.7×10^{-12} ampere sec/volt meter.

An increase in either residence time or fuel conductivity has an exponential effect on the degree of charge reduction between the point of charge generation--the filter elements--and the aircraft where charge density was actually measured. To illustrate the importance of these factors, consider the following results of this equation when a fuel of 2.0 pS/m conductivity is used as a base case.

TABLE I. COMPARISON OF MILITARY VERSUS COMMERCIAL STATIC CHARGING TESTS DURING AIRCRAFT FUELING

	Military JP-4	Commercial Jet A(1)
No. of Airports	2	6
No. of Test Runs	63	184
No. of Mobile Vehicles Tested	37	105
Range of Charge Densities Observed at 50 Per Cent Rated Flow $\mu C/m^3$	0-54	0-350
No. of Fuel Families Tested	13	31
Range of Fuel Conductivities at 74°F, pS/m	1.5-23	0.1-15.2
Per Cent of Samples Below 5 pS/m	35	80
<u>Filter-Separators Tested</u>		
Separator Type	Mostly Coated Screen	Mostly Paper
Design Type	Combination Elements(2)	Two-Stage
Residence Time to Aircraft at 50 Per Cent Rated Flow (Sec)	22-27	$\sim$8

(1) "Electrostatic Charging Survey of Airport Fueling Systems" Coordinating Research Council, Report No. 473, December 1974

(2) Separator Element Shrouds The Coalescer Element

- If residence time doubles and fuel conductivity is constant, charge density at the aircraft would drop by about 60 per cent compared with Jet A fuel. This is the effect of the military type filter-separator design alone. (The same result would occur if only fuel conductivity doubled.)

- If both residence time and fuel conductivity double, charge density at the aircraft would drop by about 93 per cent compared with Jet A fuel. This is the combined effect of military type filter-separator and JP-4 fuels of higher average conductivity.

- However, if residence time doubles and fuel conductivity is halved, charge density at the aircraft would match the commercial Jet A levels. This is the result of lower than average JP-4 conductivity.

Thus, the result actually observed in the field test is consistent with theoretical considerations. The next question to consider is whether either the military filter-separator design factor or the JP-4 conductivity factor can be relied upon to insure that low charge levels will always be produced.

In the case of the filter-separator design itself it is interesting to observe the shrouded single stage MH-2B hose cart unit provides considerably more relaxation volume (about 9 sec residence time at rated flow) than the older two-stage MH-2A unit (about 2 sec residence time at rated flow). Yet the 1973 type of MH-2B unit was considerably smaller than the 1971 type and approached the MH-2A in relaxation volume. The 1973 design probably resulted from a policy to build a more compact filter-separator unit lighter in weight, smaller in size, and easier to handle. This design step was in the wrong direction for assuring low static charge levels. It would be desirable to make internal volume a design requirement for military filter-separator units.

It should be noted that increasing the length of fueling hose to provide residence time is an alternative but not as efficient as providing internal volume. For example, 50 feet of 3-inch hose holds 18 gallons. Over 100 feet of additional hose would have to be provided to match a 1973 MH-2B unit with a 1971 model.

With respect to JP-4 conductivity, the field test program illustrated that fuels as supplied can vary considerably because one of four test periods involved JP-4 similar to Jet A in conductivity. The 1973 CRC program on samples from two air bases showed that 35 per cent of 54 samples were low in conductivity. The differences in conductivity are due primarily to the particular corrosion inhibitor used and the extent to which it has been depleted. Both laboratory and full-scale rig data reveal that it is possible to use a fully qualified corrosion inhibitor at specified concentration and not exceed 3 pS/m in conductivity. If such a JP-4 were depleted of additives in handling systems, its conductivity would drop and the extra benefit of residence time in DOD filter-separator unites would be lost.

These considerations suggest that a qualification requirement for corrosion inhibitors exclude additives that decrease electrical conductivity. Such a specification on additives would, of course, not insure that JP-4 as delivered to aircraft would be high in conductivity. However, the limited survey data available on JP-4 suggest that extremely low conductivities with additive fuels are highly unlikely. A wider survey of JP-4's to confirm this point would be desirable.

The unknown factor in this consideration of JP-4 charge level into aircraft is how much charge is actually generated in the DOD type filter elements. The CRC study was not able to distinguish among filter-coalescer elements but could detect significant differences among separators. Since the latter element is the last stage before fuel exits from the filter-separator case, it is probably the more significant. The CRC found, for example, that Teflon® -coated screens generate only 13 to 52 per cent as much charge as paper separators. The field program conducted with JP-4 generally confirmed this CRC conclusion.

Another signi cant observation of the contract test program was the high initial charge detected when new filter elements were introduced into a controlled system. A considerable amount of time (or throughput) was needed for the new element to stabilize at a lower equilibrium charging level. This finding suggests the desirability of operating a new set of elements at some fraction of rated flow for a break-in period. More data are needed to confirm this observation and to develop a break-in parameter.

The field test program revealed that the charging tendency of filters increased with age (or throughput) from the equilibrium value, probably because of the accumulation of ionic species, e.g., corrosion inhibitors. (This trend could not be statistically confirmed in the CRC program on commercial filters.) Since the extent of this increase is subject to considerable uncertainty, it does not appear desirable at this point to suggest any different filter change criteria than the ones presently used--pressure drop or time. More data would be needed to develop a throughput criteria for change as related to charge generation.

In order to assess in realistic terms the significance of flow rate on delivered charge, the data from both the hose cart tests in the field and at the Exxon Research test site have been compared in terms of charge flow, i.e., charge density times flow rate equals current actually delivered. The data from each set of tests are consistent and show that doubling the flow rate increases the current delivered to aircraft about four-fold. The maximum charge flow levels observed in hose cart tests--about 4.4 μA--are consistent with data obtained by the CRC in airport studies(Reference 1) but well below the maximum observed in commercial fueling. It would appear that the limitations on fueling flow rate actually observed in the field operates as an automatic safeguard against delivery of high levels of electrical currents into aircraft tanks.

In the final analysis, the question to answer is the probability that an excessively high charge might be delivered to an aircraft due to a combination of a high charging fuel, an active filter and a high flow rate. The CRC attempted to answer this question by plotting data on 31 fuels in 184 runs in terms of logarithmic probability distribution. It was concluded that a high charging level defined with respect to analysis of actual aircraft accidents might occur one time in 1000 if paper separators were in use(Reference 5). At the same time, the CRC study concluded that with coated screens the probability of a similar high charging level would be orders of magnitude lower. Figure 1 is reproduced from this CRC study and on it are plotted the data obtained in this program in 70 runs with 13 JP-4 fuels tested in systems with coated screens. The military charge density data is compared at 50 per cent rated flow, which is typical of Air Force fueling practice, with commercial fuel at 80 per cent rated flow. If the DOD filter-separator units were operated at 80 per cent rated flow, it is estimated that the charge density levels would produce a distribution matching the curve shown for commercial fuels. It can be concluded, therefore, that the probability of a high charging level in military POL systems is at worst no greater than the probability in a similar commercial system.

Any comparison between military and commercial fuels, however reassuring in terms of lower static charge levels in JP-4, must not overlook the vitally important difference of JP-4 versus Jet A volatility. The vapors of JP-4 produce a flammable mixture with air at temperatures below 20°C (60°F) which means that in most fuelings the vapor space in a tank is easily ignited should a spark discharge occur. The level of static charge in fuel is only a crude yardstick of the ignition hazard because many other factors within a tank can influence the development of high localized potential differences which can lead to electrical discharge.

Because handling JP-4 is so fundamentally hazardous, the research studies conducted in connection with this contract, except for field measurements and rig tests in closed systems, utilized Jet A which has a lean flammability limit above 35°C (95°F).

2. SURFACE VOLTAGE TESTS WITH THE SCR

The work performed under the earlier contract and summarized in(Reference 4) had shown that the SCR had several disadvantages, one of which was an indication that high surface voltages might be associated with a presumably functioning SCR. Surface voltages in tanks filled with charged liquids are more important than surface voltages on plastic pipe because the former can lead to spark discharge while the latter can be easily eliminated by a conductive coating.

The tests reported in Section III demonstrate that the surface voltage actually observed when filling a tank truck with charged fuel depends not on whether the SCR was in the system or even functioning but on the absolute level of charge entering the tank. There were no anomalies suggesting a high surface voltage when the fuel out of the SCR was registering a very low value.

Reference:

5. Dukek, W. G., Strauss, K. H., and Leonard, J. T. "Charge Generation by U.S. Commercial Aircraft Fuels and Filter-Separators" - Summary Report of Coordinating Research Council Studies on Static - Lightning & Static Conference, Culham Lab., England, April 1975

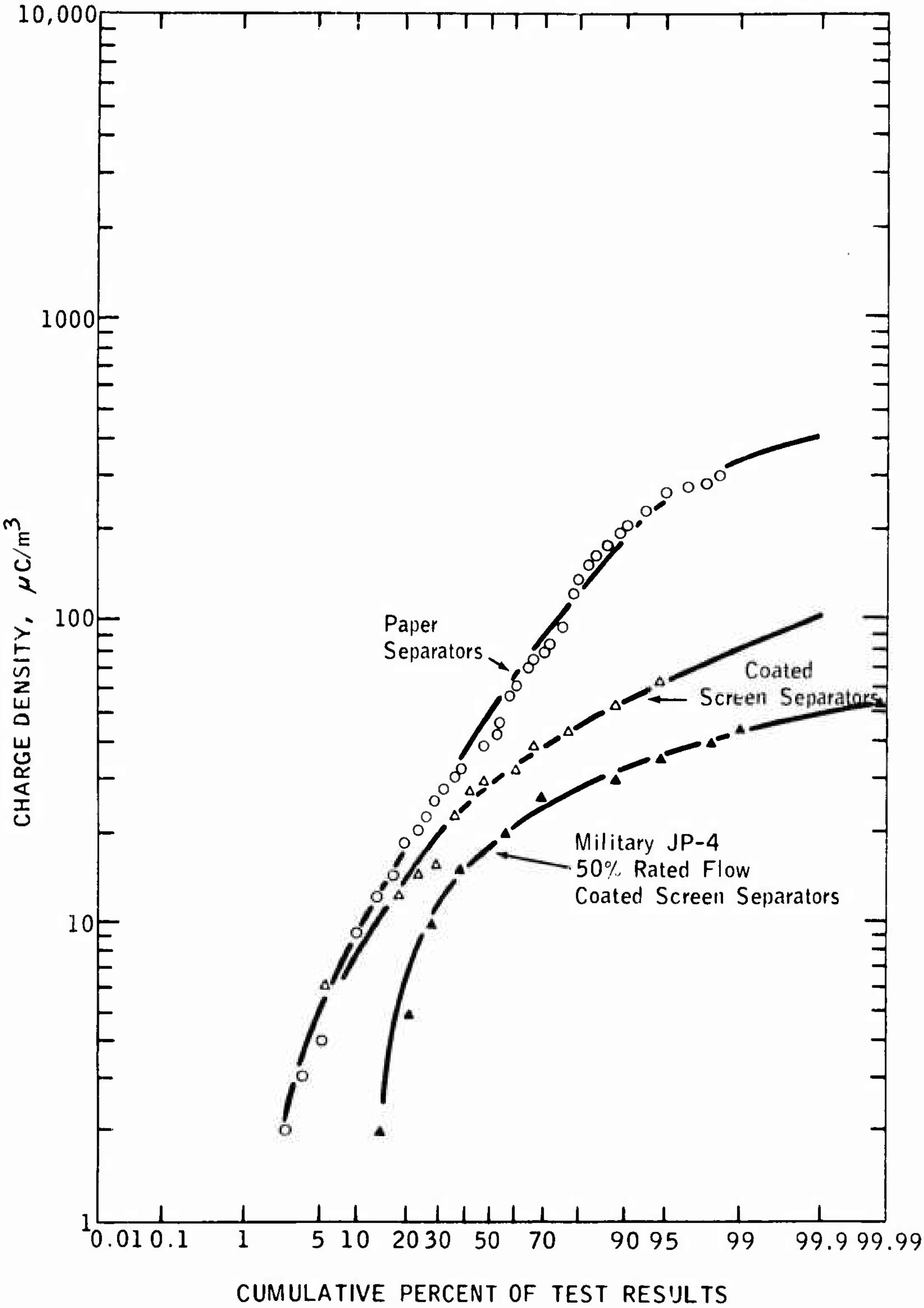

Figure 1 - Distribution of Charge Density in Airport and Airbase Tests-Paper Separators versus Coated Screens

Note: Reproduced from Figure 5 of reference 5. Top curves represent commercial Jet A fuel at 80% rated flow

The most reasonable way to explain this result in contrast to the results in plastic pipe is to recognize that the tank is an integrating device which collects the entire quantity of charged fuel; this body of fluid produces a field which is sensed by a field meter and translated into a potential on the fluid surface. In contrast, the plastic pipe is filled with flowing fuel which contains clouds or packets of charge - half negative and half positive - which are unmixed because of the high velocities. The total net charge may average close to zero but the existence of moving clouds of charge means that a field is generated on a dielectric surface such as plastic pipe. Hence, surface voltage measurements on a section of plastic pipe are, in effect, sensing only a portion of the charge in the flowing section. In a receiving tank where mixing occurs, the surface voltage is determined by the net charge after mixing.

The concept of clouds or packets of moving charge is supported by the response signals from the charge density meter (CDM). When charged fuel moving at 7 to 20 feet per second leaves the SCR, the CDM signal shows wide fluctuations oscillating about 30 cycles per minute around an average value suggesting packets of charge 7 to 20 feet long as flow passes the sensing head. On the other hand, the signal from charged fuel bypassing the SCR shows only smooth fluctuations. (Residence time in the SCR is about 1/4 second which may explain the mixing problem suggested by these signal oscillations.)

This observation might suggest that the SCR is a reliable technique for reducing surface voltage when filling a tank. However, the answer must be qualified by the other observations described in Section III. The SCR required turn-on time of 0.5 to 5 minutes before it began to function. Also, its efficiency in reducing charge depended on the polarity of the incoming charge. These factors had been quantified in the earlier evaluation program(Reference 4) and were confirmed in the current program. Finally, it has been recognized for some time that the SCR degrades with use due to the development of deposits on its plastic liner. The original drawbacks of the SCR still remain. This program has not added to the list of deficiencies but has determined that the unsatisfactory behavior of the SCR into plastic pipe is not carried over to the filling of a tank.

Spark discharges which were observed on the radio during these tank truck filling tests represented the most extreme condition, i.e., the presence of an unbonded charge collector. Discharges were observed at extremely low surface voltages (1 to 5 KV) when a charge collector was present, but a surface voltage of about 28 KV was required before discharges were detected in a tank free of collectors. These results are consistent with those reported recently by Bachman in tank truck filling studies (Reference 6).

In the field testing program described in Section III several attempts were made to measure field strength in an R-9 fueler vehicle operated as a receiver of charged fuel. In each case the input charge density was extremely low and no signal could be observed on the field meter. It is not possible to use the surface voltage versus input charge

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Reference:

6. Bachman, K.C. "Variables Which Influence Spark Production Due to Static Electricity in Tank Truck Loading" - Lightning & Static Conference, Culham Lab., England, April 1975

density relationship shown in Figure 27 to predict the behavior of charged fuel in an R-9 fueler because the internal geometry of the tank truck studied in this program is substantially different. Directionally, surface voltage in an R-9 fueler would be expected to increase with input charge but the slope of a line relating these measurements would be different for this receiver of different geometry than a tank truck.

3. RESIDENCE TIME FOR CHARGE RELAXATION OF FUEL

In a loading rack or Fillstand where fuel is pumped into a refueling unit, charges are generated in the fixed filter-separator. There has been a general API-recommended operating practice to provide a minimum of 30 seconds residence time for charge relaxation in the piping downstream of a filter-separator before fuel enters the fueler tank. The SCR was originally developed to circumvent the need for 30 seconds residence time at maximum rated flow.

The accident record of static ignitions in tank truck filling is much more serious than the record of incidents in aircraft fueling and is at least partly explained by the greater tank volumes involved in loading fuelers. An aircraft baffled compartment is at a maximum 300 gallons and usually receives at most only one-third of the charged fuel passing through the filter-separator. A refueling unit compartment can receive the entire output of a filter-separator and hence nine times more current energy than an aircraft compartment. The importance of charge relaxation volume is thus underscored.

To illustrate the need for and importance of adequate residence time for charge relaxation, data for three runs reported in Section III have been plotted in Figure 2 in terms of charge remaining after the filter versus residence time. Run D-20 from Table V was selected as the reference base because it involved fuel of the lowest conductivity. Note that Run D-54 - one of the extreme results - produced a charge at the filter 12.5 times greater than reference Run 20 but the effective conductivity was higher and the same charge level was reached in 25 seconds. Run K-5 involved fuel of the highest conductivity, produced a charge at the filter 3.8 times higher than reference and reached the same charge level in 10 seconds.

What Figure 2 illustrates is that there is a need and justification for at least 30 seconds residence time as long as the possibility exists that JP-4 fuel will exhibit a conductivity as low as 1 pS/m. At a higher conductivity level - say 5 pS/m - the residence time requirement would be less - about 10 seconds.

4. CHARGE RELAXATION IN FRP VERSUS STEEL PIPE WITH JP-4 FUEL

In the earlier study(Reference 4) of static charge effects in FRP pipe, Jet A fuel of different conductivity levels was pumped through carefully matched FRP and steel pipe sections under closely controlled conditions so that a precise comparison could be made. Two important results were obtained: (1) the difference in charge generating characteristics in FRP versus steel pipe was insignificant, and (2) positively charged fuel relaxed 30 per cent slower in FRP pipe than in steel pipe, while negatively charged fuel relaxed 8 per cent faster.

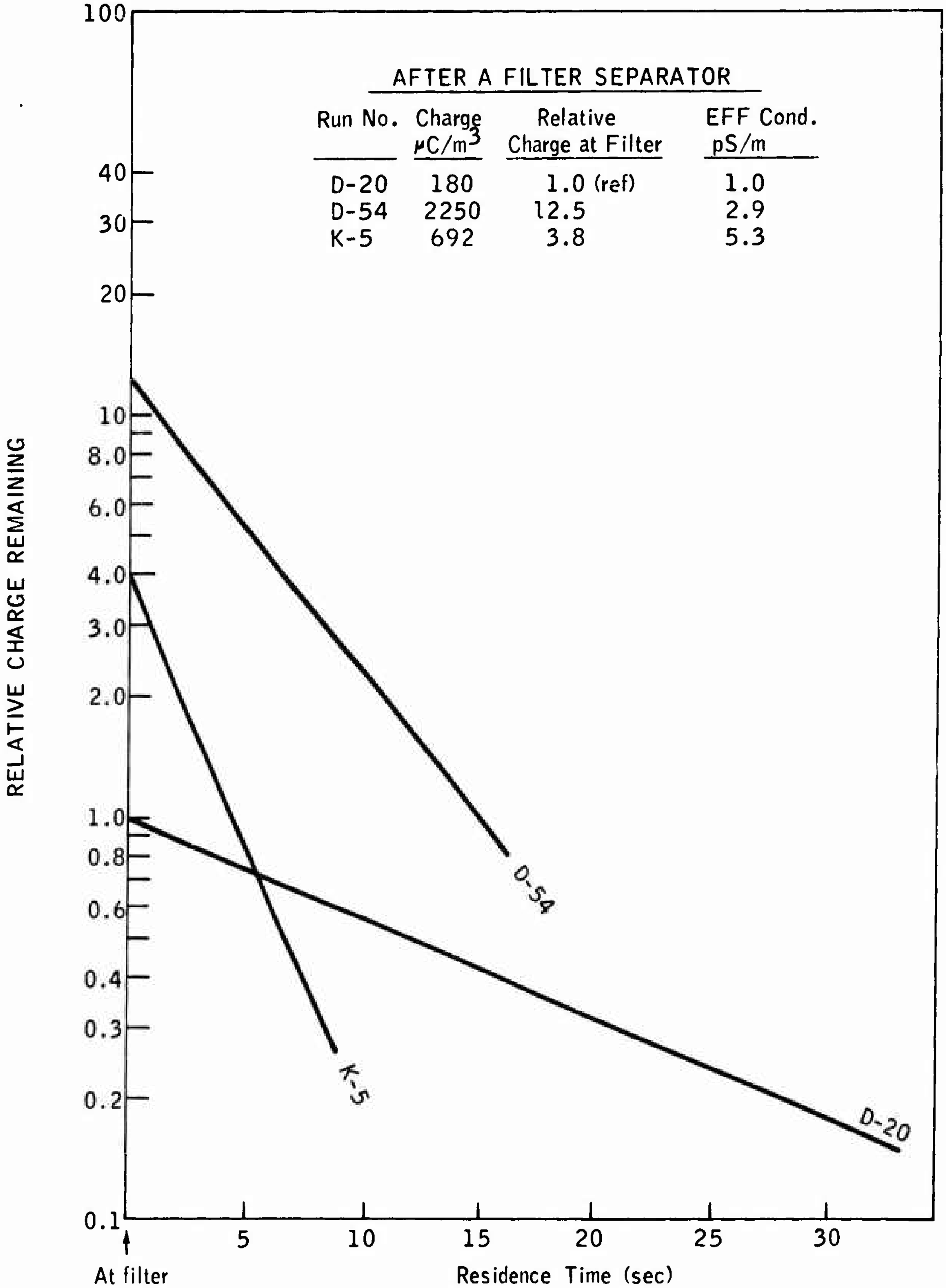


Figure 2 - Relaxation of Charged JP-4 After a Filter-Separator

The four different conductivity levels tested with production Jet A fuel (from 0.2 to 5.5 pS/m) were achieved by adding oxidized asphalt (a few ppm) as a pro-static agent. In the program described in Section III the FRP versus steel pipe experiments were reported with a specification JP-4 fuel that measured 1.5 pS/m in conductivity and contained about 1200 ppm of anti-icing additive and 17 ppm (4.5 ptb) of Hitec E-5[illegible]4 corrosion inhibitor. The results confirmed that differences in charge generating characteristics in FRP versus steel pipe were insignificant. However, the test data also showed that contrary to the first experiments there was no difference in charge relaxation rate in FRP or steel pipe.

The differences between the Jet A and the JP-4 tests that might explain the change in charge relaxation results are the following:

1. Recent tests were run at 77°F (25°C), about 37°F (21°C) higher than earlier work.

2. Latest data were analyzed by calculating the average slope of the charge-in versus charge-out line (relaxation time) from all data points, while earlier work averaged a series of individual tests to calculate average relaxation time.

3. The JP-4 contained 17 ppm of a surface-active additive that normally forms a film on pipe walls to provide corrosion protection. The Jet A contained only a fraction of additive of a non-surface active type.

Of these differences the last is considered the most important. The reasons for suggesting additive effects on pipewall are these: When ions of a certain charge are contained in flowing fuel, an opposite charge is induced on the pipewall. As flowing charges are neutralized by recombination with pipewall ions, a counter-current flows on the inside of the pipe. The conduction of this current depends upon the conductivity of the solid. In the case of plastic pipe, the conduction rate is similar to fuel unless it is altered by contaminants or additives. An additive package of a surface-active corrosion inhibitor (a dicarboxylic acid) and a polar anti-icing additive (ethylene glycol monomethyl ether) would be likely to produce a conducting film on the inside of pipe making it substantially more conductive than fuel itself. In the case of steel pipe, conductivity is inherently so high that surface changes are irrelevant. Unfortunately, it was not possible to prove this speculation by direct experimental measures of surface conductivity because the technology of measurement is not available.

It is less likely that temperature differences or current techniques used to analyze the test data explain the new results as well as the presence of additives in JP-4. Fortunately, the use of certain corrosion inhibitors in JP-4 tends to increase the electrical conductivity which in itself will promote more rapid charge relaxation. The only concern develops from an additive-depleted fuel or system. It would, of course, be desirable to verify this proposed role of corrosion inhibitors but this could probably be done in a laboratory rig rather than requiring additional full-scale tests.

5. EFFECT OF TANK COATINGS ON CHARGE RELAXATION

The concern about the role of an epoxy coating (MIL-C-4556) on the rate of charge relaxation is logical because the resistivity of such a coating could be as high or higher than fuel. Moreover, the earlier work on FRP (Reference 4), which is fabricated from an epoxy resin, indicated that positively charged fuel relaxed 30 per cent slower in plastic (i.e., epoxy) pipe than in steel pipe.

Tests conducted under carefully controlled conditions into drums, both bare and lined, with MIL-C-4556 epoxy are described in Section III. A third drum lined with a fluorinated polymer (Halar®) similar to Teflon® in composition and 1000 times more resistive than epoxy was also included in this comparison.

Charge relaxation rates observed by field meter readings were found to be highly dependent on fuel conductivity. In fact, at conductivities above 30 pS/m, charge relaxed so fast that accurate comparisons were impossible. However, in the range of fuel conductivities below 10 pS/m, which represents a large percentage of fuels, the data showed that the epoxy-lined drum caused charge to relax 16 per cent faster than in a bare steel drum. This result was surprising but could have been due to slight variations in drum geometry. JP-4 additives were introduced but these did not affect charge relaxation rates abnormally. Their main effect was to raise fuel conductivity.

The behavior of the Halar® -lined drum was peculiar in that a permanent charge was left on the surface after charged fuel had been removed. The initial rate of charge relaxation seemed to be similar to that observed in the bare metal and epoxy drums but a much longer time was required for surface voltage on the fuel to relax completely.

When a grounded metal rod was introduced into the test drums, no difference could be detected in charge relaxation rates for fuels of different conductivity levels. It appears that the use of a rod or cable as a tank level marker, for example, has no significant effect on fuel charge.

SECTION III

DETAILED RESULTS OF TEST PROGRAMS

1. FIELD TESTS OF JP-4 AND DOD FILTER-SEPARATORS

a. Air Bases Surveyed

It has been established in a number of studies, most recently in a survey of commercial airports by the CRC(Reference 1), that filter-separators are a major factor in the generation of electrostatic charges during the fueling of aircraft and that significant differences in charging exist among differing filter designs. These studies have also pointed out that fuel is a major variable with some fuels resulting in high charges and other fuels in low charges with the same filter elements. The reasons for this fuel behavior are not definitely known, but it is possible that the fuel's history, including fueling system exposure prior to aircraft fueling, is a factor.

Two air bases - Dover Air Force Base, Delaware and Kelly Air Force Base, Texas - were pre-selected by the Air Force for this survey of POL equipment. They represent two bases widely separated by climate and geography and involve different types of handling practices and facilities. Some of the more salient features and data of their respective handling facilities are given in Table II.

Dover Air Force Base is unique in that it has three different hydrant systems - North Hydrant (steel pipe, in service approximately 15 years), MAC Hydrant (steel pipe, in service approximately 20 years) and C5A Hydrant (all aluminum pipe in service approximately 3 years). Testing at Dover Air Force Base was designed to include both hydrant system and refueler truck comparisons.

While both hose (hydrant) carts and refueler trucks are used to fuel aircraft, and both vehicles put the fuel through filter-separators ahead of the aircraft, different charging characteristics may be expected from each type vehicle because of their effect on fuel thermal history. Hose carts have no storage capacity and take fuel from buried pipelines under pressure, pass it through a meter and a filter-separator, and then into the aircraft. Fueling trucks, or refuelers, on the other hand, contain a 5000-gallon storage tank, are loaded at a remote location, and may stand full overnight or longer before fueling an aircraft through a meter and a filter-separator. Fuel temperature in underground lines tends to remain relatively constant while the temperature in aboveground tanks or trucks tends to vary with ambient temperature. Therefore, fuel loaded through trucks may have a different thermal history and charging effect than fuel loaded through hose carts at the same air bases.

Identical types of DOD filter-separators exist on similar fueling apparatus at both Kelly and Dover Air Force Bases, but notable differences exist in filter-separator design between fixed and mobile equipment. Most fixed filters, all refueler trucks, and those hose carts designated MH-2B contain filter-separators employing an element configuration of a coalescer element shrouded with the separator element as shown in

TABLE II. DESCRIPTION OF SURVEY AIR BASE JP-4 SYSTEMS

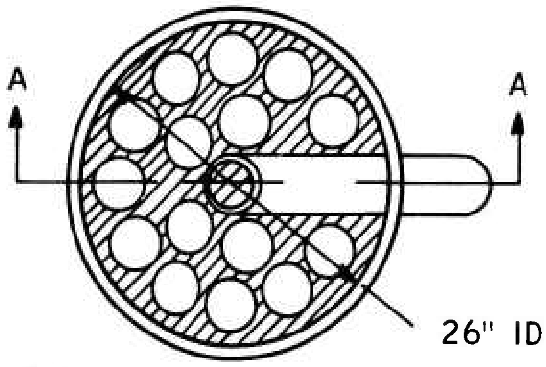
Air Base	Dover Air Force Base	Kelly Air Force Base
Supply System	Trucked from Port Mahon	Trucked from Refinery and Terminal
No. of Suppliers (comingled)	3	3
Quantity of Fuel Handled - M gal/month	4.4	1.5
Fueling by System (per cent)		
Refueler trucks	65	90
Hydrant	35	10
No. of Fueling Vehicles Refueler Trucks(1)	18	8
Hose (Hydrant) Carts		
MH-2A	10	2
MH-2B	8	1
Hydrant Systems	3	1
Fixed Filter-Separator - Fueling	21	6
JP-4 Fillstand Fixed Filter-Separator	2	2

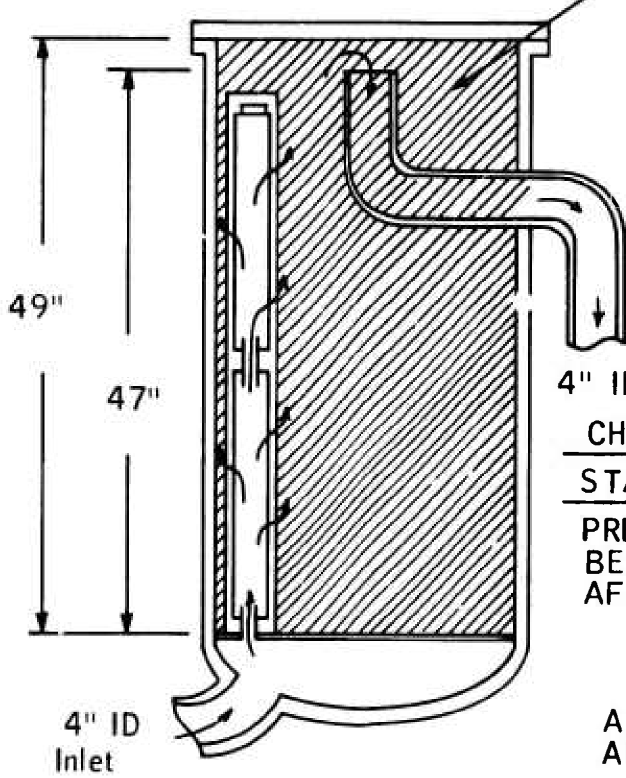
(1) Refuelers dedicated to JP-4 service only. Does not include vehicles used for defueling or those equipped with hand nozzles.

Figures 3 and 5. Some fixed filter-separators and all MH-2A carts have the more common industrial type of element configuration of two distinct and separately mounted stages of coalescer and separator elements as shown in Figure 4. Until recently, MH-2A carts had paper-type separator elements which have now been replaced with Teflon® -coated metal screen separators. Air base selection provided an opportunity to test both types of filter-separator design. One MH-2A cart at Dover Air Force Base still contained paper elements and was also included in the program.

b. Test Equipment and Instrumentation

The testing apparatus used for charge density and field strength measurements on POL equipment consisted of an instrumented fueling manifold, a receiving fueler truck to simulate a receiving aircraft tank, and a mobile





Element Data

	1st Stage	2nd Stage
Qty	30	15
Length	20"	44.5"
OD	3 3/4"	4.56"

FSN 4330-983-0998

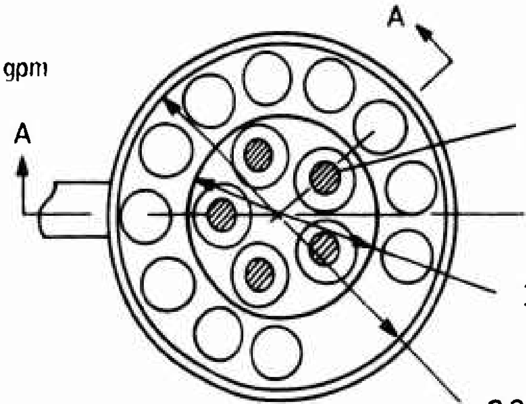
CHARGE RELAXATION VOLUMES

STAGE NO.	VOLUME (GAL)
PRE 1	35.5
BETWEEN 1 & 2	19.4
AFTER 2	64.1
TOTAL	119

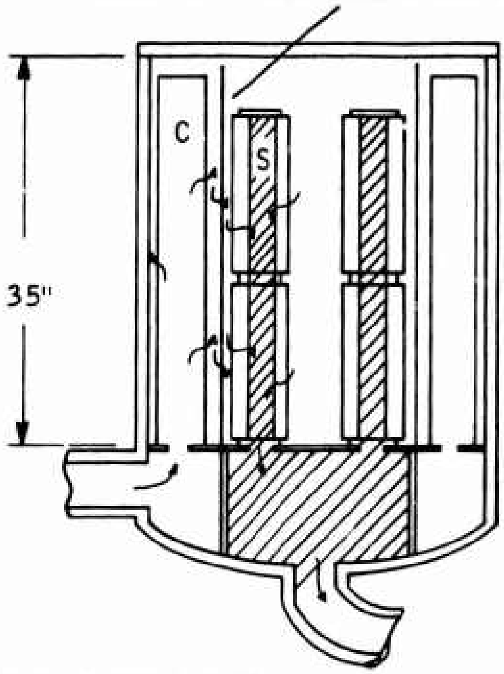
ALLOW 7 GAL FOR ELEMENT AND HARDWARE VOLUME

Figure 3 - Filter-Separator Design on R-5 and R-9 Refuelers
Kelly Air Force Base

Rated Flow: 600-gpm



NOTE: Cart #62W00171 inspected 2/7/75 @ DAFB Contained pleated paper type separator elements, all other MH2A carts converted to Teflon® elements.



Element Data

	1st Stage (Coalescer)	2nd Stage (Separator)
Qty	11	10
Length	33 13/32"	14 1/2"
O.D.	4 9/16"	6"
FSN	4930-073-4935	

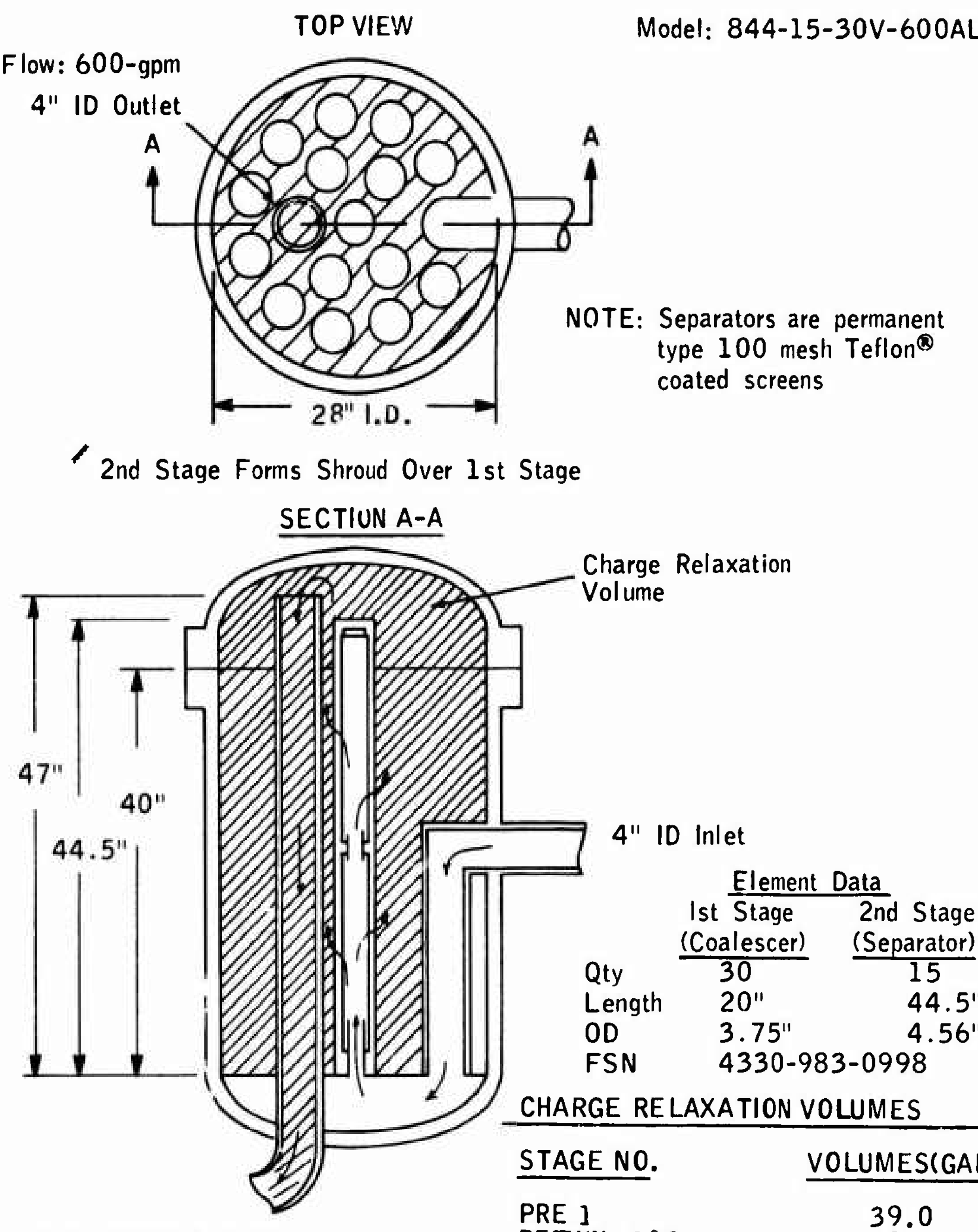
CHARGE RELAXATION VOLUMES

STAGE NO.	VOLUME(GAL.)
PRE 1	38.0
BETWEEN 1 & 2	91.0
AFTER 2	22.0
TOTAL	151.0

ALLOW 6.0 GAL. FOR ELEMENT AND HARDWARE VOLUME.

T.O. 37A2-2-4-21

Figure 4 - Filter-Separator Design on MH-2A Hose Cart Dover Air Force Base



Element Data

	1st Stage (Coalescer)	2nd Stage (Separator)
Qty	30	15
Length	20"	44.5"
OD	3.75"	4.56"
FSN	4330-983-0998	

CHARGE RELAXATION VOLUMES

STAGE NO.	VOLUMES(GAL.)
PRE 1	39.0
BETWN. 1&2	19.4
AFTER 2	84.8
	143.2

Figure 5 - Filter-Separator Design on MH-2B Hose Cart
Dover Air Force Base

van housing the electronic and data recording equipment. The arrangement is illustrated schematically in Figure 6.

The instrumented manifold, designed and constructed by the Boeing Company(Reference 1), contained a flow control valve, a charge density meter, pressure and temperature sensors, flow meter and a sampling tap. The manifold outlet was connected to hoses (one containing a second charge density meter) which discharged into a receiving fueler truck. Both inlet and outlet of the manifold were outfitted with standard aircraft-type refueling adaptors for direct connection to POL refueling equipment. The two charge density measurements, along with the residence time between meters, were to provide a method of calculating effective conductivity. Field strength measurements were made by inserting a field strength meter into an opened manhole of the receiving fuel tank compartment. The test manifold is shown in Figure 7. Figure 8 shows the general arrangement of testing refueling trucks and Figure 9 the arrangement of testing hose carts.

It was recognized that the tank of a refueler truck into which charged fuel was pumped and field strength was measured was different from an aircraft tank, but the relative ranking of fuels in terms of field strength was expected to be the same. In addition, all Air Force R-5 and R-9 refueler truck tanks are identical and therefore field strength measurements between air bases should be comparable.

Recorded measurements included fuel flow rate, fuel temperature, charge density and field strength (when measured). The outputs from the charge density meters were monitored on Model 600A Keithley Electrometers and readings manually recorded on the oscillograph recorder tracing as backup data. In addition, a totalized flow readout and manifold fuel pressure were also recorded manually on the tracing. A sampling tap on the manifold was used for free water analyses of the fuel and to obtain samples for later laboratory analyses of conductivity, specific gravity, water separation characteristics, and laboratory measurements of static charging.

c. Test Program and Procedure

The survey of electrostatic charging characteristics of Air Force POL fueling systems at Dover Air Force Base and Kelly Air Force Base was conducted according to the following schedule.

Testing fuel under summer conditions

Dover Air Force Base	7-11 October 1974
Kelly Air Force Base	21-25 October 1974

Testing fuel under winter conditions

Kelly Air Force Base	20-24 January 1975
Dover Air Force Base	3-7 February 1975

The first day the vehicle test equipment and laboratory apparatus were set up and calibrated and testing plans finalized on vehicle selection,

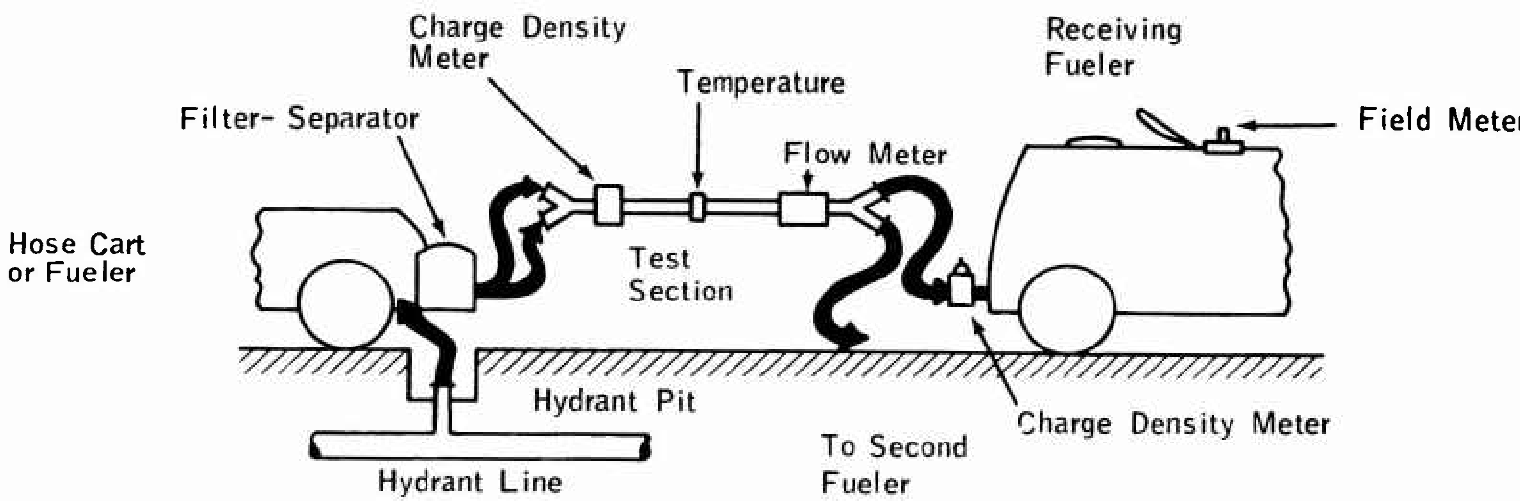


Figure 6 - Airport Charge Measuring System

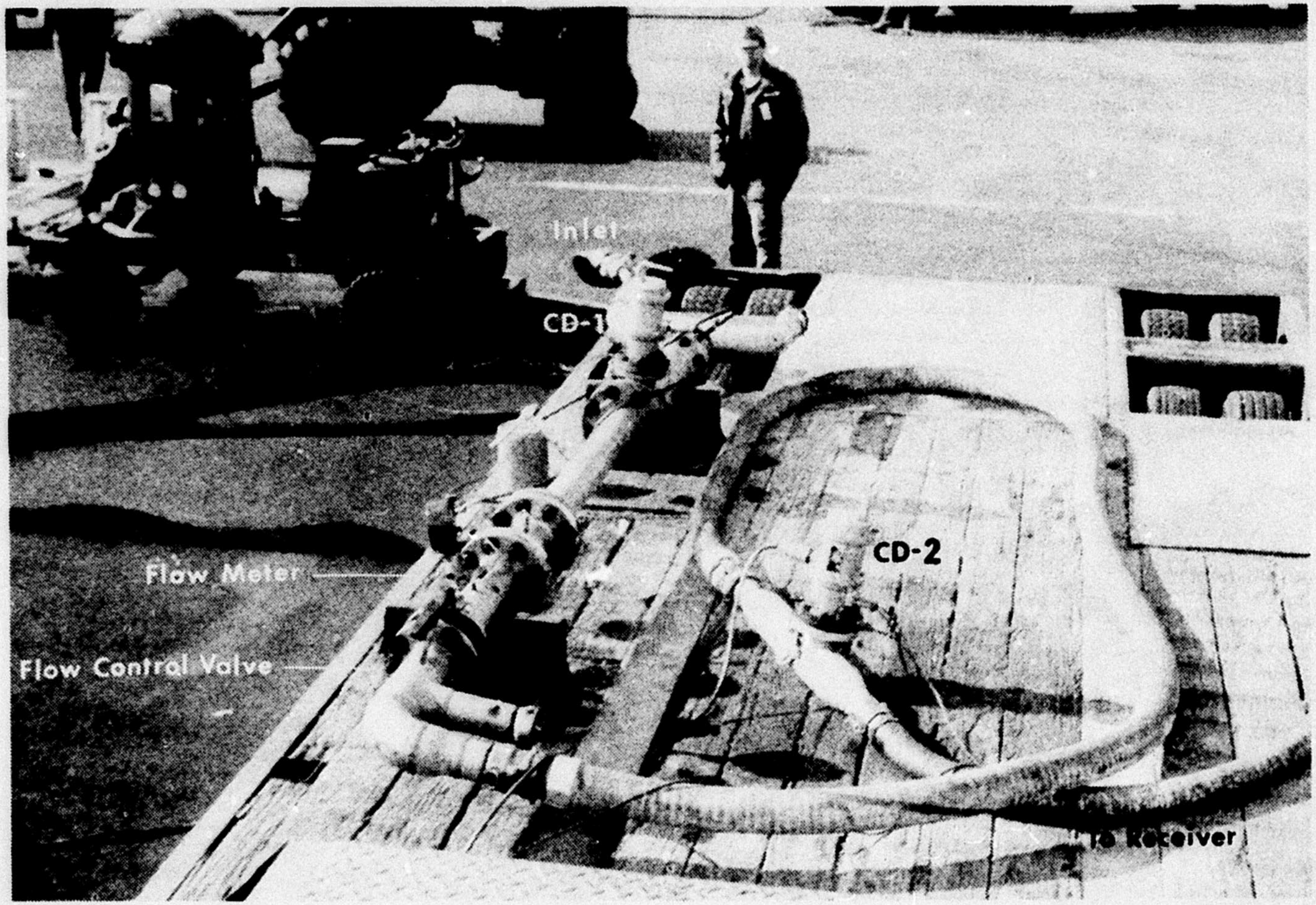


Figure 7 - Test Manifold

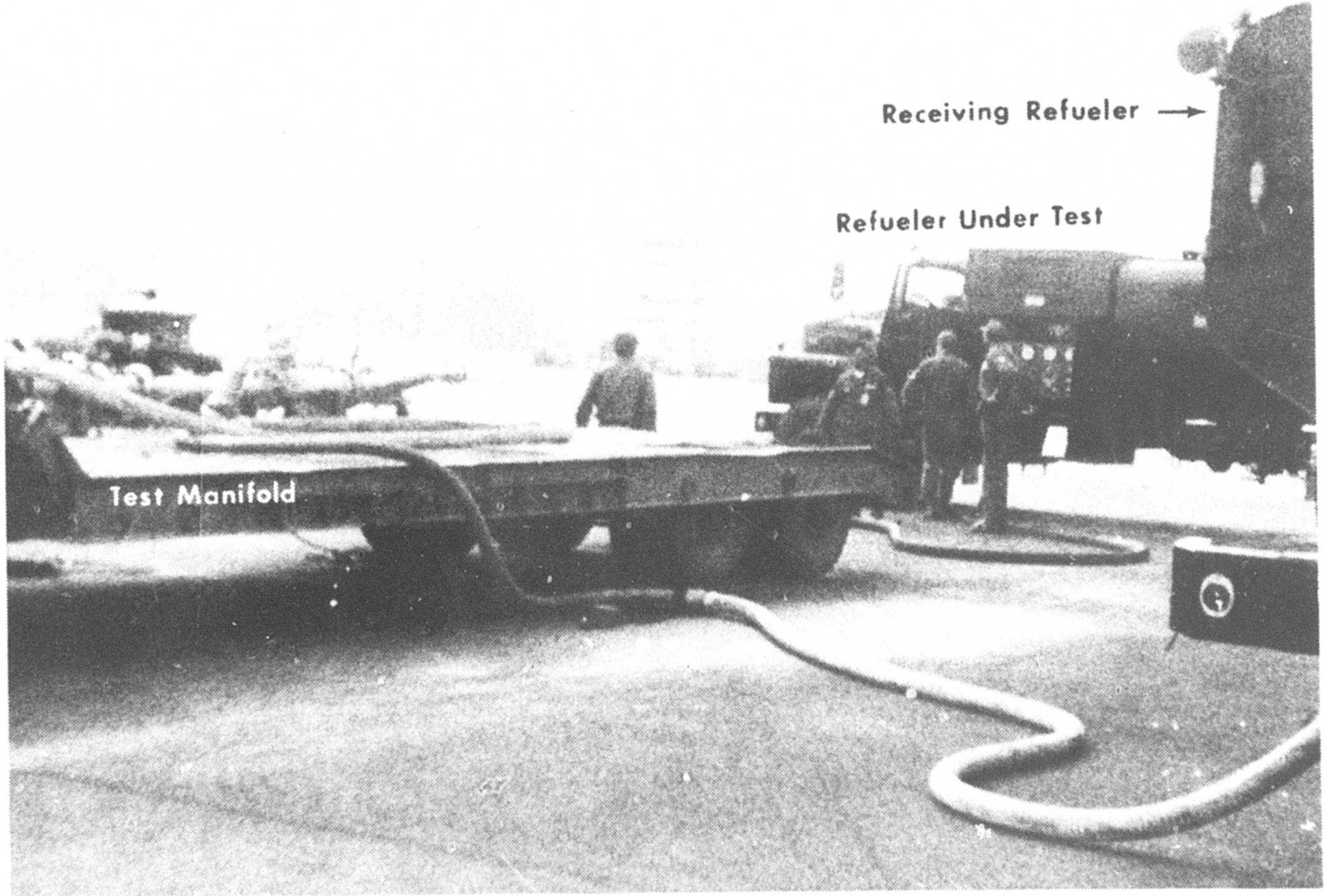


Figure 8 - General Test Arrangment for Measurement of Charge from Refueler from Dover Air Force Base

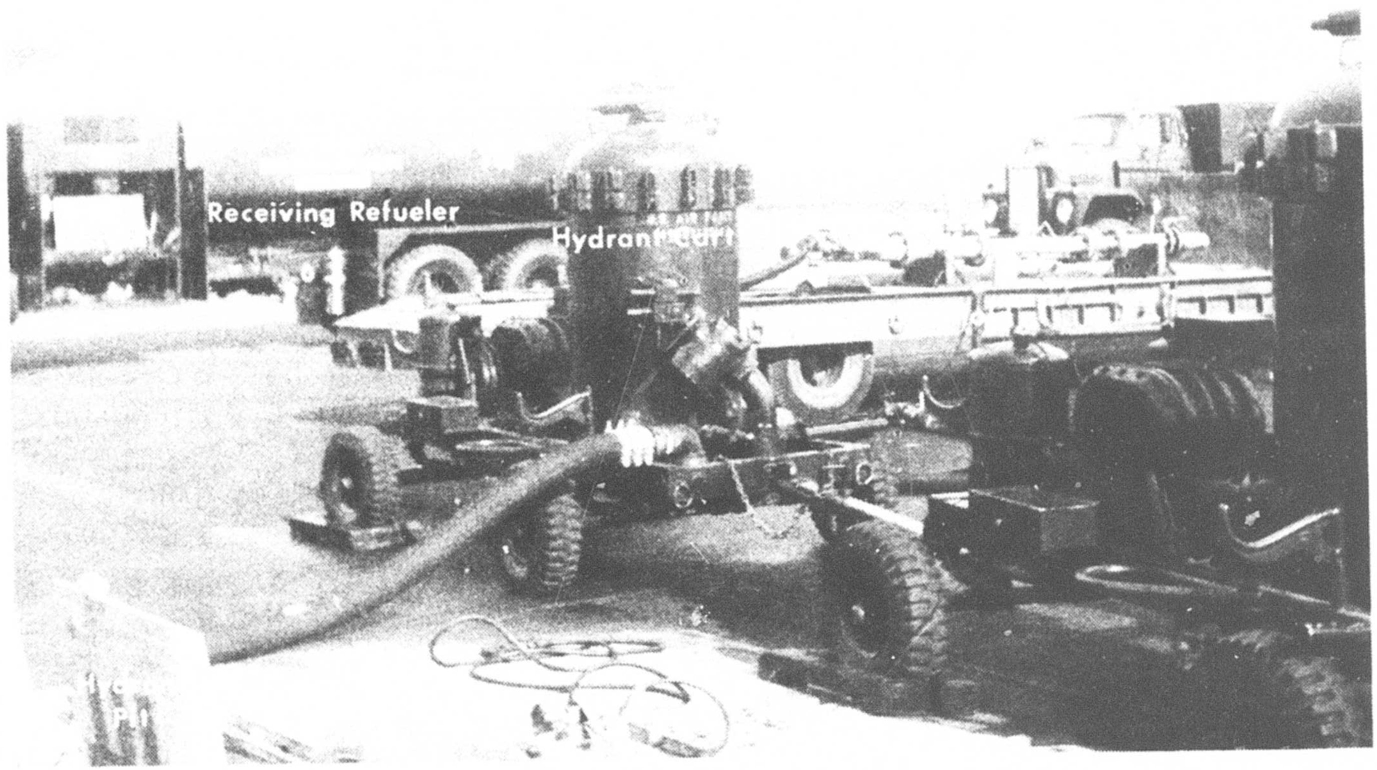


Figure 9 - General Test Arrangement for Measurement of Charge from Hose Cart at Dover Air Force Base

testing ramp locations, and testing sequence. Fuel samples were also gathered from each hydrant and fillstand and analyzed in the laboratory for charging tendency, water separation characteristics, specific gravity and electrical conductivity. At Kelly Air Force Base, individual samples were also obtained and analyzed of each fuel supplier from the supply truck as it arrived at the air base. Analysis of individual suppliers at Dover Air Force Base was not possible since they were comingled at Port Mahon and delivered to the air base by pipeline. Vehicle testing was accomplished during the remainder of the week, followed by disassembly of the test equipment for shipment to the other air base. Hose carts under test were connected to the aircraft hydrant fueling system at gate positions temporarily vacated by aircraft. Trucks were loaded at the truck fillstand and brought to the testing apparatus.

(1) Charge Density Tests

Charge density measurements were made over the flow range of the cart or truck under test, starting at the maximum flow rate obtainable on each vehicle. While Air Force hose carts and refuelers have rated flow capacities of 600 gpm, maximum flow has been intentionally limited to 300 to 350 gpm at Kelly and Dover Air Force Bases to prevent possible over-pressurization of aircraft fuel systems. Measurements were made in two to four descending increments after allowing charge density equilibrium to be reached at each point. Repeats of charge density were obtained by returning to maximum flow in similar flow increments. Other repeat tests consisted of testing the vehicle at maximum flow, stopping flow and allowing all charges to decay to zero and then conducting another run at maximum flow. (Although repeat runs conducted after a significant time lapse might be preferable in some ways, the inability to guarantee fuel identity keeps such runs from being true repeat runs.)

Figure 10 illustrates a typical data summary sheet used to record charge density and other run data. The data contained on these sheets were taken from the oscillograph recordings and other raw data sources.

(2) Field Strength Tests

Field strength measurements were made at both Dover Air Force Base and Kelly Air Force Base. Field strength of the charged fuel within the refueler tank compartment was recorded as the receiving refueler was filling at a constant flow rate. This involved inserting a field meter into the open manhole of the receiving refueler to obtain surface voltage data on the rising fuel surface. Because of the open manhole and escape of fuel vapors, the tank compartment was pre-inerted with nitrogen as a safety precaution. Oyxgen in the free space of the tank was purged to less than seven per cent with nitrogen. Field strength buildup during tank filling and decay after fill shut-off were both recorded. Original plans called for two measurements on each refueler tested - one at maximum constant flow rate and one at a lower rate. However, inability to obtain measurable quantities of field strength at the maximum flow rate negated runs at lower flow rates on other vehicles.

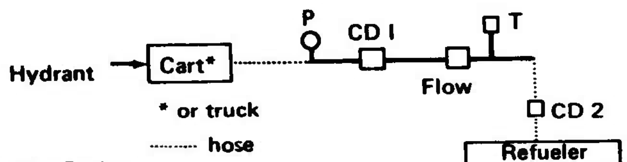
U.S. AIR FORCE FUELING EQUIPMENT SURVEY

DATA SUMMARY SHEET

AIRBASE ____________

Run No. ____________
Date ____________
Time ____________
Sample No. ____________

Test System Schematic



Filter Rating ____________
Hydrant System ____________
Gate Position ____________
Cart Number ____________
Fuel Source ____________

Coalescer Type ____________
Life ____________
Separator Type ____________
Life ____________

Fuel: Gravity ____________
Temp. ____________
Free Water ____________
Conductivity ____________

Remarks ____________

Charge Density Only						Field Strength/Charge Density									
Flowrate GPM	Recpt. Press. PSIG	Charge Density I		Charge Density 2		Liquid Level %Full	Cum. Volume GAL	Charge Density 1		Charge Density 2		Field Strength		Surface Voltage KV
		Current Amp x 10^{-6}	$\mu C/m^3$	Current Amp x 10^{-6}	$\mu C/m^3$			Current Amp x 10^{-6}	$\mu C/m^3$	Current Amp x 10^{-6}	$\mu C/m^3$	KV/m	M	

Figure 10 - Data Summary Sheet

(3) Static Charge Reducer

Efficiency measurements were made on an operating SCR at Kelly Air Force Base. An SCR has been installed downstream of the filter-separators in each of two legs of the No. 1592 fillstand for several years. The purpose of these tests was (1) to evaluate the performance of the SCR after several months of continuous usage in routine operation, (2) to evaluate the SCR performance immediately after cleaning, (3) to provide a means for Kelly Air Force Base to continue to monitor with usage the effectiveness of the SCR, and (4) to identify by laboratory analyses any deposits which may alter SCR operating efficiency. As an added feature, the SCR was compared to a section of pipe of equal outer dimensions used as a charge relaxation chamber. Efficiency of the SCR and relaxation chamber were calculated from readings of charge density meters installed just upstream and downstream of the SCR. Figure 11 shows a sketch of the modification and instrumentation installation made on the No. 1592 fillstand. Figure 12 shows a view of the fillstand and instrumentation during a test.

(4) Testing Scope

A total of 63 runs were made at Dover and Kelly Air Force Bases during two testing periods (warm and cold weather) to determine the charge generation of air base fueling equipment. In addition to charge density (CD) evaluations, these included one run at each air base for field strength (FS) and 3 runs at Kelly Air Force Base to evaluate the static charge reducer (SCR). The breakdown of testing is shown in Table III.

TABLE III. TESTING SCOPE

Air Base	Total Runs			Fuel Source	No. of Vehicles Tested	
	CD	FS	SCR		Hose Carts	Trucks
• Warm Weather Testing - October 1974						
Dover	29	-	-	3 Hydrants (2 gates each)	7	1
				1 Fillstand		4
Kelly	5	1	-	1 Fillstand	-	5
• Cold Weather Testing - January and February 1975						
Kelly	7	-	3	1 Fillstand	-	7
Dover	17	1	-	3 Hydrants (1 gate ea)	8	2
				1 Fillstand		3

(5) Treatment of Data

Charge density was measured as a function of flow rate during 61 test runs. Two more runs were made at constant flow rate in order to establish field strength. Charge density versus flow rate data were plotted for each run (these curves appear in Appendix A). Charge density at 300 gpm was interpolated and/or extrapolated from these curves to permit comparisons between vehicles and subsequent analyses. To permit comparisons

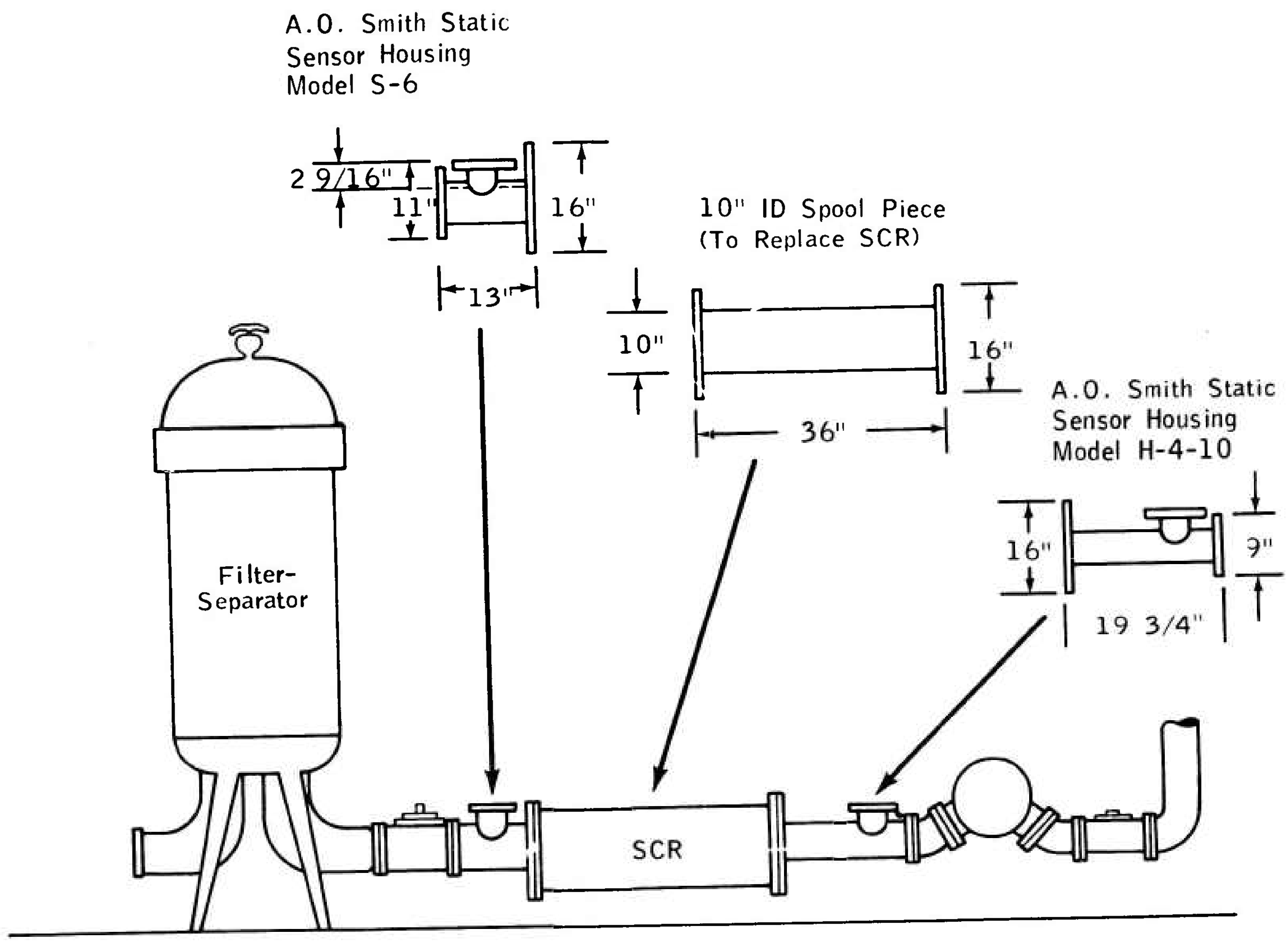


Figure 11 - Proposed Modifications to Kelly AFB 1592 Fillstand

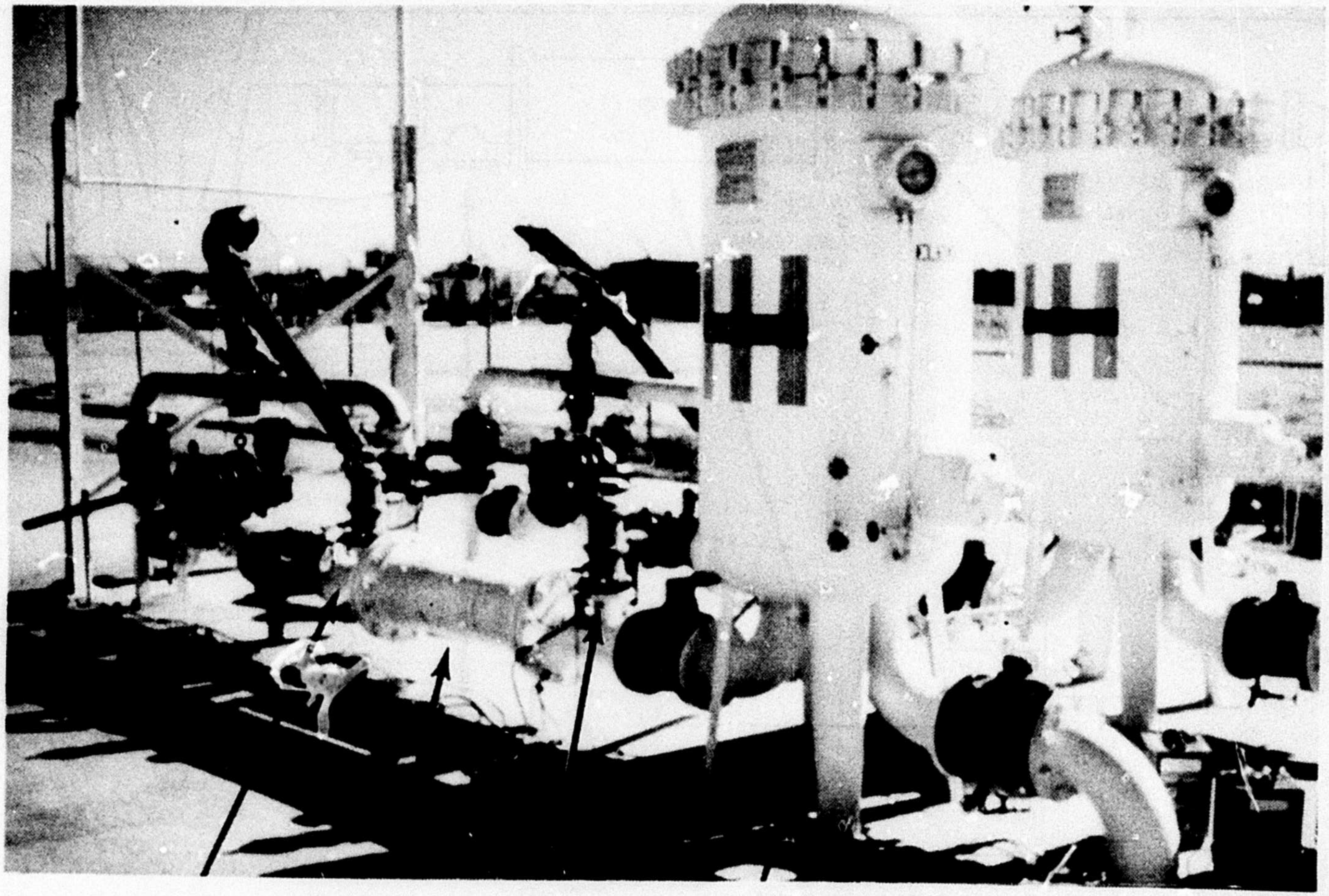


Figure 12 - General Test Arrangment - Testing of Static Charge Reducer at Kelly Air Force Base

of filter charging on an equivalent basis, initial charge, Q_{oe}, in fuel issuing from the separator elements of the filter-separator was calculated (using the equation of Section II, para. 1) for each vehicle run on the basis of fuel effective conductivity and volumes contained within the filter-separator obtained from physical measurements in each type of filter-separator and each type of hose. This approach tends to eliminate variations in hose length, filter-separator designs, and fuel conductivity differences between runs. It permits a more direct comparison of charging effects between refuelers and MH-2A and MH-2B hose carts. This method was used for charging comparisons which were then tested for statistical significance. Data for each individual run are presented in Tables V, VI and VII.

(a) Repeatability

Repeatability of charge density data was obtained from 39 repeat determinations of equilibrium charge density values at maximum flow rate. Repeatability determined in this manner was calculated to be ± 3.5 per cent. This is within the ± 4.0 per cent accuracy of charge density based on previous industry experience.

d. Discussion of Results

(1) Fuel Factors

(a) Fuel Rest Conductivity versus Temperature Data

Conductivity of fuels was measured as prescribed by ASTM D-3114-72, D.C. Electrical Conductivity of Hydrocarbon Fuels. This method applies to the laboratory determination of the rest conductivity of aviation fuels. The rest conductivity measured on samples collected during tests and from supply tanks during each of the four test periods are given in Table IV. Since the initial measurement was always made later in the laboratory after the sample was taken, the temperature at which the conductivity was measured was usually different (higher or lower) than that which prevailed at the time of sampling. In the October testing at Dover and Kelly, it was the practice to measure conductivity at two temperature levels and thereby determine the relationship between conductivity and temperature (Table IV). During the testing in January at Kelly and February at Dover, many more samples were taken than during October, and tested at several temperatures. The conductivities measured on these samples were used to find the best least squares fit to the equation:

$$\log pS/m = aT + b$$

which expressed the relationship between conductivity and temperature, T. The regression analyses of these data are summarized in Table IV. The last column of Table IV shows that conductivity doubles with an increase in temperature ranging from ΔT of 23 to 28°F (16 to 19°C) at Kelly and 23 to 49°F (16 to 27°C) at Dover. This range is broader than expected at Dover but may reflect variations in fuel supplied and held in the many hydrant storage tanks.

TABLE IV. REGRESSION ANALYSES OF MEASURED REST CONDUCTIVITY AGAINST TEMPERATURE AT CONDUCTIVITY LEVELS TESTED

AFB	Test Period	Fuel Source	Range of Fuel Test Temp °F	Range of Conductivity During Test (pS/m)	pS/m 74°F	Regression Analyses (1) Coefficients a	b	Std Error of Estimate	ΔT°F For Conductivity to Double
Dover	Oct 74	North Hydrant	60-62	1.6 - 1.7	2.15	-	-	-	33
		MAC Hydrant	69-71	1.8 - 1.9	2.0	-	-	-	38
		C5 Hydrant	65-71	1.2 - 1.4	1.45	-	-	-	43
		So. Fillstand	64-66	3.1 - 3.3	3.75	-	-	-	48
Kelly	Oct 74	Tank A & B	70-80	15.0 - 17.5	15.86	-	-	-	28
Kelly	Jan 75	Tank A	49-67	9.2 - 18.5	30.62	0.013	0.544	0.268	23.5
		Tank B	49-67	9.2 - 18.5	31.96	0.013	0.533	0.229	23
Dover	Feb 75	North Hydrant	36-38	6.6 - 6.8	11.25	0.006	0.603	0.155	49
		MAC Hydrant	38-41	4.9 - 5.3	14.64	0.013	0.167	0.107	23
		C5 Hydrant	47-50	7.4 - 8.2	17.14	0.013	0.243	0.425	23
		So. Fillstand	45-47	5.3 - 5.5	9.79	0.010	0.297	0.093	32

(1) The equation $\log pS/m = a\,T + b$ used to calculate coefficients. Where blanks appear, calculations were not made.

TABLE V. FIELD DATA: DOVER AFB
WARM WEATHER TESTING: OCTOBER 1974

Test No.	Date	Time	Testing Location Hydrant	Testing Location Position	Cart[1] or Truck ID	Coalescer/Separator Thruput (MM Gal)	Coalescer/Separator Age (Mos)	Fuel Temp(°F)	Conductivity at Test Temp (pS/m) Rest,Kr	Conductivity at Test Temp (pS/m) Eff Ke	Rest Conductivity @74°F(pS/m)	Free Water (ppm)	Charge[2] Density Meter #1, μC/m³ @ 300 gpm	Charge[2] Density Meter #2, μC/m³ @ 300 gpm	Relax Time (Sec) Between Filter & CD-1 Meter	Calc Charge @ Filter μC/m³ Qoe
D-1	1008	0830	North	X-3	71X015	3.61	34	62	1.7	1.3	2.15	2	33	31	21.7	158.2
D-2	1008	0900	North	X-3	62X181 L	0.025	1	62	1.7	1.3	2.15	2	7	7	14.2	19.5
D-3	1008	0915	North	X-3	71X017 L	4.901	34	62	1.7	1.3	2.15	2	28	28	26.8	203.
D-4	1008	0925	North	X-3	62X106	0.145	10	60	1.6	1.3	2.15	2	26	26	9.1	50.2
D-5	1008	1000	North	X-3	72L957	0.045	2	65	1.8	1.4	2.15	2	26	26	17.5	101.
D-6	1008	1120	North	X-1	62X161 L	0.025	1	60	1.6	1.3	2.15	2	15	15	14.2	41.8
D-7	1008	1137	North	X-1	71X017 L	4.901	34	60	1.6	1.3	2.15	2	27	27	26.8	187.1
D-8	1008	1145	North	X-1	71X015	3.61	34	60	1.6	1.3	2.15	2	39	37	21.7	187.
D-9	1008	1200	North	X-1	62X106	0.145	10	60	1.6	1.3	2.15	2	23	23	9.1	44.4
D-10	1008	1330	MAC	D-3	62X1[illegible]	0.145	10	69	1.8	1.4	2.0	1.3	22	22	9.1	44.6
D-11	1008	1341	MAC	D-3	71X015	3.611	34	69	1.8	1.4	2.0	1.3	29	29	21.7	156.8
D-12	1008	1350	MAC	D-3	71X017 L	4.901	34	69	1.8	1.4	2.0	1.3	20	20	26.8	160.8
D-13	1008	1400	MAC	D-3	62X181 L	0.025	1	71	1.9	1.3	2.0	1.3	18	18	14.2	50.2
D-14	1008	1430	MAC	D-3	72L957	0.045	2	75	2.0	1.3	2.0	1.8	26	26	17.5	92.0
D-15	1008	1500	MAC	D-1	62X106	0.145	10	71	2.0	1.3	2.0	0.8	24	24	9.1	46.3
D-16	1008	1510	MAC	D-1	71X015	3.611	34	71	2.0	1.3	1.0	0.8	25	25	21.7	120.
D-17	1008	1520	MAC	D-1	71X017 L	4.901	34	71	2.0	1.3	2.0	0.8	19	19	26.8	132.
D-18	1008	1530	MAC	D-1	62X181 L	0.025	1	70	2.0	1.3	2.0	0.8	20	20	14.2	5.6
D-19	1009	1005	C5	A-R	71X010	4.294	33	65	1.23	1.0	1.45	1.1	32	-	21.7	106.8
D-20	1009	1015	C5	A-R	71X014	5.682	34	65	1.23	1.0	1.45	0.8(3)	54	-	21.7	180.3
D-21	1009	1025	C5	A-R	62X187	0.022	2	65	1.23	1.0	1.45	0.8	20	-	9.1	33.
D-22	1009	1035	C5	A-R	72L957	0.045	2	70	1.35	1.1	1.45	0.8	22	-	17.5	64.
D-23	1009	1100	C5	A-O	71X014	5.682	34	71	1.35	1.1	1.45	0.8	27	-	21.7	102.
D-24	1009	1120	C5	A-O	71X010	4.294	33	71	1.35	1.1	1.45	0.8	32	-	21.7	121.
D-25	1009	1136	C5	A-O	62X187	0.022	2	71	1.35	1.1	1.45	0.8	23	-	9.1	40.
D-26	1009	1315	So.Fillstand		72L939	2.198	11	64	3.1	1.7	1.45	0.8	43	43	17.5	224.5
D-27	1009	1345	So.Fillstand		72L966	4.050	25	64	2.1	1.7	1.45	0.8	36	36	17.5	141.
D-28	1009	1415	So.Fillstand		72L956	0.017	3	66	3.3	1.8	3.75	0.8	24	24	17.5	138.
D-29	1009	1435	So.Fillstand		72L957	0.045	2	66	3.3	1.8	3.75	0.8	27	27	17.5	155.

(1)"L" after ID No. denotes carts equipped with 120-foot-long hoses.

(2)All charge density values have negative polarity. Where blanks appear, no charge density measurements made.

(3)Aquaglo taken upstream of filter-separator.

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TABLE VI. FIELD DATA: KELLY AFB
WARM WEATHER TESTING: OCTOBER 1974 (1)

Test No.	Date	Time	Truck No.	Coalescer/Separator Thruput (M Gal)	Coalescer/Separator Age (Mos)	Fuel Temp (°F)	Conductivity @ Test Temp (pS/m) Rest, Kr	Conductivity @ Test Temp (pS/m) Eff, Ke	Rest Conductivity @74°F (pS/m)	Free Water (ppm)	Charge Density Meter, μC/m³ @ 300 gpm	Charge Density Meter #2, μC/m³ @ 300 gpm	Relax Time Sec F-S to CD	Charge Generated by Filter Qoc	Remarks
K-1	1022	1000	67L573	6.981	34	70	17.5	5.3	19.5	>12 (large droplet)	0	0	17.5	-	
K-2	1022	1100	72L897	4.310	25	73	15.0	4.8	15.1		0	0	17.5	-	
K-3	1022	1330	72L959	0.128	1	-	16.0	4.7	∿ 15.1	1.1	0	0	17.5	-	
K-4	1022	1415	72L950	8.280	25	78	16.7	5.0	∿ 15.1		0	0	17.5	-	
K-5	1022	1515	67L578	10.952	52	80	17.5	5.3	∿ 15.1	<1.0	-4	0	17.5	-692	
K-6	1023	1440	67L578	10.952	52	77	16.4	4.9	15.25		-1.5	0	17.5	-260	F.S. = 0
							Cold Weather Testing: January 1975								
K-11	0121	1000	67L577	3.57	30	49	9.2	3.5	16.0	<1.0	+2.6	-0.7	17.5	+78.1	
K-12	0121	1026	72L897	0.712	2	52	9.8	3.6	16.0	<1.0	-1.0	-0.7	17.5	-33.1	
K-13	0121	1055	72L950	8.374	28	63	12.5	4.4	16.0	<1.0	+3.2	-0.9	17.5	+230.6	
K-14	0121	1120	72L959	0.514	4	66	13.4	4.3	16.0	<1.0	-1.0	-	17.5	-65.4	
K-15	0121	1143	67L578	11.64	55	58.5	12.6	4.2	18.5	<1.0	+2.0	+0.1	17.5	+119	
K-16	0121	1254	67L569	0.03	∿ 1/4	60	13.0	4.3	18.5	<1.0	-16.0	-13.0	17.5	-1046	Purge Oil
K-17	0121	1315	67L573	7.236	36	67	15.5	4.8	18.5	<1.0	+1.4	-4.7	17.5	+149	
K-18	0120	1410	#22 Fillstand	1592	16	64	18.5		23.5	-					
K-19	0121	1415	#22 Fillstand	1592	16	64	18.5		23.5						
K-20	0122	1330	#22 Fillstand	1592	16	64	18.5		23.5						

(1) Where blanks appear, data were not obtained or calculated.

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TABLE VII. FIELD DATA: DOVER AFB
COLD WEATHER TESTING: FEBRUARY 1975

Test No.	Date	Time	Hydrant	Position	Cart or(1) Truck No.	Coalescer/Separator Thruput MM(Gal)	Coalescer/Separator Age (mos)	Fuel Temp (°F)	Conductivity @ Test Temp (pS/m) Rest,Kr	Conductivity @ Test Temp (pS/m) Eff Ke	Rest Conductivity @ 74°F (pS/m)	Free(3) Water (ppm)	Charge Density(2) Meter #1, μC/m³ @ 300 gpm	Relaxation Time Sec Between Filter & CD-1 Meter	Calc Charge @ Filter, μC/m³ Qoe
D-51	0204	1125	North	Z-3	62W00172 (62X106)	0.271	13	36	6.6	2.9	11.2	1.7	29	9.1	126.
D-52	0204	1140	North	Z-3	71W00044 (71X015)	3.770	37	36	6.6	2.9	11.2	1.2	33	21.7	1089.
D-53	0204	1155	North	Z-3	62W00178 L (62X181)	0.081	5	37	5.7	2.9	11.2	1.3	14	14.2	138.
D-54	0204	1205	North	Z-3	71W00189 L (71X017)	5.038	37	37	6.7	2.9	11.2	1.2	30	26.8	2251.
D-55	0204	1435	North	Z-3	72L939	2.533	15	38	6.3	2.9	11.2	-	30	17.5	503.
D-56	0204	1520	MAC	D-3	71W00044 (71X015)	3.770	37	38	4.8	2.4	14.6	1.2	35	21.7	632.
D-57	0204	1532	MAC	D-3	62W00172 (62X106)	0.271	13	40	5.1	2.4	14.6	1.3	22	9.1	74.
D-58	0204	1540	MAC	D-3	62W00178 L (62X181)	0.081	5	41	5.3	2.5	14.6	1.3	12	14.2	86.
D-59	0204	1548	MAC	D-3	71W00189 L (71X017)	5.038	37	41	5.3	2.5	14.6	-	20	26.8	827.
D-60	0206	1107	C5	N	71W00187 (71X014)	7.471	37	47	7.4	3.0	17.1	1.2	23	21.7	855.
D-61	0206	1115	C5	N	62W00171 P (62X214)	0.980	16	45	7.0	2.9	17.1	<1.0	32	9.1	139.
D-62	0206	1138	C5	N	62W00179 (62X187)	0.296	6	44	6.8	2.9	17.1	1.7	12	9.1	52.
D-63	0206	1150	C5	N	71W00105 (71X010)	5.157	36	45	7.0	2.9	17.1	-	12	21.7	396.
D-64	0206	1335	C5	N	72L957	0.410	6	50	8.2	3.3	17.1	2.1	17	17.5	421.
D-65	0206	1352	C5	N	72L939	2.533	15	50	8.2	3.3	17.1	1.7	25	17.5	618.
D-66	0206	1520	So. Fillstand		72L967	1.211	5	45	5.3	2.5	9.8	1.8	11	17.5	125.
D-67	0206	1535	So. Fillstand		72L939	2.533	15	45	5.3	2.5	9.8	-	28	17.5	318.
D-68	0206	1600	So. Fillstand		72L943	0.488	4	47	5.5	2.5	9.8	-	14	17.5	159.

(1) 1974 Identification numbers of Hydrant Carts given in ( ). "L" after I.D. No. denotes carts equipped with 120-foot-long hoses.
(2) All charge density values have negative polarity. Note that charge density meter No. 2 was inoperative.
(3) Where blanks appear, data were not obtained.

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The rest conductivities, k_r, expressed as picoSiemens/meter (pS/m), at the test temperatures as provided in this report were calculated using these relationships. The range over which conductivity varied during the testing period because of the temperature variation is shown in Table IV and also for each individual run in Tables V through VII.

No relationship was found between rest conductivity and charging tendency as illustrated in Figure 13. This agrees with the findings in the recent CRC study(Reference 2).

The 13 fuels shown in Tables V through VII represent the individual fuel families actually tested in hydrant sources and trucks. A fuel family was defined in terms of a particular hydrant or fillstand at the air base during one day of testing. Thus, if testing was done on two different days on the same hydrant, it would be considered to represent two fuels. The 11 fuels shown in Table IV reflect the quality of air base supply sources but it was considered that the hydrant or fillstand could influence the conductivity and charging tendency of the fuels actually tested in ground equipment.

(b) Effective Conductivity

The effective conductivity is a measure of the rate at which a charged fuel loses its charge while flowing in a particular system. As such, it differs from rest conductivity which is a property of the fuel in the uncharged state. Effective conductivities tend to be higher than the rest conductivities when rest conductivities are less than 1 pS/m, and less than rest conductivities when rest conductivities are greater than 1 pS/m.

In this program no assessment of effective conductivity could be obtained from the data because all charging levels were too low to detect accurately the differences in reading between the two charge density meters installed in the test manifold. In addition, the second charge density meter (needed for this determination) became inoperative during the cold weather testing phase at Kelly and Dover Air Force Bases. In lieu of the availability of this data, it was decided to utilize the relationship of effective conductivity to rest conductivity established in an earlier CRC study(Reference 7). This relationship of effective versus rest conductivity is reproduced in Figure 14 and a mean value between the two curves was used in determining effective conductivity shown in Tables V through VII.

(c) Charging Tendency

A correlation was found between fuel charging tendency as determined by the laboratory Mini-Static Charging Test (MST)(Reference 2) and the actual charging observed in the field apparatus and is shown in Table VIII to have, on the average, excellent agreement. In this table, data from typical runs in the February 1975 survey period are given in Column (A) as a calculated charge at the separator. These calculated charges were used to eliminate differences of residence time [Column (C)]

Reference:

7 "Electrostatic Discharge in Aircraft Fuel Systems - Phase II" Coordinating Research Council, Report No. 355, August 1961

TABLE VIII. COMPARISON BETWEEN OBSERVED FIELD AND LABORATORY MEASURED CHARGES

Run No.	Separator Type	Field Measured Charge ($\mu C/m^3$): Calc Chg @ Separator[(1)]	Field Measured Charge ($\mu C/m^3$): Corr for Thruput[(2)]	Residence Time t (sec)	Conductivities (pS/m): Rest (Kr)	Conductivities (pS/m): Effect (Ke)	Laboratory Measured Charge By MST ($\mu C/m^3$): MST	CRC[(3)] Factor	MST Corr (H) = [(F x G)]	Ratio [Col (H) / Col B]
		(A)	(B)	(C)	(D)	(E)	(F)	(G)		(I)
D-51	Teflon®	126	125	9.1	6.6	2.9	735	0.135	99	0.80
53	Teflon®	138	125	14.2	6.7	2.9	770	0.135	104	0.83
55	Teflon®	503	125	17.5	6.8	2.9	505	0.135	68	0.54
56	Teflon®	632	75	21.7	4.8	2.4	665	0.135	90	1.20
58	Teflon®	86	75	14.2	5.3	2.5	475	0.135	64	0.85
60	Teflon®	855	48	21.7	7.4	3.0	535	0.135	72	1.50
61	Paper	139	95	9.1	7.0	2.9	~535	0.27	145	1.50
62	Teflon®	52	48	9.1	6.8	2.9	675	0.135	91	1.90
66	Teflon®	125	120	17.5	5.3	2.5	430	0.135	58	0.48
68	Teflon®	159	120	17.5	5.3	2.5	520	0.135	70	0.58
K-11	Teflon®	78	35	17.5	9.2	3.5	162	0.135	22	0.63
K-15	Teflon®	119	35	17.5	12.6	4.2	260	0.135	35	1.0
									Avg	0.99

(1) Values given in Tables VI and VII.

(2) Taken from Figures 13 and 14 at intersection of respective curves to 0 gal thruput. Value for paper separator was extrapolated to 0 on a parallel curve to North Hydrant curve since curves were established for Teflon® separators.

(3) CRC Factor (5) relates to correction factor established between charge developed by MST paper (type 11) and normal paper (type 10). Therefore paper factor =0.27 x MST value. The correction for Teflon® was obtained by ratioing charges from tests 60 and 61, i.e., $\frac{\text{Teflon®}}{\text{paper}} = \frac{48}{95} = 0.5$; therefore, the correction factor for Teflon separator is MST x 0.27 x 0.5 = MST x 0.135. See Reference 5.

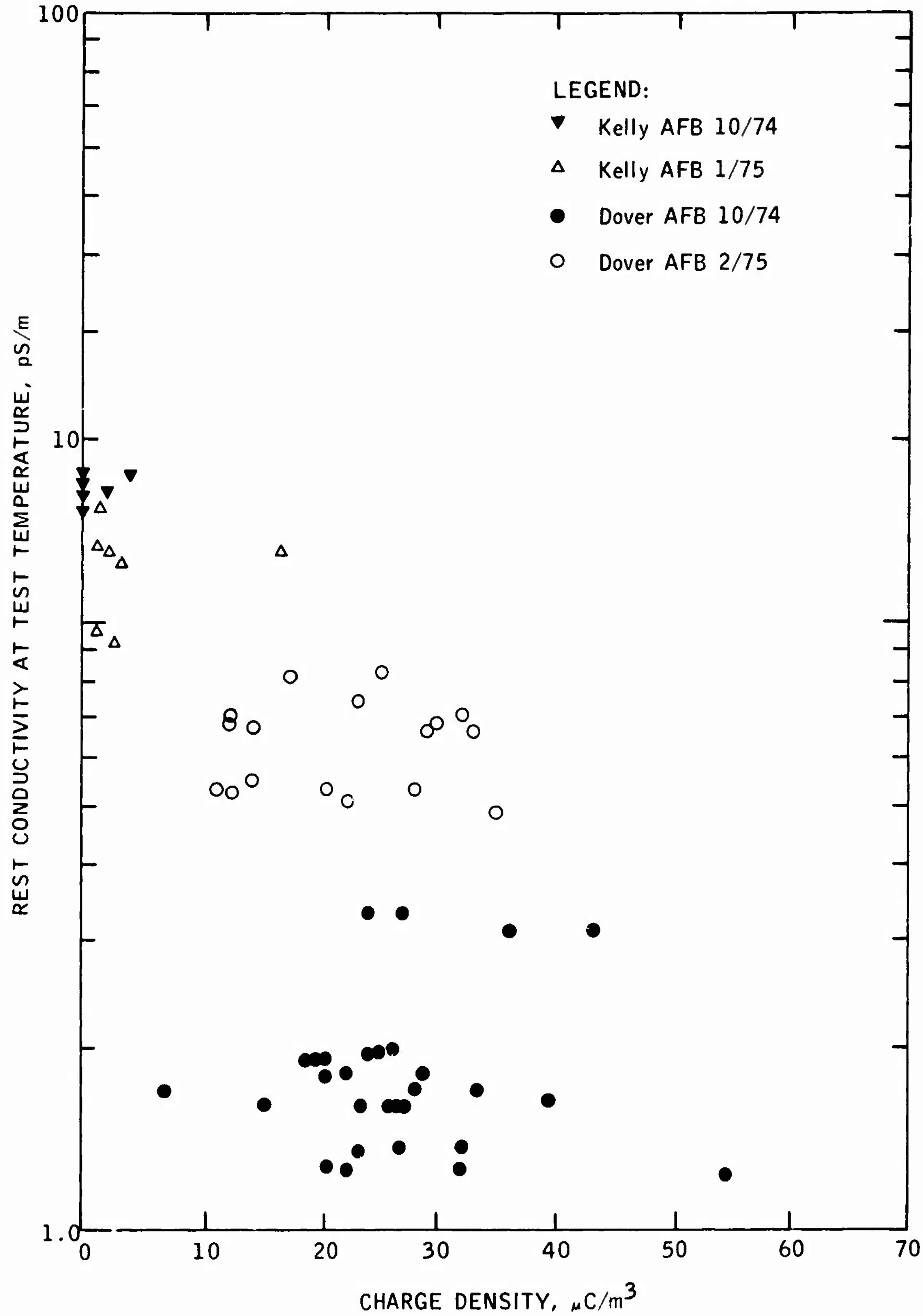

Figure 13 - Relationship of Fuel Test Conductivity versus Charge Density at 50 percent of Rated Flow

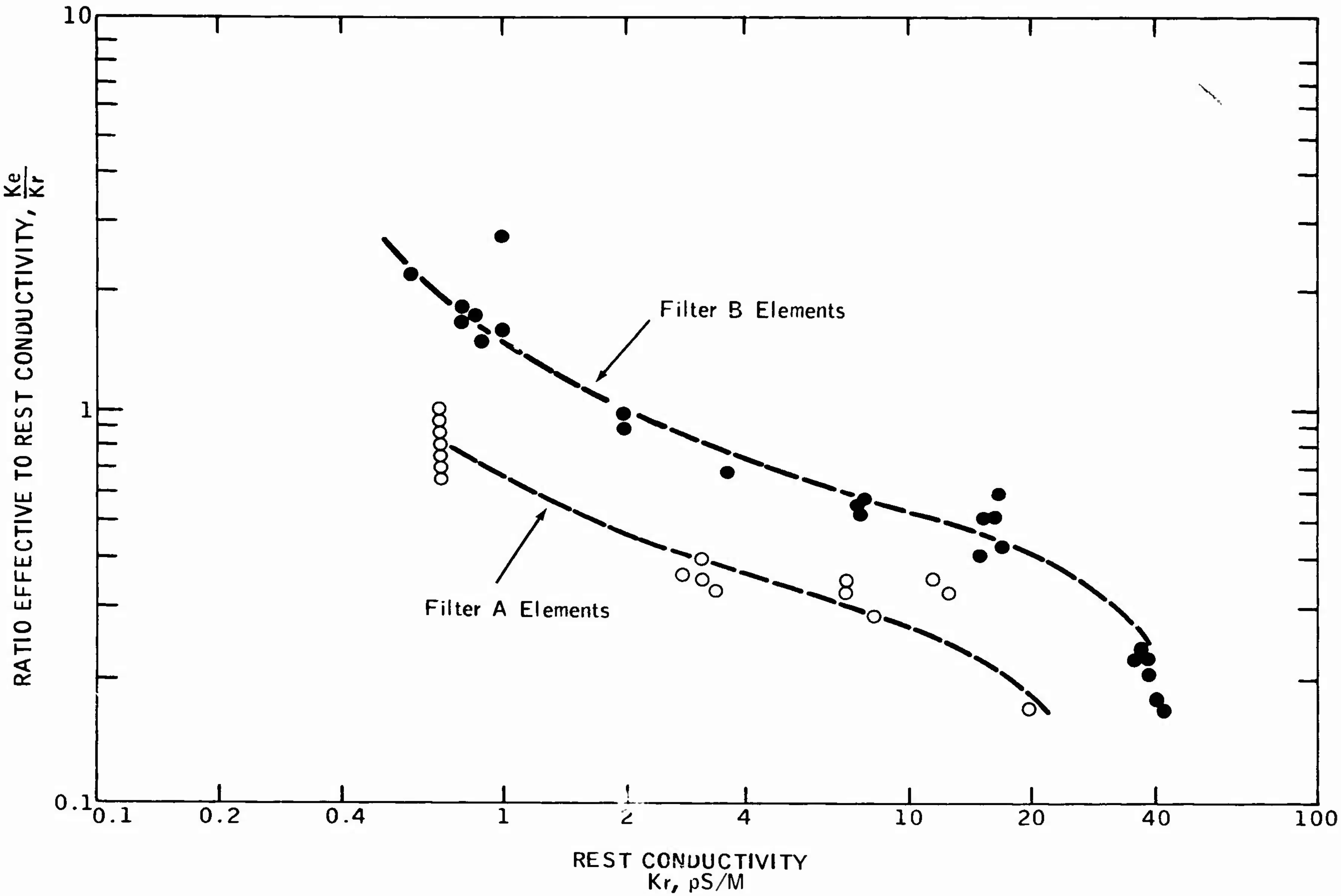

Figure 14 - Effective versus Rest Conductivity

Note: Reproduced from Figure 23 of Reference 7 between fueling vehicles and differences in fuel conductivities [Columns (D) and (E)] between fuel sources. These calculated charges were then further corrected for differences between vehicles of filter age or thruput [see Column (B)].

The MST test employs a special high charging paper (type 10) and, therefore, to compare MST data to normal filter element charging, a correction factor needs to be applied. The basis for this factor and its application are described in a recent CRC report (Reference 5). The corrected MST values and the calculated vehicle charges were then compared by taking a ratio of the MST data to the calculated vehicle charge data. The results are presented in Column (1) and show an overall averaged ratio of 0.99.

(d) Fuel Cleanliness

1. Free Water

A total of 33 determinations of undissolved (free) water were conducted on the 63 test runs. Free water was determined with the Aqua-glo instrument (ASTM D-3240) during the test run and is given in Tables V through VII. Except for one run at Kelly Air Force Base, free water content on all other runs was two ppm or less. The one run at Kelly Air Force Base showed a water content of 12 ppm but this reading was determined to be non-representative of the refueler fuel since the test pad showed exposure to one large water drop - probably precipitating from the fuel downstream of the filter-separator as the truck stood full of fuel overnight.

Effects of free water content on charging tendency could not be determined since hose carts and refuelers are generally not equipped with fuel sampling probes upstream of the filter-separator where measurements of free water content could be made on the fuel as it entered the filter-separator. One hose cart at Dover Air Force Base was fitted with a sample probe upstream of the filter-separator. Analyses of the fuel at this point showed a <1.0 ppm free water content.

2. Water Separation Characteristics

Water separation characteristics of the fuels (WSIM) tested by Mini-Sonic Separometer (MSS) (ASTM D-2550) showed all fuels to be in an acceptable range of 90 to 100 WSIM rating. On a few samples at Dover Air Force Base readings were obtained in the mid to upper 80 range and one sample had a WSIM of 74. Repeat tests on new samples of these fuels all gave readings in the 90 to 100 range. MSS data are given in Tables IX and X.

3. Particulate Contamination of Fuels

Particulate contamination of fuels was determined by ASTM D-2276-71 using Millipore filter membranes. All samples tested showed acceptable levels from 0.2 to 0.6 mg/gal. The Millipore data are given in Tables IX and X.

TABLE IX. LABORATORY ANALYSIS OF FUELS - COLD WEATHER TESTING(1)

DOVER AFB: FEBRUARY 1975

Sample Source	Rest Conductivity pS/m @ 74°F	API Gravity @ 60°F	Charging Tendency $\mu C/m^3$ (Mini Static Test)	Particulates (ASTM D-2276) mg/gal	WSIM (MSS)(2) Rating (ASTM D-2250)
North Hydrant	7.3	51.8	440	-	88,91
MAC Hydrant	12.0	53.2	475	-	87
C5A Hydrant	24.0	53.3	1230	-	84
So. Fillstand	13.0	53.2	560	-	95
Test D-51	11.2	52.1	735	0.5	96
Test D-52	-	-	-	0.6	-
Test D-53	11.2	50.3	770	-	-
Test D-54	-	-	-	0.6	-
Test D-55	11.2	51.0	505	-	-
Test D-56	14.6	51.5	665	-	93
Test D-57	-	-	-	0.5	-
Test D-58	14.6	51.5	475	-	-
Test D-60	17.1	53.9	535	0.5	-
Test D-62	17.1	-	675	0.4	97
Test D-66	9.8	-	430	-	-
Test D-68	9.8	-	520	-	-

KELLY AFB: JANUARY 1975

Sample Source	Rest Conductivity pS/m @ 74°F	API Gravity @ 60°F	Charging Tendency $\mu C/m^3$ (Mini Static Test)	Particulates (ASTM D-2276) mg/gal	WSIM (MSS)(2) Rating (ASTM D-2250)
Hydrant	32.0	54.0	720	-	98
Fillstand TKA	30.0	52.8	70	0.3	100
Fillstand TKB	31.0	55.4	330	0.2	99
Coastal Oil	19.0	55.7	330	-	98
Tesora Oil	23.5	52.9	490	-	96
Test K-11	16.0	54.7	162	-	94
Test K-15	18.5	54.7	260	-	97

(1) Where blanks appear, data were not obtained.
(2) Water separation rating of fuel by Mini-Sonic Separometer.

TABLE X. LABORATORY ANALYSIS OF FUELS - WARM WEATHER TESTING(1)

DOVER AFB: OCTOBER 1974

Sample Source	Rest Conductivity pS/m @ 74°F	API Gravity @ 60°F	Charging Tendency μC/m³ (Mini Static)	Particulates (ASTM D-2276) mg/gal	WSIM (MSS)(2) Rating (ASTM D-2250)
C5A Hydrant	1.44	53.8	950	0.6	98
North Hydrant	3.3	55.6	600	0.3	94
MAC Hydrant	2.5	55.0	1150	0.3	100
So. Fillstand	3.5	55.2	510	0.5	81,74,92
So. Fillstand	3.7	55.1	1080	0.4	96
Test D-1 North	2.2	55.3	-	-	-
Test D-4 North	2.2	55.4	-	-	-
Test D-10 MAC	2.0	55.3	-	-	-
Test D-13 MAC	2.0	55.2	-	-	-
Test D-23 C5	1.5	54.4	-	-	-
Test D-28 So. Fillstand	3.8	54.8	-	-	98

KELLY AFB: OCTOBER 1974

Sample Source	Rest Conductivity pS/m @ 74°F	API Gravity @ 60°F	Charging Tendency μC/m³ (Mini Static)	Particulates (ASTM D-2276) mg/gal	WSIM (MSS)(2) Rating (ASTM D-2250)
Hydrant 1592	15.2	53.5	1150	0.5	91
Fillstand TKA 1592	13.5	52.5	740	0.6	92
Fillstand TKB Tesors	14.3	52.5	830	0.3	97
Petrol Co.	11.2	55.1	360	0.6	99
Howell Ref. Co.	13.5	52.5	240	0.3	97
Test K-1	19.5	53.0	-	-	-
Test K-2	15.1	52.5	-	-	-
Test K-6	15.25	52.5	680	-	-

(1) When blanks appear, data were not obtained.
(2) Water Separation rating of fuel by Mini-Sonic Separometer.

(e) Variation of Rest Conductivity Between Bases and Testing Periods

Sizable variations in rest conductivity were noted between Kelly Air Force Base and Dover Air Force Base fuels as well as between testing periods of October and February. These are shown below:

Air Base	Testing Period	Nominal Conductivity @ 74°F (pS/m)	No. of Suppliers
Dover	October	2.3	3
Kelly	October	15.9	3
Kelly	January	31.3	2
Dover	February	13.2	1

The most striking difference is that between Dover and Kelly Air Force Bases during the October testing. Upon return for the winter phase of testing Kelly Air Force Base fuel conductivities have doubled while Dover Air Force Base fuel conductivity has increased by nearly a factor of six.

These variations in fuel conductivity were indeed unexpected and present one of the more significant findings of the survey. While conductivity in itself does not relate directly to charging tendency, it does relate to charge relaxation and thereby is significant to the relative hazards of static electricity.

The reasons for these variations between air bases and between testing periods is felt to be a function of the corrosion inhibitor additive contained in the fuel. The effects of different corrosion inhibitors on fuel conductivity and charging tendency is demonstrated in Table XI.

The data in Table XI were obtained from laboratory blends of four different corrosion inhibitors (three of which are approved in QPL 25017-9) in the same base fuel. Of the four, two cause the conductivity to increase while two cause a conductivity reduction. Likewise, Hitec E-515 shows a two- to three-fold increase in charging tendency while the other three show only an approximate 50 per cent increase in charging over the base fuel.

The two corrosion inhibitors which cause fuel conductivity to decrease are important to note. The data indicate that JP-4 fuel in the field could exhibit rest conductivity similar to commercial fuels if these particular additives were used. In this connection it is interesting to note that the recent 1973 CRC fuel survey(Reference 2)included 54 samples of JP-4 fuel from two air bases (Table XII). Although the average conductivity level of JP-4 was higher than Jet A, 76 per cent of the JP-4 samples were between 1 and 9.9 pS/m. Thus, it is evident that the JP-4 fuels tested at Dover and Kelly were nonrepresentative because only

TABLE XI. LABORATORY TESTS ON FUEL CONDUCTIVITY AND CHARGING TENDENCY OF CORROSION INHIBITORS

Corrosion Inhibitor	Concentration (lbs/M bbls)	Rest Conductivity @ 75°F (pS/m)	Charging Tendency By ($\mu C/m^3$)	Effective Conductivities (pS/m)[2]
Base Fuel	0	1.40	530	1.12
+ Hitec E-515	5	4.9	1245	2.5
+ Hitec E-515	16	6.3	1735	2.8
+ Emery 9855[1]	5	0.77	810	0.92
+ Emery 9855[1]	16	0.77	835	0.92
+ DuPont DCI-4A	2	0.83	845	0.91
+ DuPont DCI-4A	8	0.75	920	0.9
+ Apollo PRI-19	2	2.10	750	1.4
+ Apollo PRI-19	8	2.07	805	1.3

(1) Not QPL approved.

(2) Effective conductivity calculated from Figure 14.

37.5 per cent of the samples matched the earlier survey. The findings of high conductivities on the Air Force 1974-1975 survey are even more striking when compared to the 1962 CRC survey(Reference 2) and the 1963-1964 survey by K. J. Marsh(Reference 2) as shown in Table XII and summarized in Reference 2.

The generally lower levels of conductivity observed with JP-4 in 1962 to 1964 undoubtedly reflect the fact that the MIL-T-5624 fuel specification did not make corrosion inhibitors mandatory until 1965. Unfortunately, very few air bases have been surveyed since 1965 when the important change was made in the specification that influenced electrical conductivity.

TABLE XII. COMPARISON OF JP-4 FUEL CONDUCTIVITY DATA FROM VARIOUS SURVEYS

	1962 CRC(1)	1963-64 Marsh(1)	1973 CRC(1)	1974 Air Force	1975 Air Force
Conductivity Range, pS/m	Per Cent of JP-4 Samples				
<0.49	7.1	1.4	0	0	0
0.50 to 0.99	10.7	18.1	0	0	0
1.0 to 4.9	57.2	74.7	35.2	60.0	0
5.0 to 9.9	25.0	5.7	40.7	0	15.0
>10	0	0	24.1	40.0	85.0
	100.0	99.9	100.0	100.0	100.0
Number of Samples	28	348	54	20	20
Number of Airports	17	5	2	2	2

(1) Table VIII from Reference (2) summarizes results of earlier studies.

The answer to questions about JP-4 conductivity can only be obtained from a survey of fuels from a large number of air bases. A program of this type is recommended along with a laboratory investigation into the effects of QPL additives on fuel conductivity and charging.

(2) Charge Generation by Air Base Fueling Equipment

(a) Level of Charge Densities Obtained in Survey

The level of charge density measured at both Kelly and Dover Air Force Bases was much lower than anticipated. The distribution of charge density at maximum obtainable flow during the four test periods is shown in Table XIII. The reason for these low charge levels is felt to be due to the combination of reduced flow capacity of all the vehicles and high fuel conductivities. Kelly Air Force Base, which had the higher conductivities during both testing periods, had 92 per cent of all vehicles tested giving less than 10 μC/m^3 with 53 per cent of the vehicles registering charges in the 20 to 30 μC/m^3 range.

TABLE XIII. DISTRIBUTION OF CHARGE DENSITY LEVELS AT MAXIMUM FLOW RATE[1]

Range of Charge Density (μC/m^3)	Number of Observations			
	Dover AFB		Kelly AFB	
	Oct	Feb	Oct	Jan
+0-10				4
-0-10	1	-	6	2
-10-20	3	7	-	1
-20-30	18	7	-	-
-30-40	5	4	-	-
-40-50	1	-	-	-
-50-60	1	-	-	-

(1) Maximum flow rate obtainable was 390 to 420 gpm which is 48 to 70 per cent of rated capacity (600 gpm) of the vehicles.

Further insight into the low levels of charging obtained in testing at Dover and Kelly Air Force Bases can be obtained by comparing the Mini-Static test data from these air bases with those obtained on JP-4 fuels from Homestead and Loring Air Force Bases in the recent 1973 CRC survey(Reference 2) shown in Table XIV. Here it can be seen that, from nearly the same number of fuel samples, only 40 per cent of the Homestead and Loring samples had MST charge densities between 500-999 μC/m^3 compared to 46 per cent of the Dover and Kelly samples. Furthermore, 42 per cent of the Dover and Kelly samples had charge densities below 500 μC/m^3 compared to none from Homestead and Loring. While the differences between the 1973 CRC survey and the current data cannot be explained, it should be noted from Table VIII that the MST data show good agreement with observed charge at the two test air bases when appropriate corrections are made.

In the subsequent paragraphs the charge density data observed in the flowing fuel are translated into an estimated filter charge at the element in order to facilitate the study of effects of filter thruput, hydrant system, element type and filter-separator design. The calculation technique discussed in paragraph 1.c.(5), Treatment of Data, eliminates the variables of fuel conductivity, hose length and filter-separator design although it admittedly exaggerates inaccuracies if the observed charge density in fuel is at a low level.

TABLE XIV. COMPARISON OF JP-4 CHARGE DENSITY DATA FROM AIR FORCE AND CRC SURVEYS LABORATORY MINI-STATIC TEST DATA

	1973 CRC Survey (Reference 2)		1974-75 Air Force Survey	
Air Base	Homestead	Loring	Dover	Kelly
Range of Charge Density ($\mu C/m^3$)	Per Cent of JP-4 Samples			
<500	0	0	22.2	61.5
500-999	80	0	61.1	30.8
1000-1999	20	20	16.7	7.7
>2000	0	80	0	0
Total	100	100	100	100
Number of Samples	15	15	18	13

(b) Effects of Filter Thruput

The time in service calculated for each filter-separator unit on the basis of volume of fuel processed since the last element change was used to compare all the units tested at each air base in terms of observed charge. Age and thruput data for each vehicle tested is given in Tables IV through VI. As can be seen from these tables, some vehicles have higher utilization than others, and for this reason age or time in months of service was not used for comparing vehicles. No comparison of thruput with charge level could be made from the Kelly Air Force Base testing carried out in October 1974 since five out of six runs gave no measurable charge.

The effects of cumulative fuel thruput on filter charging are given in Figure 15 for hose carts at Dover Air Force Base. Filter charging is based on calculated values of charge leaving the filter elements. A regression analysis was performed on the data for each curve and the coefficient of correlation is given for each line. These data show that higher thruputs result in higher charging of the filter.

Differences in charge level response (creating two families of curves) between the two testing periods is felt to be related to effects of fuel changes and temperature on charge levels.

A similar plot of filter thruput versus filter charging is given in Figure 16 for refuelers. The validity of the Kelly Air Force Base refueler data is questionable because of the extremely low measured values and corresponding accuracy of charge density used in these filter charge calculations. Correspondingly, the data obtained on the refuelers at Dover Air Force Base cover a very limited range. Nevertheless, the data indicate a similar trend to that obtained on the hose carts - higher thruputs cause higher charge levels.

(c) Charging Level Between Hydrant Systems

Charging level was found to vary between hydrant systems at Dover Air Force Base. This can be seen in Figure 15 which shows that during both

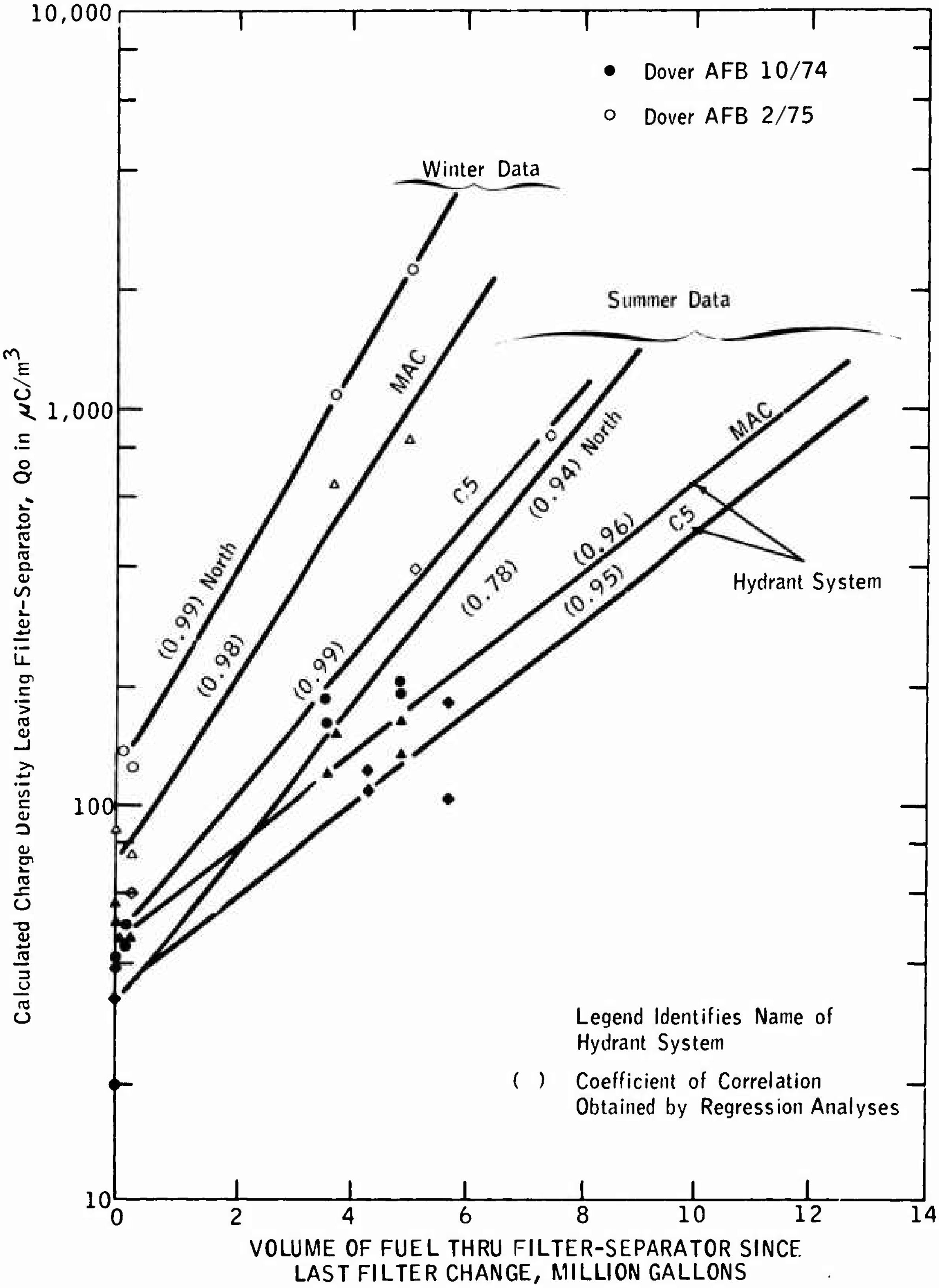

Figure 15 - Effects of Filter Thruput on Filter Charging - Hose Carts at Dover Air Force Base

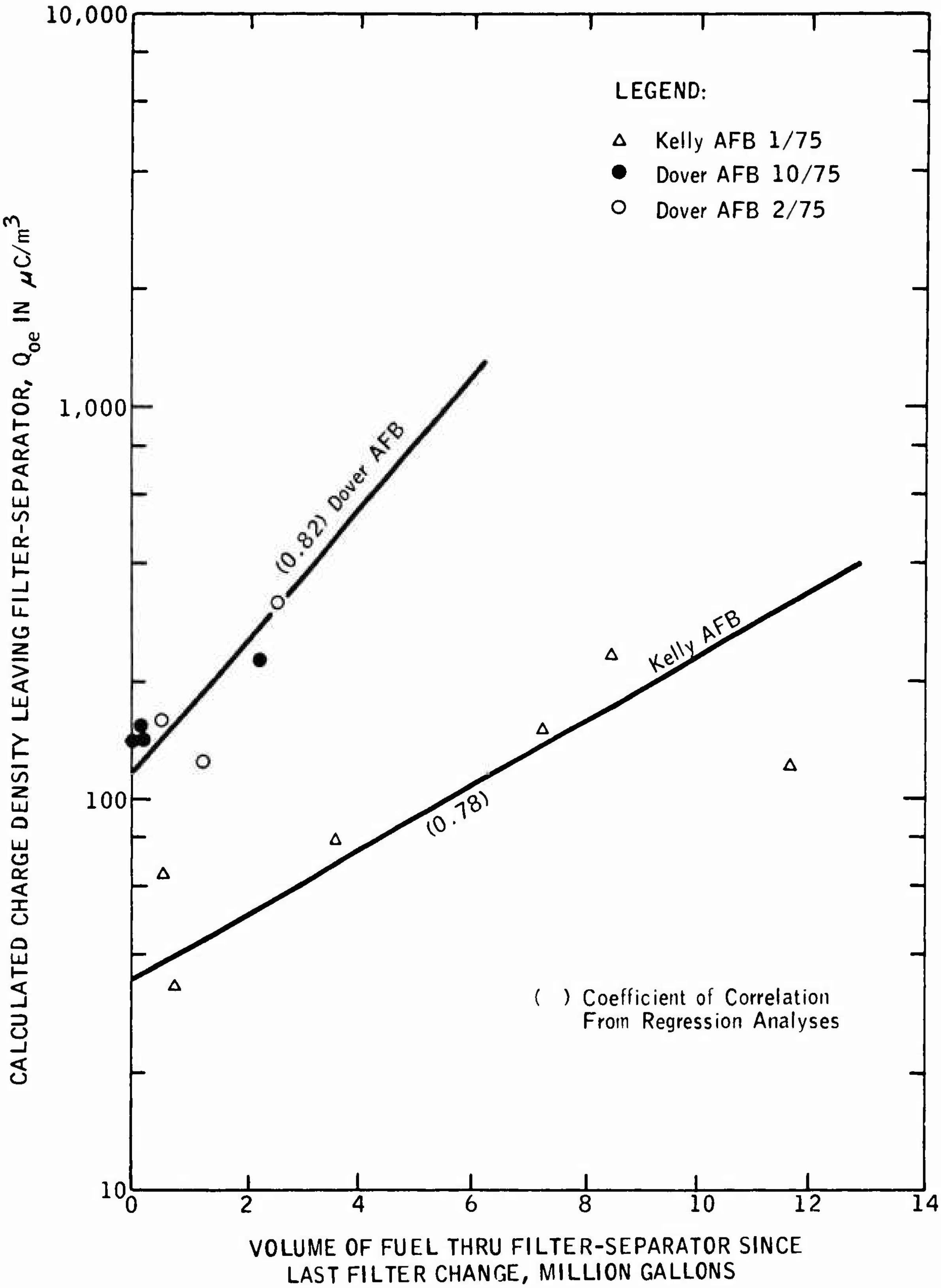

Figure 16 - Effects of Filter Thruput on Filter Charging-Refuelers

testing periods, charging was lowest on the C5A Hydrant and highest on the North Hydrant. The relative ranking of the three hydrant systems can be obtained by comparing the charge level at one filter thruput level (about 4 million (M) gallons).

TABLE XV. DIFFERENCES IN CHARGING LEVELS BETWEEN HYDRANT SYSTEMS (HOSE CART TESTING)

Hydrant System	Estimated Filter Charge (μC/m³) @ 4M Gal Thruput	Ratio of Charge
• Warm Weather Testing (October 1974)		
C5A	97	Ref = 1.0
MAC	133	1.4
North	176	1.8
• Cold Weather Tesing (February 1975)		
C5A	270	Ref = 1.0
MAC	570	2.1
North	1200	4.4

The reason for these differences is not apparent at this time. The C5A is the newest modified Pritchard system and is made of aluminum. The fact that the older steel systems generate up to four times higher charge than the C5A (Table XV) probably reflects the corrosion contaminants which are contributed to the fuel by the older systems.

(d) Effect of Filter Element Type

While all DOD coalescer elements are similar, two types of separator elements exist in Air Force use. They are the Teflon® -coated screen separator (so-called permanent type) and the replaceable paper element. The paper element is currently being phased out of use and replaced by the coated screen element. However, one hose cart at Dover Air Force Base still contained the paper type separator elements and was included in the February 1975 testing to compare any possible differences in charging with the Teflon® elements.

On the basis of one test on a cart containing paper separators, the charge issuing from the filter was calculated from the data to be 139 $\mu C/m^3$. At an equivalent volume thruput, as shown in Figure 14, carts containing permanent type elements when tested on the C5 Hydrant System show a filter-separater charge of 70 $\mu C/m^3$ or 50 per cent less charge than the paper elements. While this comparison is made on very limited data, it does agree with the CRC study(Reference 5) results showing that permanent type elements generate charges of 13 to 52 per cent of paper separators.

(e) Effects of Filter-Separator Design

Basic differences exist between filter-separator design on mobile fueling equipment which may affect the level of charge delivered to the aircraft tank. These differences relate to the fuel holdup time or residence time provided by the different filter-separators. MH-2A hose carts have filter-separators which have two distinct filter element stages - coalescer elements mounted in the first stage and separator individually in the second stage as shown in Figure 4. This type of design is common to non-military or commercial use. On the other hand, MH-2B hose carts and refuelers have a combined or common mounting for the coalescer and separator elements where the separator element shrouds the coalescer element as shown in Figures 3 and 5. Therefore, a major amount of the volume inside the filter-separator vessel on the MH-2B cart is relaxation volume after the separator. In the case of the MH-2A carts, the major portion of the filter-separator internal volume is between coalescer and separator elements and therefore fuel that is relaxed between stages is re-charged again by the separator elements just before exiting to the hoses.

The effect of these design differences on fuel charge residence time is shown in Table XVI.

TABLE XVI. COMPARISON OF FILTER-SEPARATOR DESIGNS AND CHARGE RELAXATION VOLUMES

Vehicle	Filter-Separator Type	Flow Volumes (1) (gal) Inside Filter-Separator After Separator Element		Residence Time (sec) Provided @ 300 gpm After Separator
		Between Coalescer and Separator	After Separator	
MH-2A Cart	2 Stage	91	22	4.4
MH-2B Cart	Shrouded	19	85	17.0
R-9 Refueler	Shrouded	20	64	12.8

(1) Volumes calculated from dimensions given in Figures 3 through 5.

To illustrate the great importance of filter-separator design, it is useful to calculate the output charge density for the two types of hose carts, assuming the same filter charge. If the data for Run-51 at Dover Air Force Base in February 1975 are used as a basis, the increase in residence time of 12.6 seconds for the MH-2B cart would reduce the output charge density from 29 to 3.6 $\mu C/m^3$.

It is not to be construed that the MH-2A cart design is unsafe since this design is used safely in millions of fuelings per year in commercial operations. Rather, it is the intent here to point out that the DOD design of MH-2B carts and refueler filter-separator have an inherent safety factor by having a built-in larger charge relaxation chamber. It should be noted that the fueling hoses which deliver fuel to the aircraft manifold can provide additional relaxation volume. For example, a 50-foot length of 3-inch hose holds 18 gallons; with two such hoses in use the additional residence time at 50 per cent of rated flow is over 7 seconds.

(3) Field Strength Measurements

Measurements of field strength were attempted at both Kelly Air Force Base and Dover Air Force Base. In both tests no measurable surface voltage was observed while the refueler was filling at maximum flow rate. Immediately after automatic shut-off when the tank was full a small movement in the recorder tracing was noted. In the case of Kelly Air Force Base this movement was calculated to be approximately 1 kv/m and had a duration of approximately 8 seconds. At Dover Air Force Base, upon fill shut-off, field strength increased from 0 to a calculated peak of 27.0 kv/m at 7 seconds after fill shut-off and decreased to zero 13 seconds after shut-off. This behavior has been observed by others who have made field strength tests by flowing charged fuel into an instrumented fueler vehicle. It has been attributed to internal mixing in the tank which brings a body of charged fuel to the surface after flow stops.

In both the Kelly and Dover tests, the level of field strength was generally far too low for any meaningful interpretation. Because of the low readings at maximum flow rate, no attempt was made to measure field strength at lower flow rates on other vehicles.

(4) SCR Evaluation

(a) SCR Efficiency Measurements

Tests were conducted on an SCR installed in No. 1592 Fillstand at Kelly Air Force Base to determine its operating efficiency: (1) after 7 months of operation since it was last cleaned in June 1974, (2) after cleaning, and (3) compared to a relaxation chamber of equal outer dimensions (8-inch diameter X 36-inch-long pipe). The data obtained are shown in Table XVII. Fuel with a conductivity of 18.6 pS/m was pumped at 500 gpm to fill a R-9 receiver. In all cases, low charge levels leaving the fillstand filter-separator and entering the SCR were due to the combination of high fuel conductivity and considerable relaxation volume in the filter-separator. The calculated SCR efficiency values are not significant because of the low level of input charge.

TABLE XVII. STATIC CHARGE REDUCER (SCR) EFFICIENCY MEASUREMENTS KELLY AIR FORCE BASE: JANUARY 1975

Test Duration: Time to fill refueler truck (∿4500 gals)
Flow Rate: ∿400 gpm
Fuel Conductivity: 18.6 pS/m @ 64°F

Approximate Test Time, (Minutes)	Charge Density Into SCR ($\mu C/m^3$)	Charge Density Out of SCR ($\mu C/m^3$)	Per Cent Efficiency
SCR after 7 months service (cleaned 6-74)			
2.5	-4.5	-2.0	56
10 (end)	-6.0	-4.5	25
SCR immediately after cleaning			
2.5	-2.0	-3.0	-50
10 (end)	-4.0	-6.0	-50
Replacing SCR with 8-inch ID X 36-inch-long Spool Piece			
2.5	-8.0	-4.0	50
10 (end)	-8.0	-4.0	50

(b) Analyses of Deposits Taken from SCR

Before the SCR was cleaned with solvent (MEK) and brushes, deposits were wiped from the inner white polypropylene surface. These deposits produced a faint brown stain on the filter paper used to wipe the surface. No visible deposits were evident on the white plastic surface before wiping. The deposits collected on the ashless laboratory filter paper were submitted for elemental analysis by qualitative emission spectroscopy. The results showed the ash of deposits to contain the estimated amounts of the following metals:

TABLE XVIII. ANALYSES OF DEPOSITS TAKEN FROM SCR

Amounts	Metal
Major (>10 per cent):	Zinc, Nickel
Minor (1 to 10 per cent):	Titanium
Trace (<1 per cent):	Phosphorus, Vanadium, Copper

Further analyses by infrared spectrophotometers or by atomic absorption spectrometer were also attempted but difficulty was experienced in separating sufficient quantities of the deposits from the filter paper. Additional wipings of SCR deposits were obtained in May 1975 from Kelly Air Force Base, but again insufficient sample was obtained for analyses.

2. TESTING OF DOD HOSE CARTS AT EXXON FULL-SCALE FACILITY

a. Purposes of the Tests

Analyses of the data obtained from the tests conducted at two air bases revealed that in a number of respects the fuels and the filter-separators available for test did not represent the critical condition extremes that may currently exist at U.S. air bases and which may cause a significant electrostatic hazard to exist. Some of these deficiencies were:

- High fuel conductivity in three of four test periods. A low conductivity JP-4 would be apt to cause higher static charge to be delivered.
- No control over fuel additives. It was known that some corrosion inhibitors affect fuel conductivity and charging tendency adversely.
- Limited flow rates through filter-separators. Since static charge generally increased with flow rate, the inability to test in the field beyond about 50 per cent of rated flow made test measurements and interpretation difficult.
- Limited availability of critical filter-separators. It was known that two-stage design filter-separator and paper separator elements would be theoretically more critical in static generation but such equipment was not available for comparison testing in the air bases.

It was felt that most of these deficiencies in test parameter could be overcome if full-scale testing were conducted in the Exxon Research Full-Scale Facility using borrowed military hose carts of the critical types. This facility was capable of pumping JP-4 at rated flows and controlling the quality of this JP-4 in terms of conductivity and additive type. Accordingly, to supplement the field data, a program extension was proposed and granted to evaluate the critical conditions.

b. Test Equipment and Instrumentation

The Exxon Full-Scale Test Facility into which the two hose carts were installed is shown schematically in Figure 17. The portions of this facility used in this study included a 22,000-gallon tank containing approximately 20,000 gallons of JP-4, three 600 gpm centrifugal pumps, a turbine flow meter, pressure and temperature sensors, a shell-in-tube heat exchanger to control fuel temperature to ∿25°C, a commercial 1100 gpm horizontal filter-separator (CHFS) and two A. O. Smith Charge Density Meters (CD-1 and CD-2).

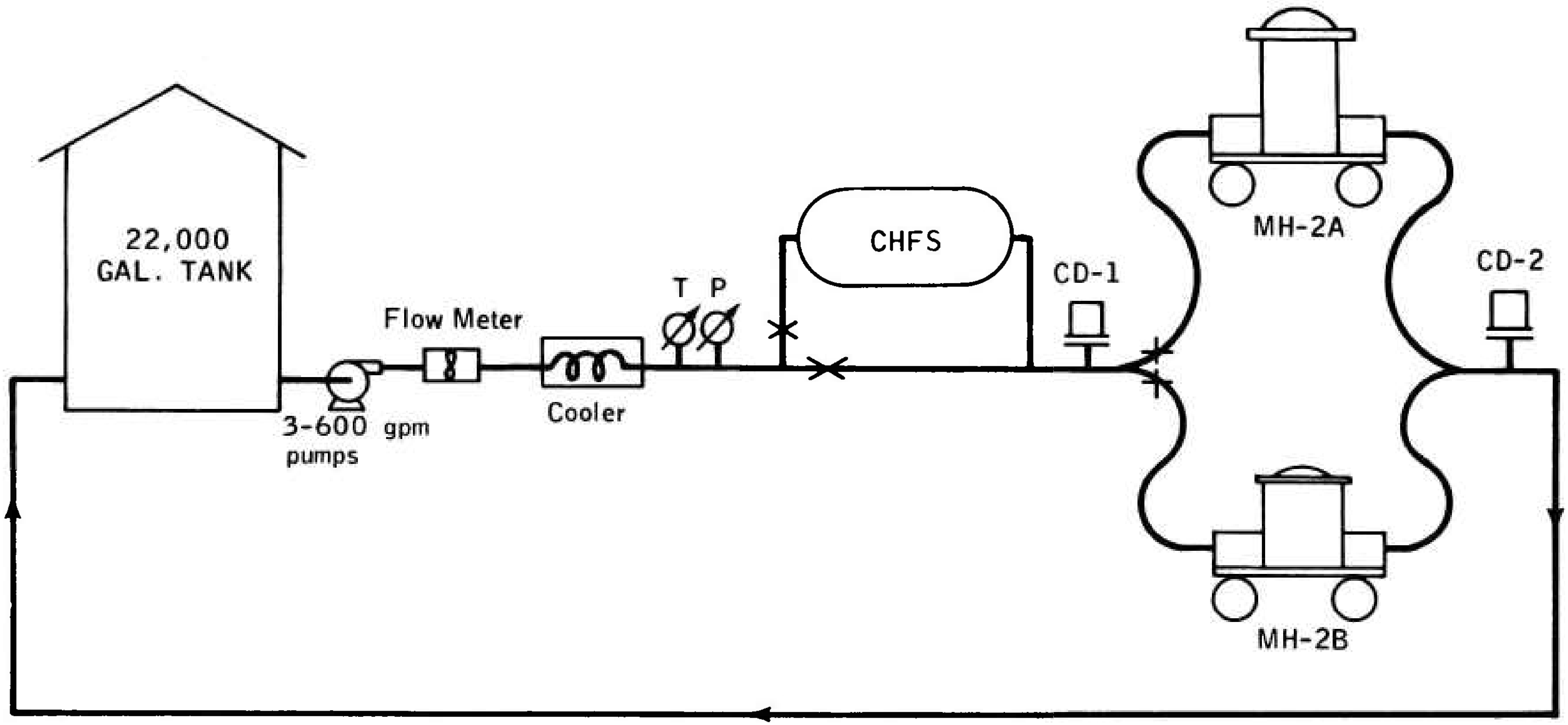

Figure 17 - Schematic of DOD Hose Cart Testing in Exxon Research Full-Scale Rig

Two Air Force hose carts (62W00191 and 74W00128) were obtained through a loan arrangement from McGuire Air Force Base, New Jersey. They were a type MH-2A (Model 2130) and an MH-2B (1973 Model)/DOD Trailer Mounted Aircraft Fuel Servicing Unit. To adapt the servicers to the Exxon system, the aircraft refueling nozzle and hydrant coupler valve were removed and replaced with manual valves and quick-coupling adaptors. Prior to testing, adjustments were made to the cart pressure control valves to permit flow rates up to 700 gpm (116.7 per cent of rated capacity).

Recorder tracings were obtained on charge density measurements downstream of the CHFS and upstream and downstream of the hose carts. During each run, readings of flow rate and fuel temperature were manually recorded on the tracing. Daily determinations of electrical conductivity of the fuel were also made and recorded.

c. Test Program and Procedure

(1) Corrosion Inhibitor Testing

Four different fuel-additive situations were evaluated. Two corrosion inhibitors conforming to MIL-L-25017 were employed to develop the test fuels described in Table XIX.

TABLE XIX. FUELS UTILIZED IN DOD HOSE CART TESTING AT EXXON RESEARCH CENTER

Fuel Additive Treat	Additive Concentration ptb (1)	Level
JP-4 + Hitec E534 + 0.1% FSII	4.5	Minimum effective
JP-4 Clay Treated	0	Represents depleted additive case
JP-4 +DCI-4A + 0.1% FSII	2.0	Relative effective (represents partially depleted additive)
JP-4 + DCI-4A + 0.1% FSII	3.0	Minimum effective

(1) ptb - pounds per thousand barrels

DCI-4A is a product of E. I. duPont de Nemours Co., Inc., while Hitec E-534 is supplied by Edwin Cooper, Inc. FSII is a Fuel System Icing Inhibitor as specified by MIL-I-27686. The Hitec E-534 was supplied with the fuel and the other corrosion inhibitor was selected from previous laboratory experience for its differing effects on charging and conductivity (Table XI).

Each fuel/additive blend was pumped through each of the two hose carts and commercial filter-separators at four different flow rates ranging from 300 to 700 pgm representing 50 to 117 per cent of hose cart flow capacity. For each run, fuel temperature was controlled as close as possible to 25°C. A minimum of three replicate runs were conducted on each additive fuel blend.

(2) Tests on DOD Hose Carts

Two different type DOD hose carts MH-2A and MH-2B were obtained by loan agreement from McGuire Air Force Base. Tests were conducted on these hose carts to assess the effects of differences in filter-separator design on downstream static charge levels. The MH-2A cart has two distinct and separate filter element stages (filter/coalescer first stage and separator element in second stage), while the MH-2B cart filter-separator is designed with a filter/coalescer element shrouded by the separator element. For comparison, tests were also conducted on a typical commercial filter-separator unit which has a two-stage element configuration similar to the MH-2A hose cart.

(3) Filter Age

Results from the field survey had indicated that filter elements with greater fuel thruputs showed higher charging tendencies. To gain further information on this finding, new filter/coalescer elements were obtained from the Air Force and installed in the MH-2B cart. Data were then obtained on the effect of aging of new elements on fuel charge levels.

(4) Testing Scope and Treatment of Data

A total of 47 runs were conducted on the DOD hose carts and the CHFS. Each run consisted of measuring charge density as a function of flow rate which was varied in increments from 300 to 700 gpm (these rates represent 50 to 117 per cent of rated capacity for the 600 gpm DOD hose carts and 27 to 64 per cent of rated capacity of the 1100 gpm CHFS). A summary of averaged data obtained is presented in Table XX for each hose cart and additive situation tested. Measured values are given in the columns identified as Q_t. From this data, charges in the fuel at the separator element were calculated, based on fuel effective conductivities and fuel residence times in the lines between filter-separators and charge density meters. (Fuel residence times were obtained from calculated fuel volumes between the separator element and downstream charge density meter. Data for residence volumes are presented in Table XXI for both the ERE tests and field survey tests.) These calculated charges are given in Table XX under the column identified as Q_o.

Charge density represents the concentration of static charge in a unit volume of fuel. Measurement of charge density over a wide range of equipment flow rates tends to conceal the actual amount of electrical energy flowing in the fuel. If charge density (in $\mu C/m^3$) is multiplied by the flow rate (in m^3/s) the resulting product is the current (in μA) flowing in the fuel (one ampere equals one coulomb per second) and provides a more realistic assessment of the degree of hazard from fuel being delivered to a tank.

TABLE XX. TESTING OF DOD HOSE CARTS AT EXXON RESEARCH CENTER - SUMMARY OF MEASURED AND CALCULATED CHARGE DENSITIES

Fuel: JP-4 + 0.1% FSII + Corrosion Inhibitor		Hitec E-534		None		DCI-4A					
Concentration: Lbs/1000 Bbls		4.5		Clay Treated JP-4		2.0 Before Filter Chg[3]		2.0 After Filter Chg		3.0 After Filter Chg	
		Q_t[1]	Q_c[1]	Q_t	Q_c	Q_t	Q_c	Q_t	Q_c	Q_t	Q_c
		K_r[2] = 7.0		K_r = 0.3		K_r = 1.6		K_r = 1.6		K_r = 2.7	
HOSE CART		K_e = 3.0		K_e = 1.05		K_e = 1.2		K_e = 1.2		K_e = 1.7	
MH-2A Rated @ 600 gpm	Flow Rate gpm										
	600	+86.0	+254	+1.7	+2.5	-9.1	-12.5	-30.7	-47.0	-22.4	-41.3
	450	+59.6	+251	+2.1	+3.5	-7.2	-12.8	-28.2	-50.1	-21.8	-49.2
	300	+23.0	+242	+2.7	+5.7	-5.4	-12.8	-19.6	-46.4	-20.0	-67.9
	600	+86.3	+254	+1.6	+2.3	-8.1	-12.5	-31.4	-48.3	-22.1	-40.[illegible]
	700	+99.1	+249	+0.7	+1.0	-9.1	-11.7	-32.8	-47.5	-22.2	-37.5
MH-2B (1973 Model) Rated @ 600 gpm											
	600	+45.7	+205	+1.9	+3.2	-8.9	-16.2	-21.7	-21.3	-10.8	-25.3
	450	+29.0	+214	+1.9	+3.8	-9.8	-19.6	-9.7	-21.6	-9.7	-30.1
	300	+11.6	+233	+2.0	+5.7	-7.9	-26.2	-5.7	-8.9	-7.[illegible]	-41.1
	600	+42.4	+190	+1.8	+3.0	-6.8	-16.0	-10.8	-19.7	-10.9	-25.5
	700	+54.4	+197	+0.7	+1.1	-8.5	-14.2	-11.7	-19.6	-11.0	-22.8
COMMERCIAL F-5 (CHFS)											
	600	+95.6	+162	-8.6	-10.3	-	-	-49.1	-60.6	-54.3	-73.1
	450	+71.1	+143	-8.7	-11.1	-	-	-38.5	-50.9	-45.7	-67.9
	300	+35.7	+102	-6.7	-9.7	-	-	-17.9	-27.3	-31.7	-57.5
	600	+96.6	+163	-7.5	-9.0	-	-	-47.8	-59.0	-55.9	-75.3
	700	+109.6	+173	-7.7	-9.0	-	-	-56.9	-68.1	-60.3	-77.9

(1) Q_t = Measured charge at charge density meter downstream of filter $\mu C/m^3$.
Q_c = Calculated charge on fuel $\mu C/m^3$ as fuel leaves separator element based on calculated residence volumes and effective conductivity, K_e.

(2) K_r Rest conductivity in pS/m as measured by ASTM D3114-72, K_e = Effective Conductivity in pS/m as determined from Figure 14.

(3) Where blanks appear, data were not obtained.

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TABLE XXI. CHARGE RELAXATION VOLUMES BETWEEN SEPARATOR ELEMENTS AND CHARGE DENSITY METER

Vehicle		Estimated Relaxation Volume (Gallons)
• Air Base Tests		
Hose Cart	MH-2A	45.5
	MH-2B 120 foot hose	71.0
	MH-2B (1971 model)	108.5
	MH-2B (1971 model) 120 foot hose	134.0
Refueler R-9		87.5
• ERE Tests		
Hose Cart	MH-2A	64.0
	MH-2B (1973 model)	88.3
Commercial Filter-Separator (CHFS)		31.0

Charge density data obtained by varying flow rate for each of the additive fuels is presented in Figures 18 through 21 along with charge flow data. Plots of charge density versus flow rate show that with increasing flow rate, charge density begins to level off - which is the usual behavior of most filters. However, the plots of charge flow versus flow rate show that when the flow rate increases from 300 to 600 gpm the increase of current flow is exponential (i.e., doubling the flow increases the current approximately four-fold).

Measured charge density values observed for MH-2A and MH-2B hose carts at Dover Air Force Base during summer and winter testing were averaged for all runs at 200 and 300 gpm flow rates. These averaged values were then used to obtain charge flow values for the respective carts. Charge density and charge flow data or these hose carts are shown in Figures 18 and 21 which represent fuels treated with the full corrosion inhibitor additive level. In both cases the field cart data fall within the charge density/charge flow obtained on the ERE test results at the respective flow rate level.

(5) Repeatability

Measured quantities of charge density at a flow rate of 600 gpm (100 per cent of rated capacity for the DOD hose carts) were tested for their statistical significance. The measured charge density data were found to have a pooled standard deviation of 2.7 $\mu C/m^3$.

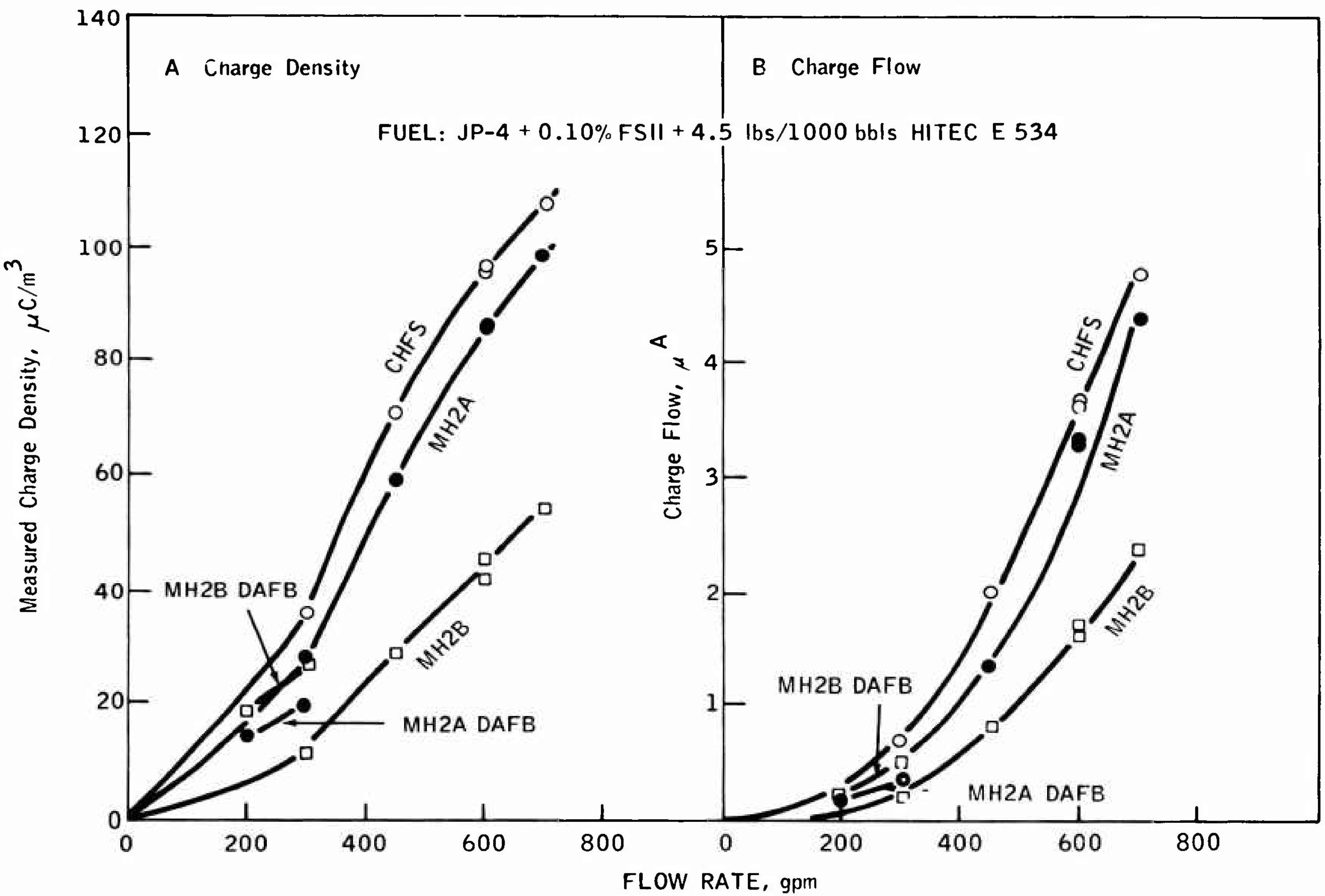


Figure 18 - Charge Density versus Charge Flow - JP-4 + HITEC E 534

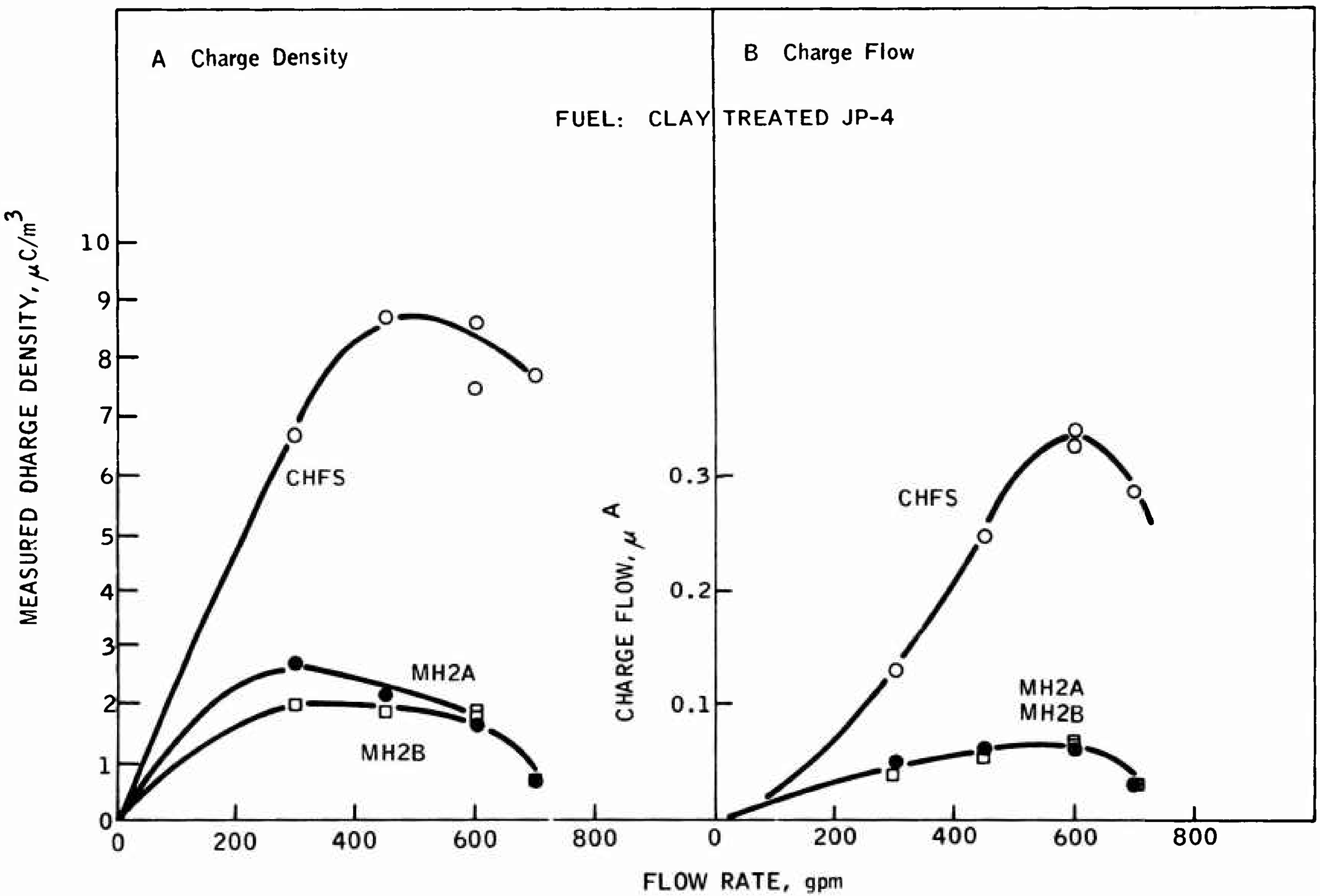


Figure 19 - Charge Density versus Charge Flow - JP-4 Without Additive

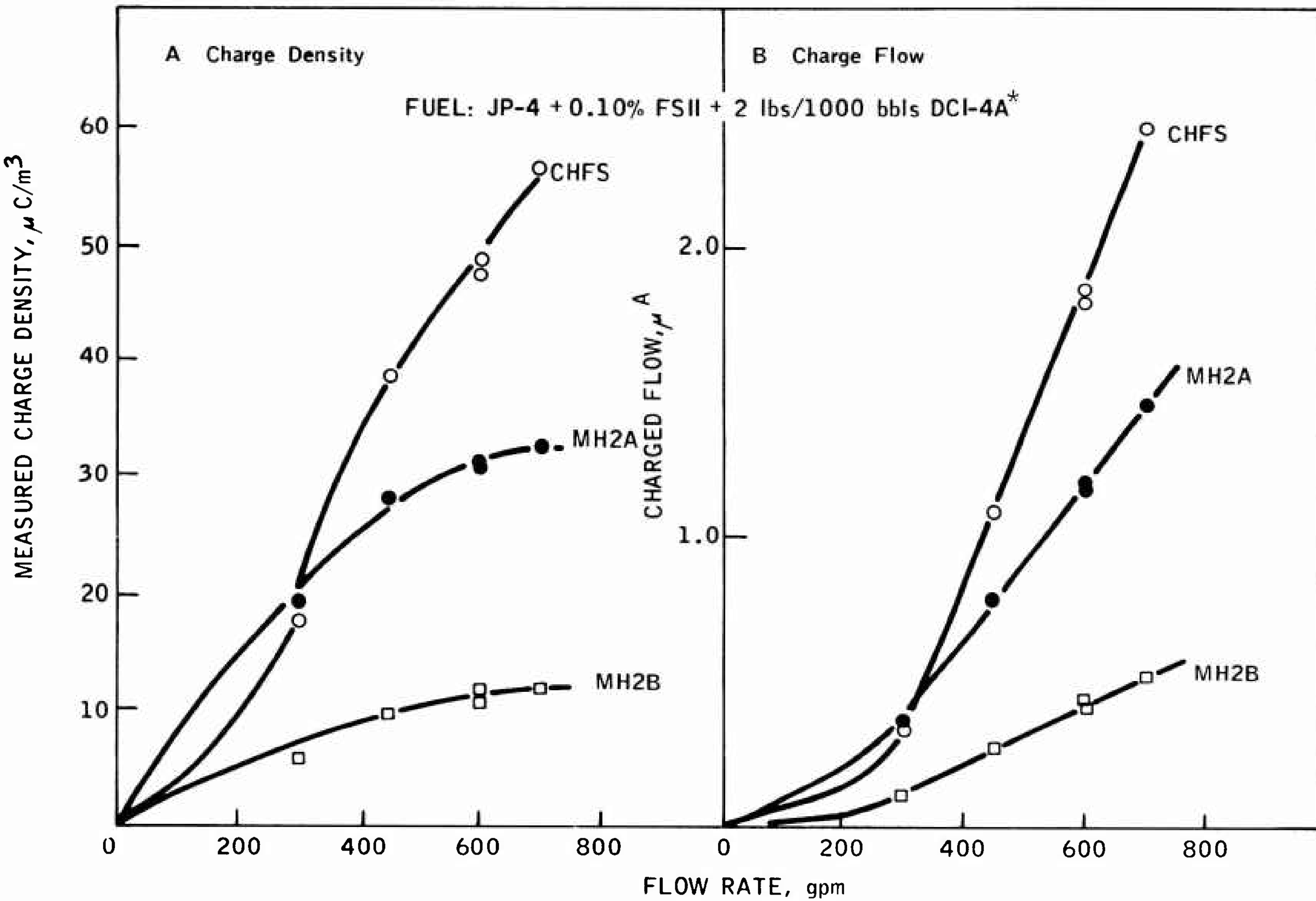


Figure 20 - Charge Density versus Charge Flow - JP-4 + DCI-4A at 2-ptb

*data represents charges obtained after filter change

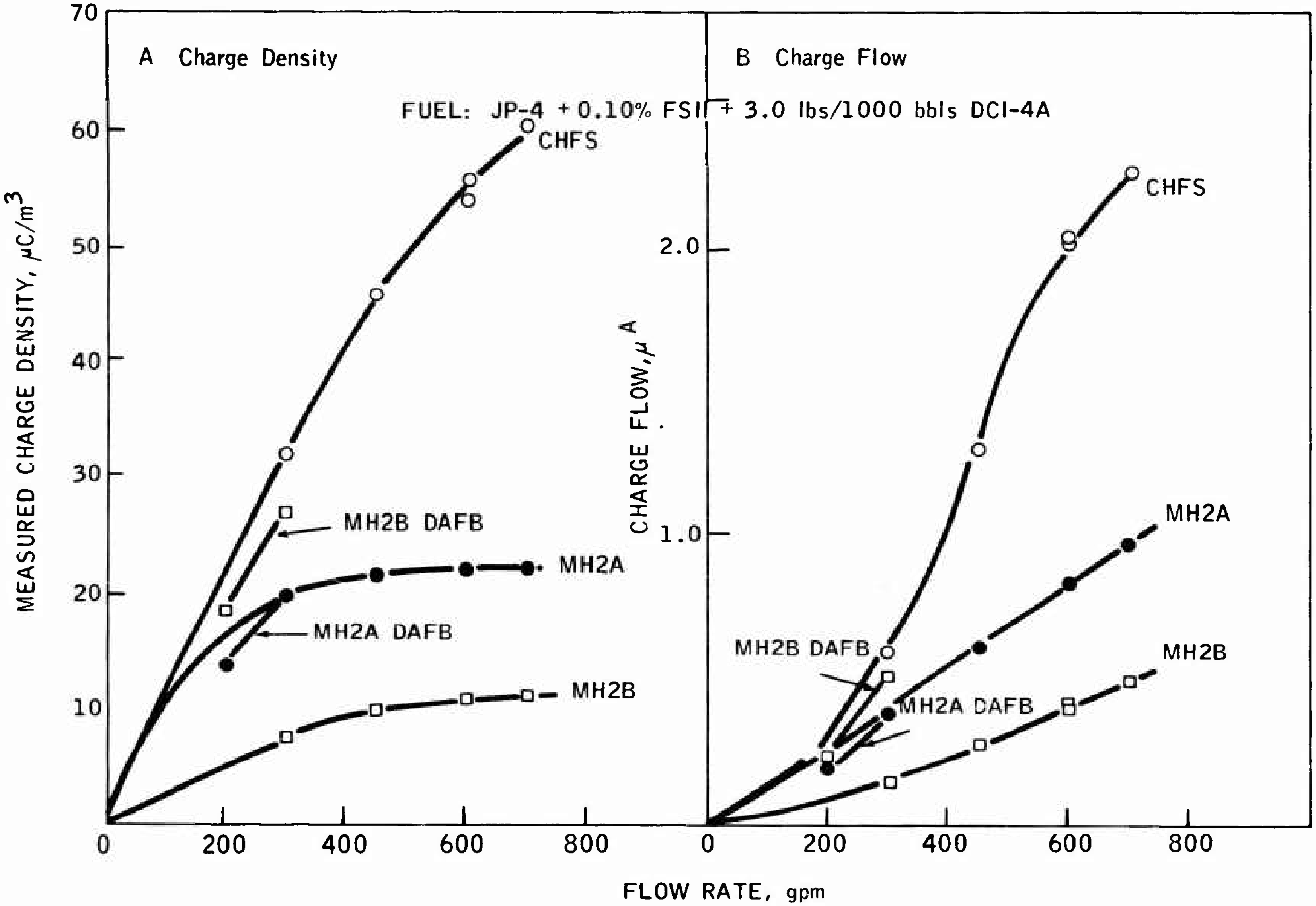


Figure 21 - Charge Density versus Charge Flow - JP-4 + DCI-4A at 3-ptb

d. Discussion of Results

(1) Charge Generation of DOD Hose Carts

(a) Effect of Flow Rate on Hose Cart Charge Flow Level

The data obtained on charge flow for the MH-2A, MH-2B and CHFS are discussed in para. C(3) presented in Figures 18 through 21. Included for comparison in Figures 18 and 21 are averaged data taken from the field survey. It will be noted that doubling the flow rate from 300 to 600 gpm (rated flow for the carts) increases the charge flow exponentially approximately four-fold. If flow rate could have been increased on the hose carts during the field survey portion of the program, similar observed four-fold increases in charge flow would be predicted.

(2) Fuel Factors

(a) Effect of Corrosion Inhibitor on Fuel Conductivity

One of the more significant findings of the field survey was the wide variation found in fuel conductivity between air bases and between testing periods on the same air base. It was theorized at the time that these differences were due to the use of different corrosion inhibitor additives by the fuel suppliers. The possibility that different corrosion inhibitors affect fuel conductivity and charging tendency was demonstrated in laboratory blends with Jet A (Table XI). To further test these possible effects two corrosion inhibitors (Hitec E-534 and DCI-4A) were tested at their minimum effective concentration in JP-4 in this program on DOD hose carts. In addition, two other JP-4 additive situations, representing a completely depleted additive (clay treated fuel) and a partially depleted additive level (2.0 lbs/1000 bbl DCI-4A), were evaluated. These depleted levels were included in the testing to represent practical situation where additives have been depleted by such normal processes as absorption on pipe walls, etc. The conductivity results obtained on these fuels are shown below in Table XXII.

TABLE XXII. EFFECT OF CORROSION INHIBITORS ON FUEL CONDUCTIVITY - RIG DATA

Fuel	Corrosion Inhibitor	Concentration (lbs/1000 bbls)	Conductivity (pS/m) @ 25°C Rest	Conductivity (pS/m) @ 25°C Effective(1)
JP-4 + 0.1% FSII	Hitec E-534	4.5	7.0	3.0
JP-4 (Clay treated)	0	0	0.3	1.05
JP-4 + 0.1% FSII	DCI-4A	2.0	1.6	1.2
JP-4 + 0.1% FSII	DCI-4A	3.0	2.7	1.7

(1) Calculated from relationship shown in Figure 13.

The preceding data confirm that corrosion inhibitors do have different effects on fuel conductivity which are in general agreement with earlier effects shown in data on Jet A fuel (Table XI). However, the additives selected for this program (Hitec E-534 and DCI-4A) did not show the large spread of fuel conductivities encountered in the field survey (2.3 to 31.3 pS/m).

(b) Effect of Corrosion Inhibitors on Fuel Charging Tendency

Previous laboratory data obtained on Jet A fuels had shown that, in addition to conductivity effects, corrosion inhibitors also affected fuel charging tendencies. Similar findings using the laboratory Mini-Static Test (MST) are shown for JP-4 fuels and the four additive situations employed in this program. The results are shown in Table XXIII.

TABLE XXIII. EFFECT OF CORROSION INHIBITORS ON JP-4 CHARGING TENDENCIES - RIG DATA

Corrosion Inhibitor	Concentration (lbs/100 bbls)	Charging Tendency By MST[(2)] ($\mu C/m^3$)	Calculated[(3)] Static Charge After 4 seconds Relaxation ($\mu C/m^3$)
Hitec E-534[(1)]	4.5	1900	965
0 (Clay Treated)	0	490	386
DCI-4A[(1)]	2.0	1215	926
DCI-4A[(1)]	3.0	860	586

(1) Plus 0.1 per cent FSII
(2) Laboratory Mini-Static Test (MST)
(3) Calculated on the basis of effective conductivity as shown in Table XXI. Four-second relaxation time represents the fuel residence time in the filter-separator vessels (downstream of the separator element) and 50-foot hose of an MH-2A hose cart flowing at 600 gpm (100 per cent of capacity).

The above data show that these corrosion inhibitors clearly have pro-static effects on fuel charging tendencies with some additives having greater pro-static effects than others. This is evident when the charging tendency of clay treated fuel is compared with the additive fuels. This also agrees with the earlier findings of additive effects with Jet A fuel (Table XI).

The above data also indicate that relative additive treat levels may also affect the relative charging tendency and that maximum charging may occur at low or intermediate additive concentrations after the additives have been partially depleted by adsorption on tank or pipe surfaces. These charging tendencies are particularly significant when considered in conjunction with the additive effects on conductivity. This combined effect is demonstrated in the above table under "Calculated Static Charge After 4 Seconds Relaxation" which represents the relative charge delivered into the aircraft. Comparing the different additive situations, it can be seen that these charge levels differ by a factor of as much as 1.6 between additives and 2.5 between the additive and non-additive situations.

(3) Charge Generation of DOD Hose Carts

(a) Effects of Filter-Separator Design on Effluent Charge Levels

During the field survey portion of this program, basic differences were noted in the filter-separator design on mobile Air Force fueling equipment [paragraph 1. d.(2)(c)]. These differences in filter-separator design related to the fuel holdup time or charge relaxation time and therefore the charge level delivered to the aircraft fuel tank. The greatest differences in relaxation times were noted between the MH-2A and MH-2B hose carts. For this reason, both type hose carts were included in this study of corrosion inhibitor effects.

The MH-2B cart loaned from McGuire Air Force Base was a 1973 model. The MH-2B cart used in the field survey was a 1971 model. The basic difference between these two carts is the overall size of the filter-separator. The 1973 model is smaller and has a more compact profile. This smaller size (Figure 22) necessitates a more compact arrangement of elements per unit inside volume. This causes a sizable reduction in residence or charge relaxation volume.

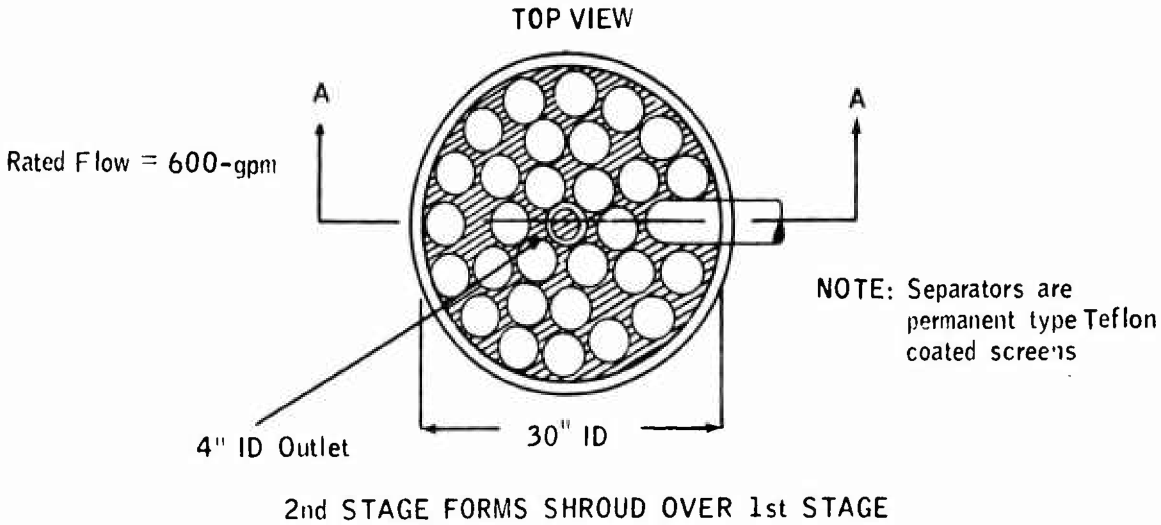
The relative flow volumes and relaxation times of the DOD filter-separator and a commercial horizontal filter-separator (CHFS) used in this program are compared in Table XXIV.

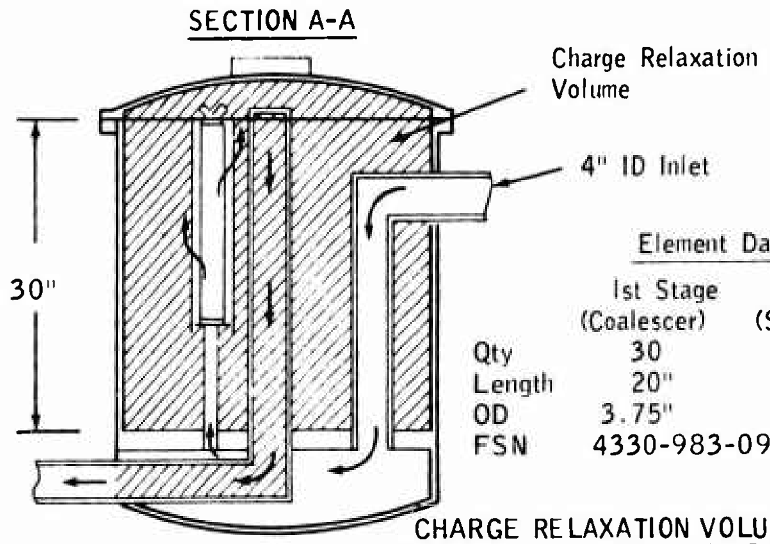
TABLE XXIV. COMPARISON OF FILTER-SEPARATOR DESIGN AND CHARGE RELAXATION VOLUMES

Vehicle	F-S Type	Flow Volumes, Gal. Inside - F-S(1): Between Coalescer and Separator	Flow Volumes, Gal. Inside - F-S(1): After Separator	Relaxation Time (sec) Provided @ 50% Flow Separator Element: (Gpm)	Relaxation Time (sec) Provided @ 50% Flow Separator Element: (Seconds)
MH-2A Cart	2 Stage	91	22	300	4.4
MH-2B Cart					
1971 Model	Shrouded	19	85	300	17.0
1973 Model	Shrouded	19	47	300	9.4
R-9 Refueler	Shrouded	20	64	300	12.8
CHFS	2 Stage	∿190	23	550	1.25

(1) Volumes calculated from dimensions given in Figures 3 through 5 and 22.

While the 1973 model MH-2B has only half the relaxation volume of the 1971 MH-2B, it still has over twice as much relaxation volume as the MH-2A cart. On the other hand, the CHFS has only 1.25 seconds relaxation time at 50 per cent flow capacity compared to the MH-2A hose with 4.4 seconds relaxation. On this basis, the MH-2A design must be considered safe while the shrouded element design provided in the MH-2B cart and R-9 refuelers provide a further inherent safety factor by having a larger built-in charge relaxation chamber.





Element Data

	1st Stage (Coalescer)	2nd Stage (Separator)
Qty	30	30
Length	20"	22"
OD	3.75"	4.56"
FSN	4330-983-0998	

NOTE: A FRAM FILTER-SEPARATOR IS USED ON THIS CART

CHARGE RELAXATION VOLUMES

STAGE NO.	VOLUMES, GAL
PRE 1	39.0
BETWEEN 1&2	19.4
AFTER 2	47.0
TOTAL	105.4
ALLOW FOR ELEMENT AND HARDWARE VOLUMES	11.2 GAL

Figure 22 - Filter-Separator Design on MH-2B (1973 model) Hose Cart - McGuire Air Force Base

(b) Effect of Corrosion Inhibitors on Charge

In an effort to compare the true effects of corrosion inhibitors on charging, it was necessary to normalize the data. This was done by (1) using the calculated charges leaving the separator elements, thus eliminating the variable of different residence times between filters and (2) comparing the charge levels at an equal 50 per cent of rated flow to insure an equal fuel velocity per unit area of the filter. For the 600 gpm rated DOD carts, charges were taken at 300 gpm while for the 1100 gpm rated CHFS charges were interpolated at 550 gpm. The normalized data are shown in Table XXV.

TABLE XXV. EFFECT OF CORROSION INHIBITOR ON CHARGING OF SEPARATOR ELEMENTS

Corrosion Inhibitor:	Hitec E-534	None	DCI-4A	
Concentration lbs/1000 bbls:	4.5	0 (Clay Treated)	2	3
DOD Hose Carts	Calculated Charges, $\mu C/m^3$ at Separator Element at 50 per cent of Rated Flow			
MH-2A (paper separator)	+242	+5.7	-46.4	-67.9
MH-2B (Teflon® separator)	+233	+5.7	18.9	-29.1
CHFS (paper separator)	+156	-9.8	-58.0	72.0

From the data in Table XXV it is evident that differences in charging levels exist between corrosion inhibitors, and polarity of the charged fuel appears to be a function of additive (compare Hitec E-534 versus DCI-4A) and filter type, CHFS versus DOD element charging in clay treated fuel).

(c) Effect of Filter Element Type

The MH-2A cart received from McGuire Air Force Base contained paper separator elements while the MH-2B cart contained Teflon® -coated screen separators. An earlier CRC study(Reference 5) had shown that the permanent Teflon® -type separator elements generate charges of 13 to 52 per cent of paper separator element types. (A similar trend was shown in one test at Dover Air Force Base which showed 50 per cent less charging by Teflon® elements than by paper elements (See section 1. d (2)(e)). Even though basic differences exist in filter-separator designs between the MH-2A and MH-2B carts, some estimate can be obtained from the DOD hose carts study of relative charging by Teflon® versus paper separators by calculating ratios for the data shown in Table XXV.

It is impossible to completely normalize the data between cart designs in this case since the charges generated by the coalescer elements are relaxed in different volumes (91 gallons for the MH-2A cart and 19 gallons for the MH-2B cart) before being recharged by the separator elements. In other words, the individual charging contribution of the coalescer elements themselves would be needed to completely normalize the data, particularly in the case of the MH-2B cart where only 4 seconds of residence time exists after the coalescer at 50 per cent rated flow.

TABLE XXVI. ESTIMATE OF DIFFERENCES IN CHARGING BETWEEN TEFLON® AND PAPER SEPARATORS

Ratio of Charge, Teflon® /Paper Separators

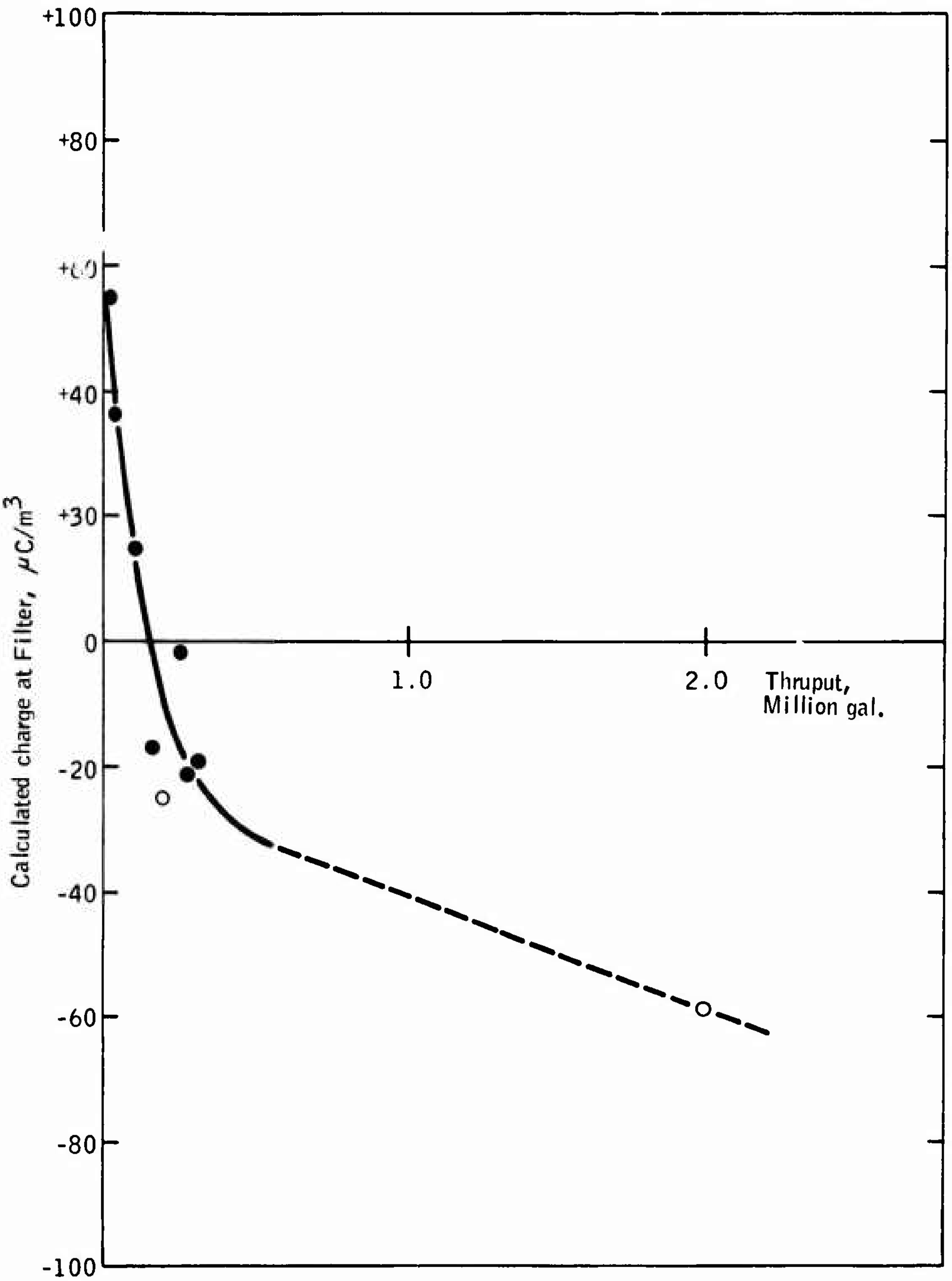
F-S	Separator Type	Concentration lbs/1000 bbls:	Hitec E-534 4.5	(Clay Treated Fuel) 0	DCI-4A 2.0	DCI-4A 3.0
MH-2B / MH-2A	Teflon® / Paper		0.96	1.0	0.41	0.43
MH-2B / CHFS	Teflon® / Paper		1.49	0.58	0.33	0.40
	Average	Teflon® / Paper = 0.7 or 70 per cent				
MH-2A / CHFS	Paper / Paper		1.55	0.58	0.8	0.94
	Average	Paper / Paper = 0.97 or 97 per cent				

The above data show that the MH-2B cart containing Teflon® separators average overall about 70 per cent as much charge as paper separators contained in the CHFS or MH-2A filter-separator. Closer agreement to the CRC rating or the 50 per cent value obtained in the one test at Dover Air Force Base (see section 1. d (2) (e)) might have resulted if the coalescer element charging effect could have been determined. Shown also in the above table is a comparison between paper elements of the MH-2A cart and CHFS which do have similar two-stage filter-separator designs. In this case the overall average agreement is 97 per cent.

(d) Effects of Filter Thruput or Age on Charging

Results obtained in the field survey showed that filter age or fuel thruput had a significant effect on charge levels with higher thruputs causing higher charge levels. To further assess this effect, new elements were installed in the MH-2B cart and charge levels monitored with cumulative thruput. The results are shown in Figure 23. Upon initial start-up with the new elements, the calculated charge issuing from the filter-separator peaked at +55 $\mu C/m^3$. As thruput increased, the charge continually decreased in positive polarity, became more negative, and began to level out around 200,000 gallons thruput. It is theorized that beyond this initial break-in period, charge levels increase similarly to the trends noted in the field survey. After 2.0 million gallons thruput the charge level would be estimated to be approximately -60 $\mu C/m^3$ based on field survey data.

The initial high charge observed in new elements has particular significance in reference to a possible hazardous static discharge. When the old elements are replaced by new elements, the filter-separator vessel is empty of most fuel. When the vessel is reclosed, it may contain a volatile mixture of fuel vapors and air. At this point, the combination



NOTE: Data points shown as open symbols were taken from field survey data. See Figure 15.

Figure 23 - Break-in of New Elements - Filter Charging versus Cumulative Gallonage Thruput

of high charging by new elements and a flammable mixture inside the filter-separator vessel present the potential situation for static discharge and vapor explosion. Such accidents have occurred. It is therefore strongly recommended that during the initial displacement of air by fuel in the filter-separator vessel, pumping be held to an absolute minimum (about <10 per cent of rated flow) to minimize charge generation by the filters and a potential spark discharge between elements and vessel case. If possible, it is a good practice to let the filter-separator fill slowly by gravity.

A second charging phenomenon was observed to occur following the new element installation. Following the change of elements in the MH-2B cart a sizable change occurred in the MH-2A charging level as shown in Table XX. This is also demonstrated in Table XXVII.

TABLE XXVII. EFFECTS OF CHANGE OF MH-2B COALESCER ELEMENTS IN MH-2A AND MH-2B CARTS

DOD Hose Cart	Measured Charge Before Filter Change ($\mu C/m^3$)	Measured Charge After Filter Change ($\mu C/m^3$)
MH-2A	-8.1	-31.0
MH-2B	-8.9	-11.3

NOTE: Data in Table XXVII were obtained at a flow rate of 600 gpm on JP-4 fuel containing 2.0 lbs/1000 bbls DCI-4A and 0.1 per cent FSII.

While this change was unexpected, it is probably explained by the material on the new coalescer elements which was washed into the system. Note from Figure 23 how a new element behaves during the break-in period. It is theorized that the ionic species newly introduced into the recirculatory system by the new MH-2B elements also affected the older MH-2A element's charging characteristics. Data from the commercial filter-separator tends to substantiate this theory even though the before versus after observations are lacking.

(e) Correlation of DOD Hose Cart Charging to MST

From the field survey data, a correlation was found between fuel charging tendency as determined by the Mini-Static Charging Test (MST) and the actual charging observed in the field apparatus [paragraph 1. d. (1)(a)].

A similar correlation was attempted with the data obtained on the MST and DOD hose cart testing conducted at the Exxon Research facilities. While a 1:1 correlation could not be obtained as with the field data, it was found that both the MST and DOD carts show the same relative ranking of charging between the four additive fuels as shown in Figure 24. Calculated charges at the separator element in the respective filter-separator (MH-2A, MH-2B carts and CHFS) are compared with MST charge data normalized with the

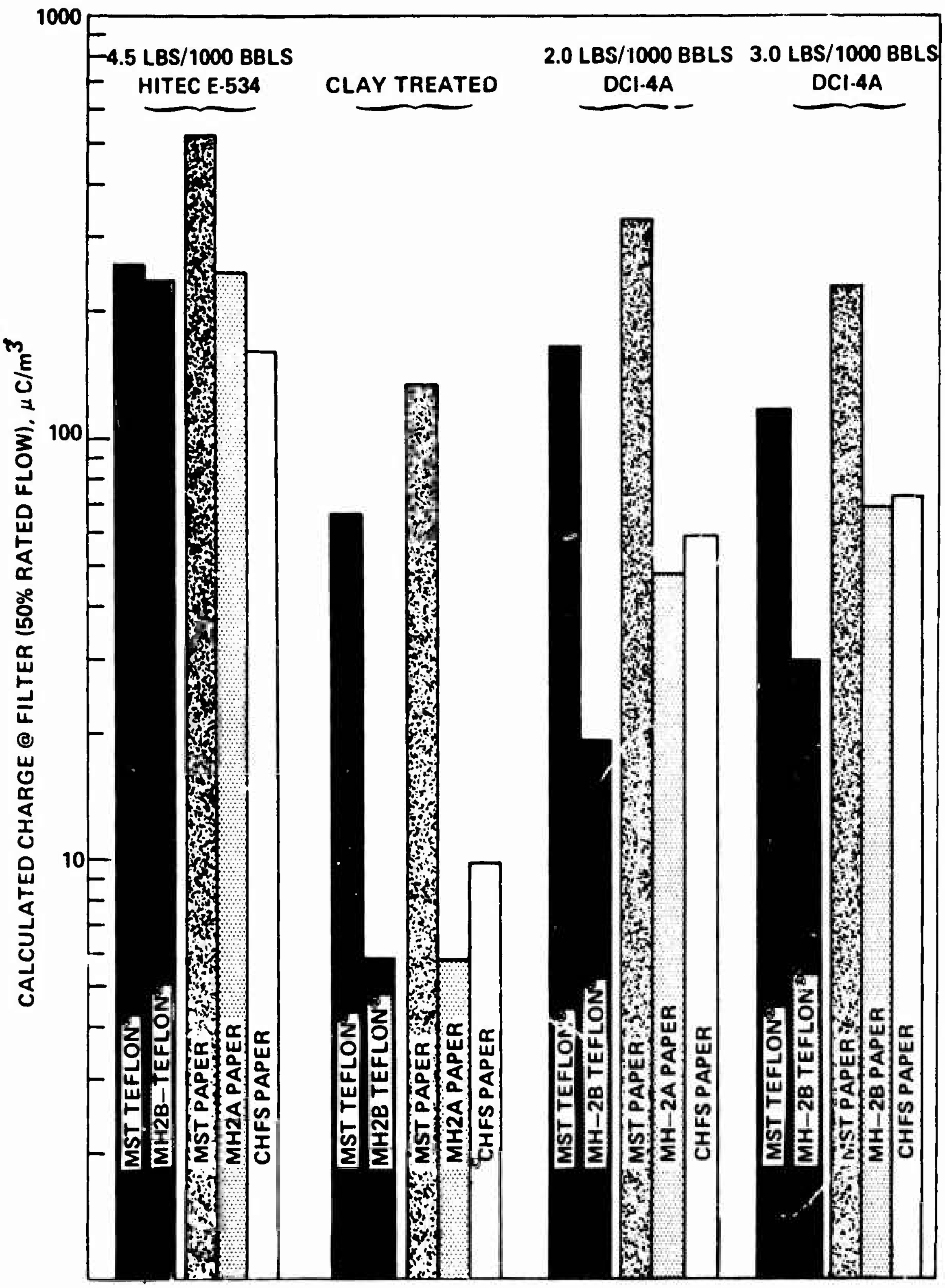


Figure 24 - Comparison of Calculated Filter Charge in Hose Carts and Laboratory Tests (MST)

appropriate CRC factor as described in paragraph 1. d. (1)(a). These factors were determined experimentally(Reference 5) to be 0.27 times the MST value for paper separator charging and 0.135 times the MST value for Teflon® separator charging.

3. SURFACE VOLTAGE TESTS ON CHARGED FUEL RELAXED THROUGH AN SCR

a. Experience with the SCR

The static charge reducer (SCR) was a commercial device for reducing static charge in flowing fuel. It had been developed by Amoco Oil Company and was manufactured and marketed by the A. O. Smith Company, Erie, Pennsylvania until the end of 1972. The SCR consists of a 3-foot-long section of 10-inch-diameter pipe lined with a 2-inch-thick cylinder of polyethylene. Sixteen pointed pins grounded to the pipe pass through the liner and protrude into the fuel stream. When the fuel flowing through the device is charged, an electrostatic field is formed between the fuel and the outer pipe. The liner becomes in effect the dielectric of a capacitor. Since the pins are bonded to the pipe and, therefore, at the same potential as the wall, current can flow between the pins and the fuel, effectively neutralizing the charge on the fuel. After warming up, the SCR can eliminate more than 90 per cent of the charge on a fuel.

The SCR has two limitations: (1) a lag in effectiveness when fuel velocity or inlet charge level is changed, and (2) a loss of efficiency when deposits collect on the liner.

A third potential problem was the finding that fuel relaxed through the SCR to low charge density still resulted in a high surface voltage on fiberglass reinforced plastic (FRP) pipe. Work by Exxon Research and Engineering Company(Reference 4) showed that with the SCR operating at high efficiency and supplying a fuel of -1 to -2 coulombs/m^3, a surface voltage of -23 kv was observed on the wall of the FRP pipe. With a fuel of the same charge density which had not been relaxed with an SCR, only very low surface voltages were observed on the pipe wall. It was noted that the charge density oscillated over a much wider range after having been relaxed in the SCR. No explanation of the high surface voltage was found but the suggestion was made that this observation should be checked. If high voltages were produced on the fuel surface even though the SCR was producing low charge densities, then a static discharge could occur. One task of this effort was to examine this question: Does surface voltage on fuel depend only on charge density and fuel conductivity or does it depend on how the fuel reached that charge density?

b. Description of the Test Facility and Procedures

The test facility has been fully described in a previous report (Reference 4). The description is repeated here for completeness. The test facility used in this work consists of two separate, but integrated, systems. One system, the base facility, contains the storage tanks, clean-up filters, refrigeration equipment, flow meters, and pumps and is used to establish and maintain the test fuel at the desired conductivity levels, temperatures and flow rates required for the test program. The other system is the test section. It consists of a tank truck, loading facilities, instrumentation and means of supplying charged or uncharged fuel to the truck.

Details on the two systems are contained in the following paragraphs.

(1) The Base Facility

A schematic of the base facility is shown in Figure 25. The important features of this facility include two 20,000-gallon storage tanks (one is insulated), three 600-gpm Gilbarco 6 x 4 series centrifugal pumps, and a fuel clean-up system consisting of three different types of filters manufactured by Filters, Incorporated. No. 1 is a 600-gpm vertical Velcon Filter/Separator Model W-2238B; No. 2 is a 600-gpm vertical Clay Filter, Model VC-4854B and No. 3 is an 1800-gpm vertical Filter-Separator Model V-4256. The 600-gpm filter-separator is used in conjunction with the clay filter to pick up any clay that might migrate out of the clay filter.

All piping is stainless steel and all vessels, including the storage tanks, are epoxy-lined to minimize unwanted contamination from corrosion products. Means are available for adding measured amounts of water to the fuel.

The refrigeration system consists of two York Model PS15-45A compressor units with a total capacity of 40 tons. The heat exchanger is U-tube bundle type having stainless steel tubes made by Precision Heat Exchanger Co., Inc., Montvale, New Jersey.

The turbine flow meter is a Model 6X5-5555X, Pottermeter made by Potter Aeronautical Corporation, Union, New Jersey.

(2) The Test Section

A schematic of the test facility for carrying out the tank truck loading experiments is shown in Figure 26. The fuel enters the test facility from the base facility into either a pair of 600-gpm filter-monitors, an 1100-gpm commercial filter-separator, or a bypass. The filters and bypass allow a wide range of charge levels to be put on the fuel which then goes to the A. O. Smith Static Charge Reducer (SCR) or directly to the tank truck. The fuel from the truck is then pumped back to the base facility.

Full-scale truck loading experiments were carried out using a 1963 Heil, 7-compartment, 8000-gallon aluminum semi-trailer. The exterior valve manifold which interconnects the compartments was removed. Additional manholes were installed in each compartment to provide access for instrumentation as well as sampling and purge lines. The 1900-gallon compartment is divided into two bays by a bulkhead which contains a centrally-located, 18-inch diameter, open manhole; the loading hatch is located in the bay nearest to the front end of the trailer. Both compartments contain standard level markers mounted inside the respective loading hatches.

The truck is oval in cross section with a maximum internal width of 94 inches and a maximum height of 65 inches (62.5 inches to the bottom edge of the loading hatches). The lengths of the front and rear bays of the 1900-gallon compartments are 50 and 44 inches, respectively.

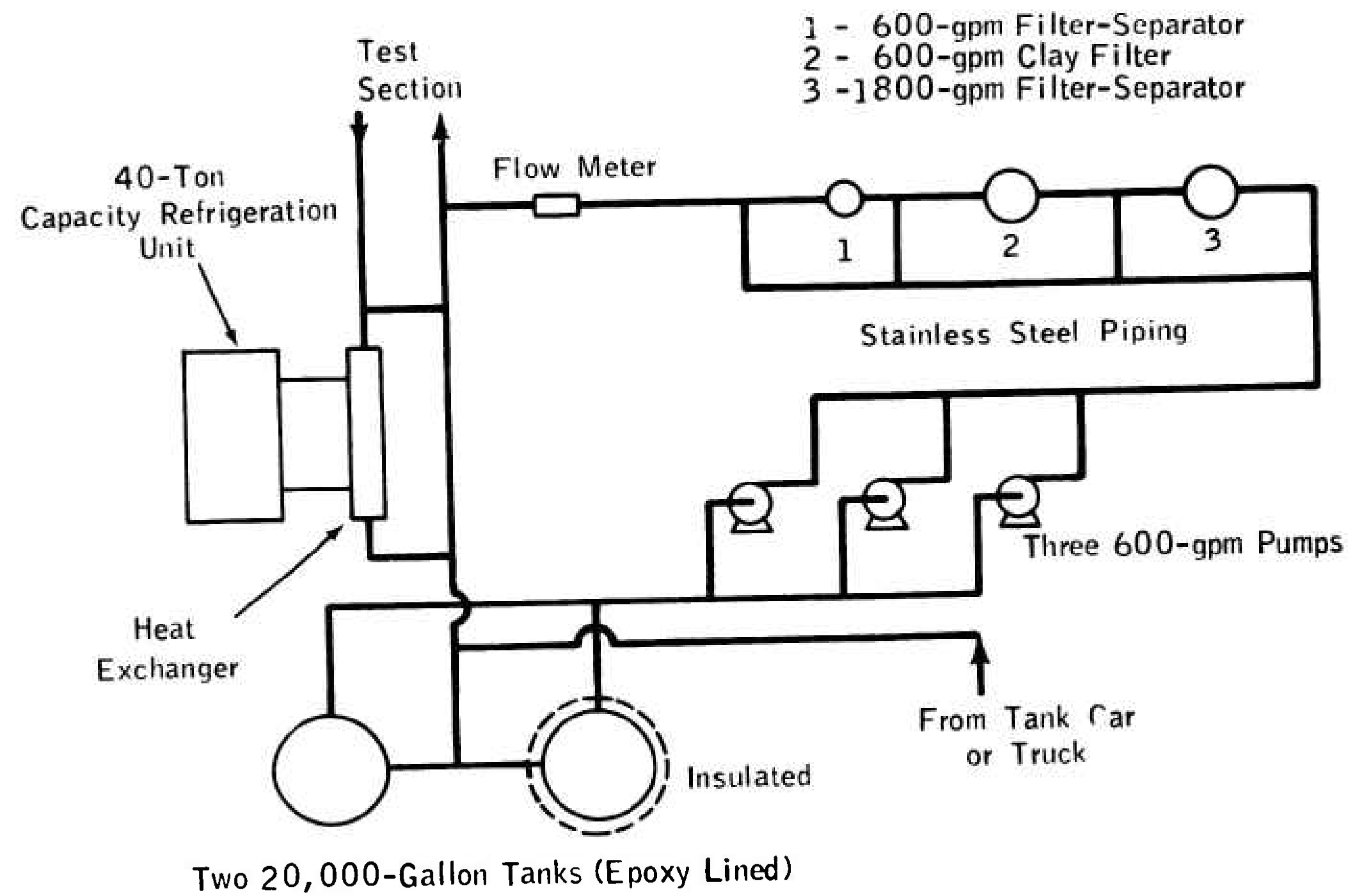


Figure 25 - Key Features of Basic Fueling Facility

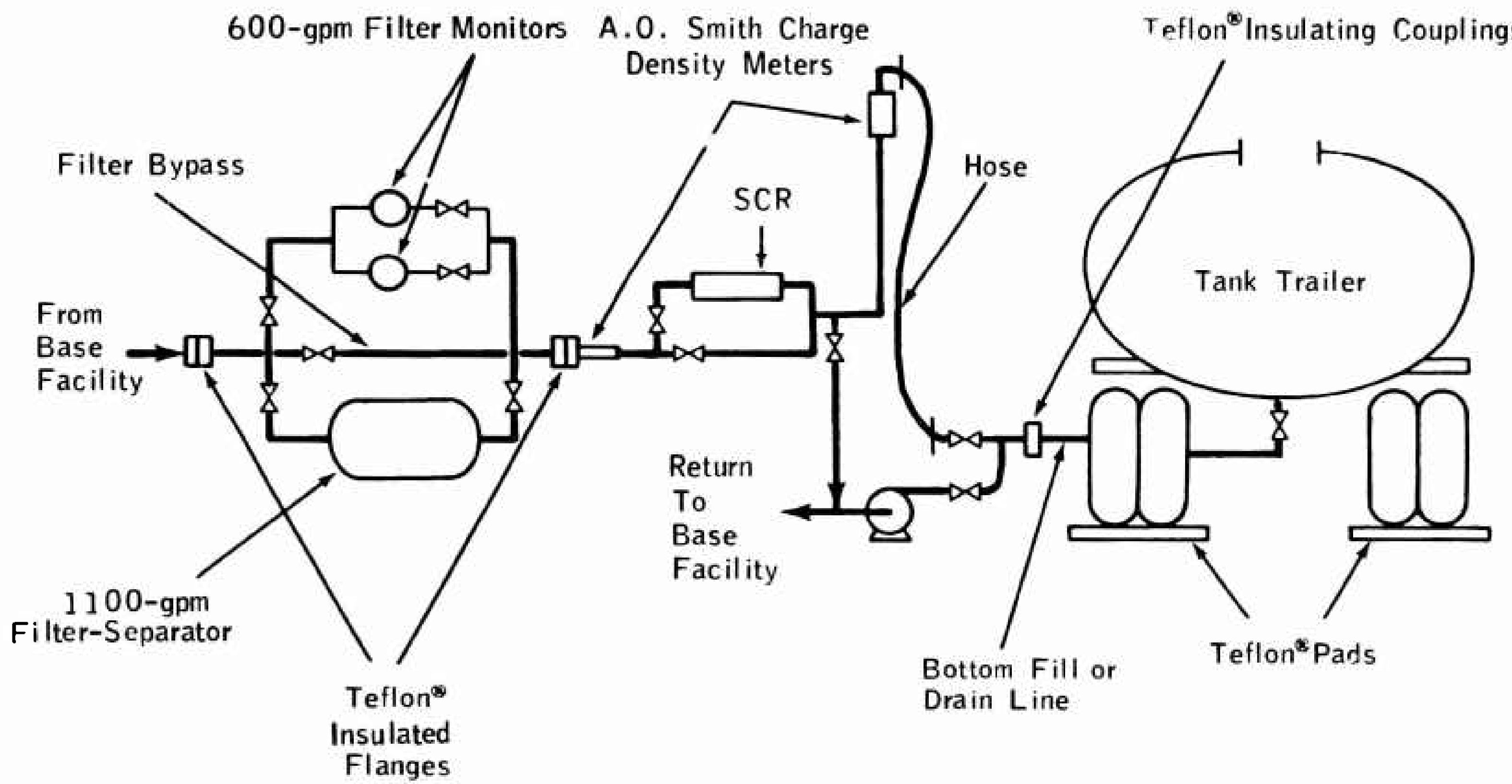


Figure 26 - Test Facility for Tank Truck - SCR Study

In these experiments the truck was bottom loaded through a 4-inch hose. Fuel enters the tank through a trough that provides the equivalent of a splash plate in the trough cover.

(3) Test Measurements; Instrumentation

(a) Continuous Measurements

The following measurements were made and recorded continuously during each run:

Charge Density is the charge per unit volume of fuel expressed in microcoulombs/cubic meter ($\mu C/m^3$). It was measured at the outlet of the filter bypass array and at the inlet to the loading arm in the tank truck installation, using an A. O. Smith Charge Density Measuring System which consists of a Charge Density Sensor Housing, Model H-66, containing a Sensor Head, Model SH-1 and a Sensor Drive Head, Model SD-1.

Current Flow Between Tank and Ground was measured by means of a Keithley electrometer. Since this current divided by the fuel flow rate into the tank (in m^3/second) is equal to charge density, a comparison of this value with the charge density measured at the inlet to the loading arm, as described above, provides a measure of the amount of either charging or charge relaxation produced in the loading arm.

Field Strength; Surface Voltages Field strength is the voltage gradient at the top of the tank, measured in kilovolts/meter (kv/m). It was measured and recorded using rotating-vane, Model 12009, Electrostatic Field Meters obtained from Comstock and Wescott, Cambridge, Massachusetts.

Field strength gives an indication of the likelihood of sparking in the vapor space of a tank. Sparks are generally produced in air when the local field strength exceeds 3000 kv/m. In an actual tank, it may be impossible to determine the location and magnitude of the highest field strength. As a result, field strengths high enough to generate spark discharges may be produced at the end of probes or other sharp projections due to highly distorted electric fields, although the average field strength measured at the tank top, as in this program, is much lower than 3000 kv/m. However, measurements made at the tank top reflect the changes in local field strength within a tank and provide a measure of the relative static hazard.

Two meters were used with the 1900-gallon compartment, one to monitor the surface voltage in the front or fuel inlet bay, and one to monitor surface voltage in the rear bay. Special hatches were installed in the truck so that the meters could be mounted at the tank top.

Surface voltage is the voltage in kilovolts (kv) developed on the surface of the fuel as a tank is filled. It is the product of field strength and the distance, in meters (m), between the tank top (field meter) and the fuel surface. This is a reasonable approximation if the meter is mounted flush with the tank top and the geometry of the tank is relatively simple as in this study. The distance between the meter and the fuel surface was obtained by subtracting fuel depth from the height of the meter above the tank bottom.

Since surface voltage is derived from field strength, it also provides a relative measure of the static hazard.

Spark Discharges were detected by specially-tuned transistor radios, which could easily detect discharges with energies as low as 0.02 mj., less than 1/10 the minimum energy required to ignite hydrocarbon/air mixtures (i.e., 0.26 millijoules). Separate radios in the front and rear bays made it possible to determine in which bay sparks were being produced.

(b) Other Measurements

In addition, the following measurements were made:

Flow Rate was measured using a Model 6X5-5555X, Pottermeter, a turbine flow meter.

Fuel Depth was measured by the back pressure developed on nitrogen bubblers; the bubbler in each test tank was calibrated at several fuel levels between 0 and 100 per cent full.

Fuel Conductivity (i.e., conductivity of the uncharged fuel) was measured on grab samples taken at random times during each series of runs using the ASTM Method, D 3114-72.

(4) Test Procedure

The procedure that was used each day that tests were scheduled is as follows:

The test tank was blanketed with nitrogen and the test fuel was recycled through the filter-monitor (at 700 to 1000 gpm) and back to the storage tank to stabilize the temperature and charge level. The field meters and radios were installed on the tank and all necessary connections were made. The meters and recorders used for the various measurements were zeroed. The voltage on the batteries supplying power to the radios was checked and the signal output of each radio was then checked by setting off spark discharges of about 0.26 millijoules inside the tank using a portable spark generating device.

The zero setting for the field meters was checked by putting the meter on a grounded metal plate. The conductivity of a sample of the temperature-stabilized fuel was measured.

For each test run, the following procedures were carried out:

The oxygen content of the tank was measured (runs were not started until the oxygen content was below 5 per cent). The pumps were started and flow was allowed to stabilize through the test facility by-passing the tank truck. In runs where the SCR was in use, at least 20 minutes was allowed to completely warm up the SCR. When everything else was ready the recorders were turned on, the return line to the base facility was closed and the valve to the truck was opened. The flow rate was monitored and adjusted if necessary. The elapsed time for the fuel level to reach a series of fixed levels was recorded. The run was terminated when the fuel reached a final fixed level.

At the end of the run, the inlet valve to the tank was closed, the fuel pump stopped and the flow control valve was shut. The recorders were allowed to run until the charge in the bulk fuel, as measured by the A. O. Smith Charge Density Meters, and the charge on the fuel in the tank, as measured by the field meters, had dissipated. Nitrogen flow to the tank was started and the tank was drained.

Fuel conductivity was measured several times during the series of runs and after the last run carried out each day. At the end of a day's testing the field meters and radios were removed from the tank.

(5) Test Fuel

The fuel used in these tests was a commercial turbo fuel A from the Exxon Company's Bayway refinery which had been used in several previous tests. Trace quantities of oxidized asphalt, No. 6 heating oil, dirt and water, and Shell's anti-static additive, ASA-3, had been added for various tests. The fuel was water washed and clay filtered to remove residual traces of these contaminants before this program began. The conductivity of the fuel was less than 2 pS/m (at 60°F) and the Water Separation Index Modified (WSIM) was greater than 95 at the beginning of the tests. After a series of tests with the clean fuel, an additive package consisting of 4.5 lbs/1000 barrels of DuPont's corrosion inhibitor DCI-4A and 0.12 per cent by volume methyl cellosolve was added to the fuel. This additive package as specified by MIL-T-5624J would allow a wide-cut fuel to meet military specifications. A surfactant, Cyanamid's Aerosol AY®, was added for the final series of tests.

c. Test Results

The objective of this phase of the work was to determine if the use of an SCR to reduce charge levels on a fuel would be detectable in the surface voltage in filled vessel. It is, of course, known that the surface voltage will depend on the charge level and conductivity of the incoming fuel. The question which is to be answered is whether at a given inlet charge density the surface voltage of an SCR-related fuel is higher than one which has not been relaxed.

The raw results of each test run, field strength in the truck vapor space versus time, was converted into a plot of surface voltage versus fuel depth. The maximum of the surface voltage versus fuel depth curve has been plotted against the inlet charge density of the fuel in Figure 27. The figure shows two lines, one for the DCI-4A containing fuel and the other for the same fuel after the addition of a surfactant (Aerosol AY®). The Aerosol AY® was added to increase the charging tendency of the fuel and allow measurements to be made at higher charge levels at the inlet of the SCR. The data points for the SCR operation do not differ significantly from the line for positively and negatively charged fuel. The least squares lines which best represents

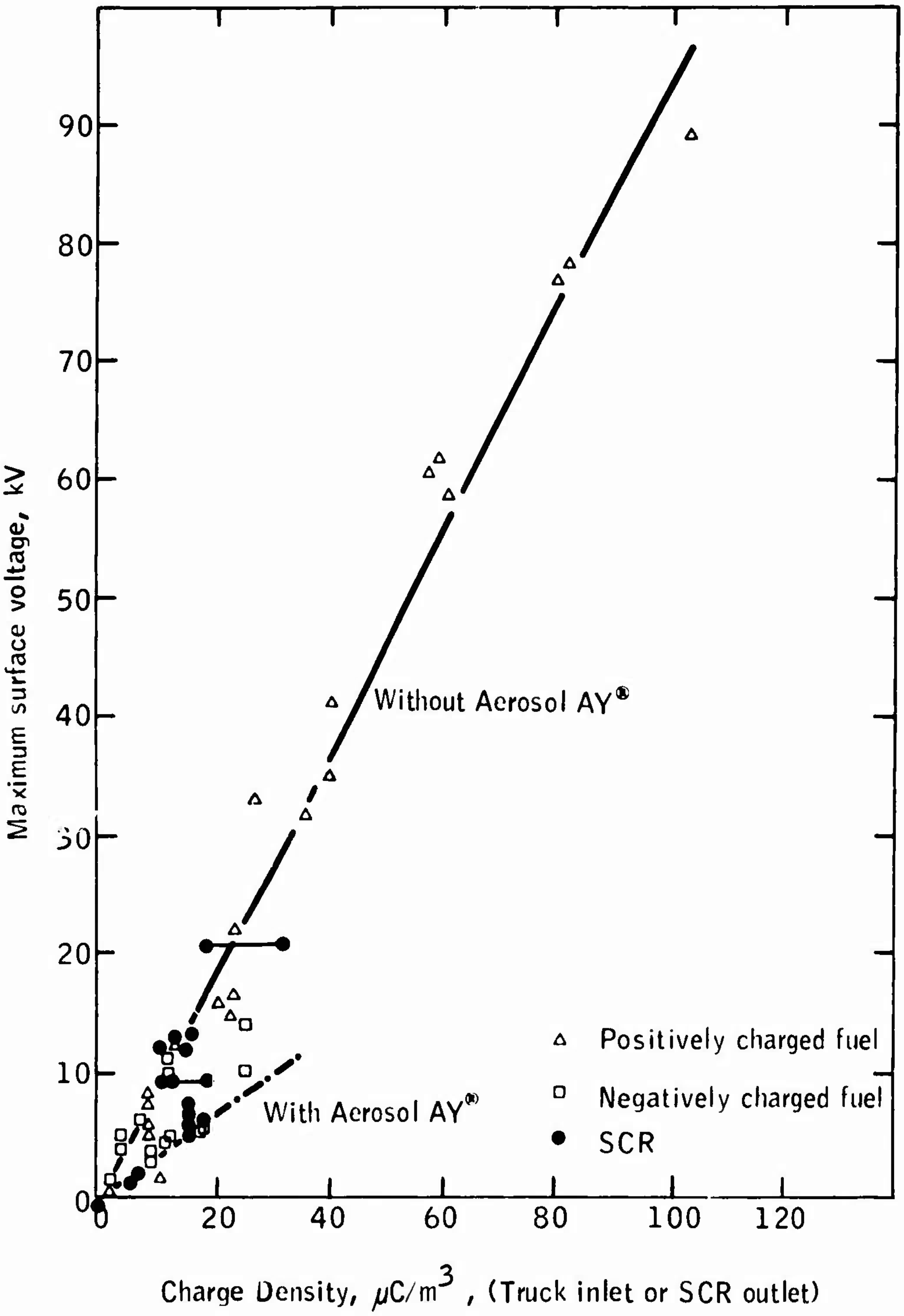


Figure 27 - Surface Voltage versus Charge Density

the 29 data points which were generated without the use of the SCR and before the addition of the surfactant, Aerosol AY®, is

Surface Voltage = 0.98 x Charge Density - 0.6

where the surface voltage is in kilovolts and the charge density is in microcoulombs per cubic meter. The points representing the use of the SCR do not fall significantly off the line.

The addition of aerosol AY® changed the slope of the line relating surface voltage and charge density considerably because the conductivity changed. But, as in the previous case, the relationship was not significantly affected by the use of the SCR. The SCR was reducing charge densities from about 700 $\mu C/m^3$ to under 20 $\mu C/m^3$.

At the beginning of this program, the SCR had been cleaned. It was operating with efficiencies equivalent to that in the previous program (Reference 4).

The results of this program were somewhat surprising in that, based on the previous work, a difference had been expected between a charge density produced with the SCR and a similar charge density produced without the SCR. There is a tentative hypothesis to explain the variance between the results. The charge density of a fuel relaxed with an SCR is characteristically noisy. The recorder trace is sharply spiked with a band width much wider than is found for an unrelaxed fuel. The fuel which is pumped into a tank has an average charge density and produces a surface voltage which is dependent on that average charge density. In other words, the tank is essentially integrating and averaging the charge density. It effectively washes out the noise which is characteristic of the SCR relaxed fuel. On the other hand, when the electrostatic voltmeter is supported on the outside of the FRP pipe, it responds to a much smaller volume of fuel. The voltmeter in this case would give more of an instantaneous reading of the surface voltage produced by a particular charge density. The voltmeter does not show a noisy reading. Either its response time is much slower than that of the charge density meter or the FRP pipe is damping out the oscillations. Either way, it is possible that the meter or pipe is responding to the maximum charge density rather than the average. It is known that the pipe itself responds slowly to charge density changes; however, no attempt has been made to measure any bias. If this explanation is correct, it would explain both results. An instantaneous measurement of surface voltage would give a higher than predicted value from an SCR. A time average reading such as obtained from filling a tank would be the same for both SCR and non-SCR relaxed fuel. This bias between types of measurements of surface voltage only occurs with the SCR because this is when the very large spikes and noise occur. The spikes and noise are probably caused by discharges off the pins of the SCR as it reduces the charge in the fuel.

Although not directly pertinent to the question of SCR efficiency and operation, additional very useful information was collected during this test program. The radios in each test bay detected spark discharges.

The number of discharges during a run are plotted against the maximum surface voltage in each bay in Figure 28. The crosses in the figure represent the frequency of occurrence of discharges as a function of surface voltage for the inlet fuel bay. The inlet fuel bay had no charge collectors in it. Therefore, the discharges occurred at a higher surface voltage in a clean tank. The circles on the other hand represent the frequency of discharges when three charge collectors were suspended in the tank. The charge collectors are 1-inch by 2-inch strips of aluminum metal suspended by nylon fish line from the supports in the rear bay. They are free to move enough to contact the wall. If the fuel has even a small charge on it, the charge collector will collect it and probably will discharge when it contacts the wall. As can be seen from the figure, very little surface voltage was needed to produce several discharges from the charge collectors. In addition to the plotted points, there were 50 more runs in which the maximum surface voltage remained below 20 kv during which no discharges occurred (in the absence of charge collectors).

Since the maximum surface voltage is a function of tank geometry, flow rate, inlet charge density, and fuel conductivity, it is difficult to predict. In addition, since frequency of discharges as a function of surface voltage is dependent on the geometry (projections) of the tank, generalization is not practicable. This work shows the extreme importance of having no unbonded conducting objects in a tank. Any conductive object which floats or is not bonded to the tank wall will vastly increase the frequency and probability of discharges.

The complete data are presented in Table XXVIII.

d. Discussion of Results

The conclusion which can be reached as a result of this test program is that, at constant charge density, the SCR has no detrimental effect on surface voltage in the receiving vessel. Under normal circumstances, given that the SCR has had time to warm up, the charge density on the fuel will be substantially reduced. This reduced charge density will of course produce a lower surface voltage on the fuel. The comparison which was being made in this program was at constant charge density. For example, if one leg of a fueling system had an SCR to reduce charge density and another leg had a relaxation tank such that the charge density of the fuel from each leg was the same, then the safety of the fuel from the SCR leg could be compared with that from the other leg. Previous work(Reference 4) suggested that, in fact, the surface voltage from the SCR treated fuel would be higher and, therefore, more dangerous, than the fuel from the relaxation tank. No evidence was found to support that hypothesis in filling large tanks. The surface voltage of the fuel in the tank depended only on the charge density and was independent of the use of the SCR.

An added point which was not considered experimentally; the two hypothetical legs of the fueling system would not be equivalent because the SCR has a turn-on time. It requires several minutes to achieve peak efficiency. During that time, the fuel from the SCR leg would have a higher charge density than the fuel from the relaxation tank. As pointed

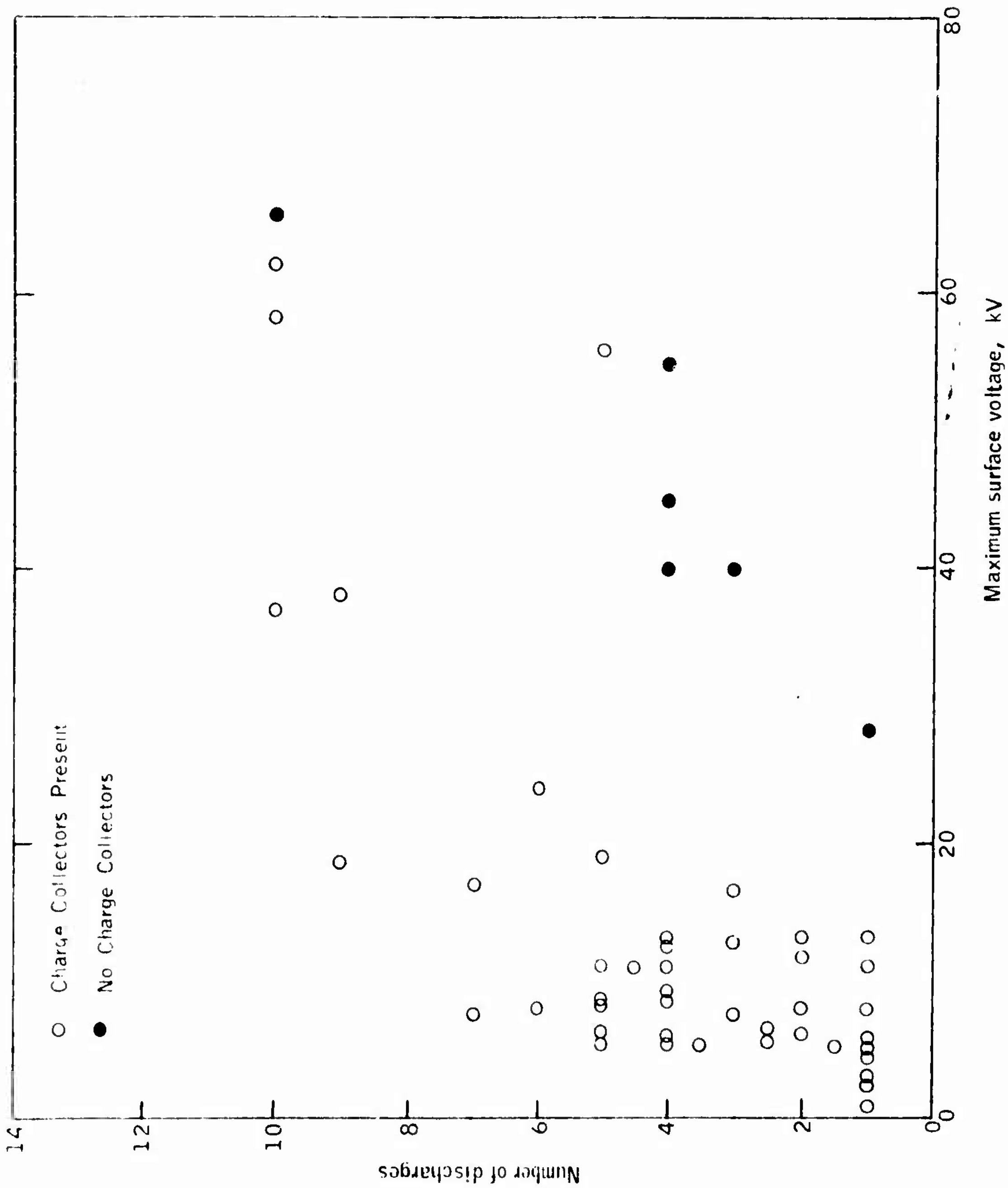


Figure 28 - Spark Discharges versus Maximum Surface Voltage

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TABLE XXVIII. EFFECT OF SCR ON FUEL SURFACE VOLTAGE WHEN FILLING A TANK

Run[1] No.	Rest Conductivity (pS/m @ (Temp.°F))	SCR	Per Cent[2] SCR Efficiency	Charge Density ($\mu C/m^3$) Inlet to SCR	Charge Density ($\mu C/m^3$) @ Truck Inlet (or SCR Outlet)	Maximum Surface Voltage (kv) Inlet Bay	No. of Discharges	Rear Bay	No. of Discharges	Average
5	1.21 (42)	Yes	70	100	+ 30 to -17[3]	23.48	0	17.21	7	20.34
6	1.87 (52)	Yes	90	100	+ 10 to -12	12.68	0	11.02	1	11.85
7	1.87 (52)	Yes	90	100	+ 12	13.14	0	11.85	2	12.50
8	1.87 (52)	No	-	110	+100	84.13	Many	94.77	Many	89.45
10	1.87 (52)	No	-	~+40	+ 22	22.63	0	19.63	5	21.13
11	1.87 (52)	No	-	~10	+ 8	7.47	0	7.34	0	7.40
12	1.87 (52)	No	-	0-20	+ 8	7.71	0	7.69	0	7.70
13	1.87 (52)	No	-	20-50	+ 21	17.51	0	15.70	3	16.60
14	1.38 (48)	No	-	90	+ 80	71.63	20	85.96	26	78.80
15	1.38 (48)	No	-	185	+ 78	80.76	Numerous	73.44	Numerous	77.10
16	1.38 (48)	No	-	~60	+ 56	66.12	~10	55.94	5	61.03
17	1.38 (48)	No	-	~60	+ 57	66.12	~15	58.50	~10	62.31
18	1.38 (48)	No	-	~60	+ 59	55.51	4	62.26	~10	58.88
19	1.38 (48)	No	-	30-70	+ 38	44.84	4	37.15	~10	41.00
20	1.38 (48)	No	-	+30-70	+ 38	40.77	1 + 4 small	29.60	~10	35.18
21	1.65 (57)	No	-	20-50	+ 20	18.72	0	12.67	4	15.70
22	1.65 (57)	No	-	+20-50	+ 21	16.87	0	12.72	3	14.80
23	1.65 (57)	No	-	+20-20	+ 8	7.47	0	5.12	1	6.30
24	1.65 (57)	No	-	+0-20	+ 8	6.89	0	5.12	0	6.00
25	1.65 (57)	Yes	82-90	~100	+ 18 to -10	9.76	0	7.82	7	8.79
26[4]	1.65 (57)	Yes	88	~100	+ 12	10.19	0	7.69	3	8.94
27	0.33 (40)	No	-	~-20	- 24	14.52	0	13.32	2	13.92
28	0.33 (40)	Yes	25	-20	- 15	14.05	0	13.74	4	13.90
29	0.33 (40)	No	-	~-25	- 22	14.33	0	18.79	9	16.56
30	0.33 (40)	Yes	60	~-25	- 12 to -10	7.55	0	8.39	4	7.97
31	0.33 (40)	Yes	60	~-25	- 12 to - 8	7.69	0	7.94	2	7.82
32	0.33 (40)	Yes	60	~-25	- 10 to - 8	7.55	0	7.94	1	7.74
33	0.33 (40)	No	-	- 3	- 3.5	3.49	0	4.18	1	3.84
34	0.33 (40)	No	-	- 3	- 3.5	4.38	0	4.87	0	4.62
35	0.33 (40)	No	-	-20	- 7	6.39	0	6.07	2	6.23
36	0.33 (40)	No	-	-20	- 7	6.51	0	6.04	0	6.28
37	0.33 (40)	No	-	-25	- 11	10.38	0	9.00	4	9.69
37B	0.41 (43)	No	-	-25	- 25	28.39	1	38.05	9	33.22
38	0.41 (43)	No	-	-11	- 11	11.48	0	11.10	4-1/2	11.29
39	0.41 (43)	Yes	58	-24	- 10	12.38	0	11.10	4	11.74
40	0.41 (43)	Yes	50	-20	- 10 to -14	12.68	0	13.26	1	12.97

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TABLE XXVIII. EFFECT OF SCR ON FUEL SURFACE VOLTAGE WHEN FILLING A TANK (CONCLUDED)

Run No.	Rest Conductivity (pS/m @ (Temp. °F))	SCR	Per Cent SCR Efficiency	Charge Density ($\mu C/m^3$) Inlet to SCR	Charge Density @ Truck Inlet (or SCR Outlet)	Maximum Surface Voltage (kv) Inlet Bay	No. of Discharges	Rear Bay	No. of Discharges	Average
41[5]	0.41 (43)	No	-	- 2	- 2	1.20	0	1.20	1	1.20
42	0.66 (44)	No	-	+37	+ 34	40.14	4	23.69	6	31.92
43	0.66 (44)	Yes	76	+32	+ [illegible]	9.92	0	6.34	2-1/2	8.13
44	0.66 (44)	Yes	83	+30	+ 5	6.40	0	3.87	0	5.14
45	0.66 (44)	No	-	~+10	+ 9	12.76	0	8.00	0	10.19
46	0.66 (44)	Yes	25	+ 2	+ 1.5	1.54	0	0.94	0	1.24
47	0.77 (32)	No	-	+ 4	+ 3.0	4.10	0	2.99	0	3.54
47B[6]	2.2 (53)	Yes	95	+125	+ 6	1.60	0	No Reading	0	1.60
48	2.2 (53)	Yes	96	+125	+ 5	0.94	0	0.40	0	0.67
49	2.2 (53)	No	-	+ 1	+ 2	0.05	0	0.08	0	0.07
50	2.2 (53)	No	-	+25	+ 10	1.73	0	0.94	0	1.34
51	2.2 (53)	Yes	97	-690	- 30 to -15	5.73	0	8.21	6	6.97
52	2.2 (53)	No	-	-50	- 24	9.09	0	11.30	5	10.20
53	2.2 (53)	No	-	-15	-10.5	3.94	0	6.28	4	4.96
54	2.2 (53)	No	-	-54	- 10	3.43	0	5.89	1	4.66
55	2.2 (53)	Yes	95	-510	- 40 to -15	5.29	0	8.82	5	7.06
56	2.2 (53)	Yes	97	-460	- 15	5.70	0	8.54	5	7.12
57	2.75 (57)	Yes	93	-850	- 15	4.22	0	5.18	1-1/2	4.70
58	2.75 (57)	Yes	97	-700	- 12	5.05	0	6.80	5	5.92
59	2.75 (57)	Yes	(100)	+ 48	+ 0	1.17	0	0.93	0	1.05
60	2.75 (57)	No	-	- 12	- 8	2.73	0	2.65	1	2.69
61	2.75 (57)	No	-	- 12	- 8	3.10	0	3.05	1	3.08
62	2.75 (57)	No	-	- 35	- 17	4.64	0	5.19	4	4.92
63	2.75 (57)	No	-	- 30	- 16.5	4.46	0	5.12	3-1/2	4.79
64	2.75 (57)	Yes	96	-365	- 15	5.29	0	5.57	5	5.43
65	2.75 (57)	Yes	95	-330	- 15	4.53	0	6.06	2-1/2	5.30

NOTES:

(1) Runs 1-4 not reported. They were carried out without warming up the SCR.

(2) SCR efficiency is defined and tabulated only when the SCR is in use.

(3) A range in charge density is given if the charge density varied significantly during the run.

(4) Fuel was clay treated to decrease conductivity.

(5) DCI-4A + methyl cellosolve added to the fuel.

(6) Aerosol AY® added to the fuel.

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out previously, all experiments in this program were made with a completely warmed up SCR. Since turn-on time cannot easily be built into an SCR installation, the relaxation tank would be the preferred method for reducing inlet charge when filling a tank.

The work also confirmed previous work of the extremely hazardous nature of unbonded charge collectors in a tank which is being filled. Prior Exxon Research studies(Reference 6) had shown that spark discharges were possible when filling a tank truck with essentially uncharged fuel if charge collectors were present. This hazard exists for either top or bottom filling.

4. FRP VERSUS STEEL PIPE; TESTS WITH JP-4

a. Prior Work with FRP Pipe

In a previous report (AFWL-TR-72-90) it had been shown that under certain conditions charged fuel relaxed considerably slower in fiberglass reinforced plastic (FRP) pipe than in steel pipe. The results depended on the polarity of the charge on the fuel; on the average, relaxation was 30 per cent slower in FRP than in steel for postitively charged fuel and 8 per cent faster for negatively charged fuel. The tests had been carried out with kerosene jet fuel without additives. The differences in the two types of pipes was greatest with low conductivity fuel.

FRP pipe is lighter, easier to install, and produces less resistance to flow than steel pipe. The most important advantage of FRP pipe is its freedom from corrosion. When steel pipe corrodes, it contaminates the fuel with particulate matter and sometimes with metal ions which decrease the fuel's thermal stability. With these advantages the use of FRP pipe is certainly desirable. It was, therefore, disturbing to find that the relaxation rate of charged fuel could be substantially slower than in steel pipe. This task was essentially a repeat of the previous work using JP-4 with all appropriate additives in place of the non-additive Jet A which had been used previously.

b. Description of the Test Facility and Procedures

Paragraph 2. b. contains a description of the base facility and most elements of the test section. This portion of the report will include only those items where differences occur in equipment used to test the two kinds of pipe.

(1) Test Section

A schematic of the test section is shown in Figure 29. The only change from Figure 26 is that the test pipe sections replace the tank truck.

(2) Experimental Pipe Test Sections

Two types of nominal 6-inch-diameter pipe were used in the test section, a standard, Schedule 40, commercial grade carbon steel pipe and Bondstrand 2000, a fiberglass reinforced epoxy pipe manufactured by Ameron (formerly Amercoat) Corporation. Since electrical resistivity was considered to be a critical factor in dissipation of charge from plastic pipe, the highest resistivity that might be encountered in this type of pipe was

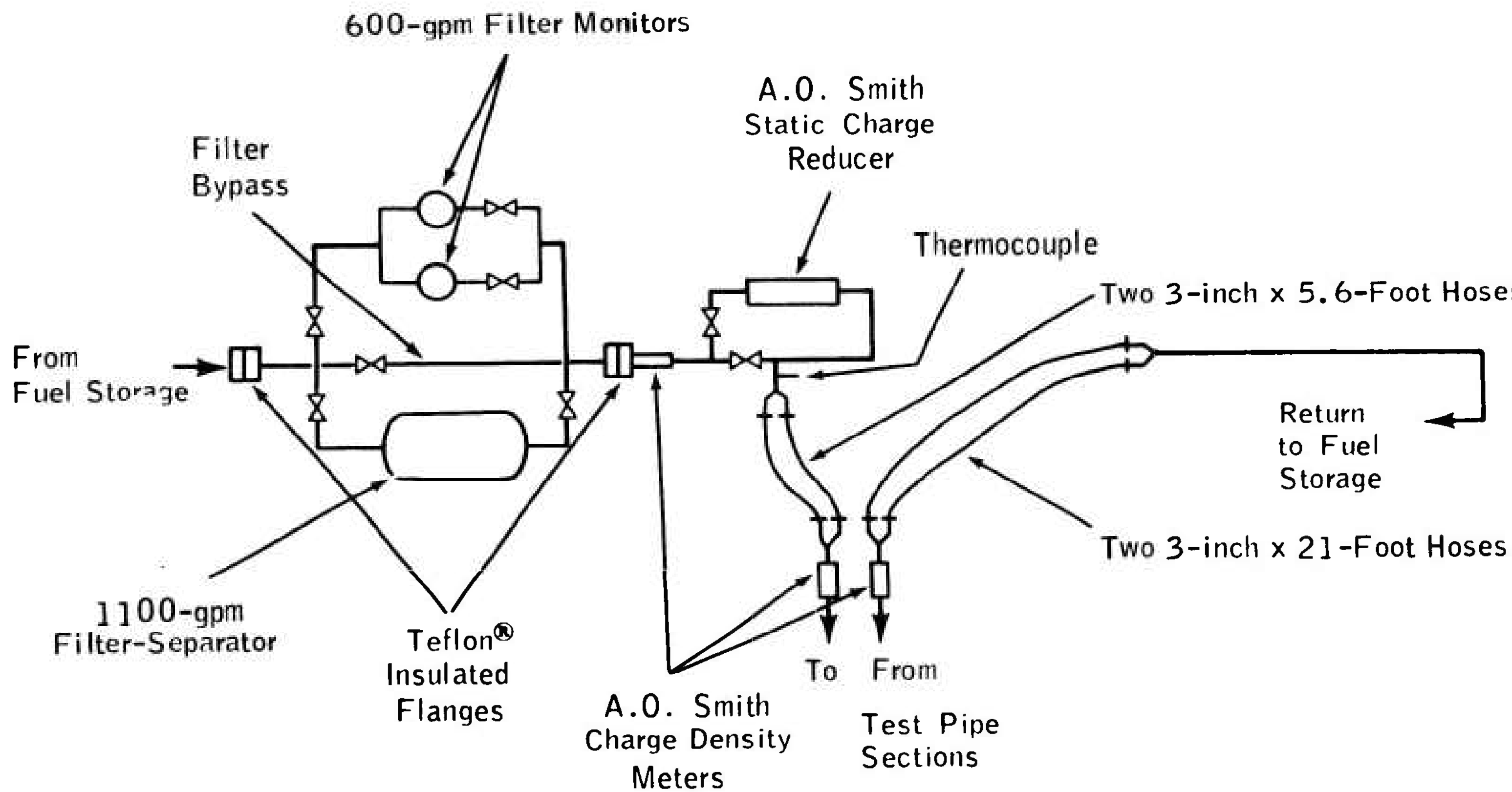

Figure 29 - Test Facility for FRP versus Steel Pipe Study

desired for this installation. Bondstrand 2000 was selected because it showed the highest volume resistivity (e.g., 1.1 to 8.8 x 10^{14} ohm cm) of the commercially available plastic pipes which meet Air Force specifications and for which typical measured resistivity data were available. Other electrical properties and dimensions of Bondstrand 2000 are shown in Table 16 of AFWL-TR-72-90.

Each pipe type was installed in two lengths, a U approximately 80 feet long and a W approximately 160 feet long, as shown in Figure 30. Jumpers, made of corresponding materials, were provided, so that the two pipe lengths could be joined together to give a total run length of approximately 240 feet. (For this program, tests were conducted in the 80- and 240-foot lengths only.) The steel pipe runs were welded and the open ends were provided with Victaulic connections. The FRP sections were fabricated from nominal 20-foot pipe lengths and fitted with FRP flanges at the open ends. All joints were made using the approved epoxy adhesive. Carbon steel stubs (8-1/2 inches long) were used to convert the flanged ends of the plastic pipe to Victaulic connections.

Although FRP pipe is only approved for underground use at present, the installation was constructed above ground to allow for detection and observation of electrical discharges from the surface of the FRP pipe, the measurement of surface voltages and possible application and evaluation of grounding techniques. Each type of pipe was supported on four stanchions (12 to 13 feet apart) which were carefully grounded.

An A. O. Smith Charge Density Sensor Housing, Model H-66 (containing a sensor head, Model SH-1, and a Sensor Drive Head, Model SD-1), was installed at the outlet of the filter/filter bypass array to measure the charge density in the fuel at this point. Two more housings, with sensor heads and drives, were mounted on a rack in front of the test pipe array (as shown in Figure 29) to measure the charge densities on the fuel at the inlet and outlet of the pipe section under test. The ends of the sensor housings facing the pipe array were fitted with Victaulic connections for easy coupling with a given test section (as shown in Figure 30).

Parallel 3-inch hoses, 5.6 feet long, and a pair of reducing Y's connected the filter/filter-bypass/SCR array to the charge density meter at the pipe inlet. The meter at the pipe outlet was connected to the line which returned the fuel to storage through a similar system using a pair of 3-inch hoses, 21 feet long. The hoses made it possible to move the charge density meters from one pipe section to another with relatively little difficulty.

To allow for a direct and unambiguous comparison of the charge generation and relaxation characteristics of the two pipe types, a special effort was made to match the holdup volumes between the inlet and outlet charge density meter sensors for both short and long sections of the two pipe types, so that the residence times would be the same for equivalent test pipe lengths at a given flow rate. The inside diameters of the steel and FRP pipes were 6.065 and 6.265 inches, respectively. As a result, the steel runs were somewhat longer than the FRP runs. The calculated volumes of the test sections were almost identical, as shown in the following table.

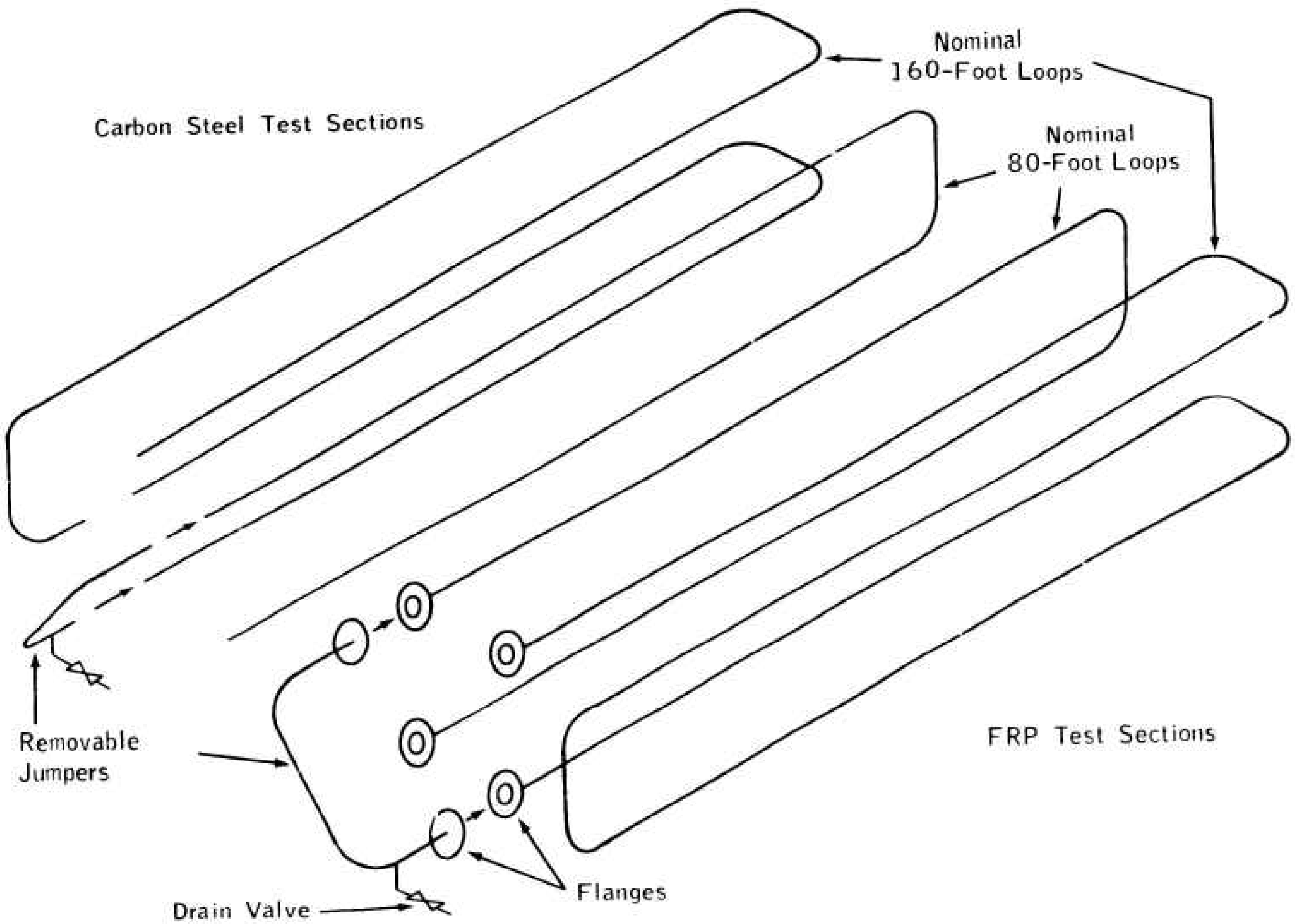

Figure 30: Schematic of Carbon Steel and FRP Test Pipe Installation

	Volume of Test Pipe Section (Gal)	
Pipe Length	FRP	Carbon Steel
Short	136.0	135.7
Long	401.3	402.5

(3) Fuel

The fuel used for this program was JP-4 purchased from Ashland Oil Company. It contained the anti-icing additive, methyl cellosolve and a corrosion inhibitor, Hitec E-534, at a concentration of 4.5 lbs/1000 barrels. The conductivity of the fuel as received was 1.5 pS/m and the Water Separometer Index-Modified (WSIM) was 97. Additional inspections are given in Table XXIX.

(4) Test Procedure

At the beginning of each day instruments and pumps were turned on and allowed to warm up for at least 1/2 hour before running. After warm-up the instruments were zeroed with no fuel flowing. Fuel flow was then started through one of the four pipe configurations, either long or short, and either FRP or carbon steel. Fuel temperature was adjusted continuously using the air conditioning equipment and heat exchanger described in paragraph 2. b. (1). The fuel temperature was maintained at 77°F ±1°F. The charge density on the fuel was measured continuously at three points in the system: (1) just after the monitors, filter-separator, and bypass, (2) at the inlet to the test section, and (3) at the outlet of the test section. The conductivity of the fuel was measured several times during each day. For a run, the change in charge density from the inlet to the outlet of the test section was recorded at three different flow rates, 300, 600 and 1200 gallons per minute at several different inlet charge densities. The inlet charge density was varied by opening the bypass and allowing some of the fuel to avoid charge generation in either the filter-separator or the monitors. Therefore, there was a maximum achievable charge density obtained with 100 per cent flow through the filters. Lower charge densities were achieved through mixing.

After complete collection of the data on one pipe configuration, the system was shutdown, partially drained down to empty the test sections, and the inlet and outlet were changed to allow testing another configuration.

c. Test Results

The results of the test program as summarized in Table XXXII* consisted of the measured outlet charge density on the fuel as a function of pipe type (FRP or carbon steel), configuration (long or short), flow rate (1200, 600 or 300 gpm) and inlet charge density. The following procedure was used to analyze the data. For each test of pipe type, configuration, and flow rate, the inlet charge density was plotted versus the outlet charge density. A sample data sheet for the 1200-gpm short pipe configuration is shown in Figure 31. Under these conditions, the residence time in the test sections is 6 seconds. As can be seen from the figure, the slopes of the two least squares lines are very similar. In fact, they differ by

TABLE XXIX. INSPECTIONS OF JP-4 TEST FUEL[1]

SOURCE: ASHLAND OIL COMPANY

Specific Gravity	0.7543
Distillation °F	
Initial Boiling Point	134
10 per cent Evaporated	202
20 per cent Evaporated	227
50 per cent Evaporated	296
90 per cent Evaporated	446
Final Boiling Point	481
Residue Volume per cent	2
Loss Volume per cent	0
Reid Vapor Pressure (pounds per square inch - gauge)	2.64
Water Separometer Index-Modified	97
Conductivity (pS/m)	1.5
Additives As Received:	
Fuel System Icing Inhibitor (FSII) Volume per cent	0.1
Hitec E-534 Corrosion Inhibitor, lbs per 1000 barrels	4.5

(1) This fuel was used in the FRP versus Steel Pipe study reported in Section III, para 3 and also in the DOD Hose Cart study reported in Section II, para 2 (Table XIX).

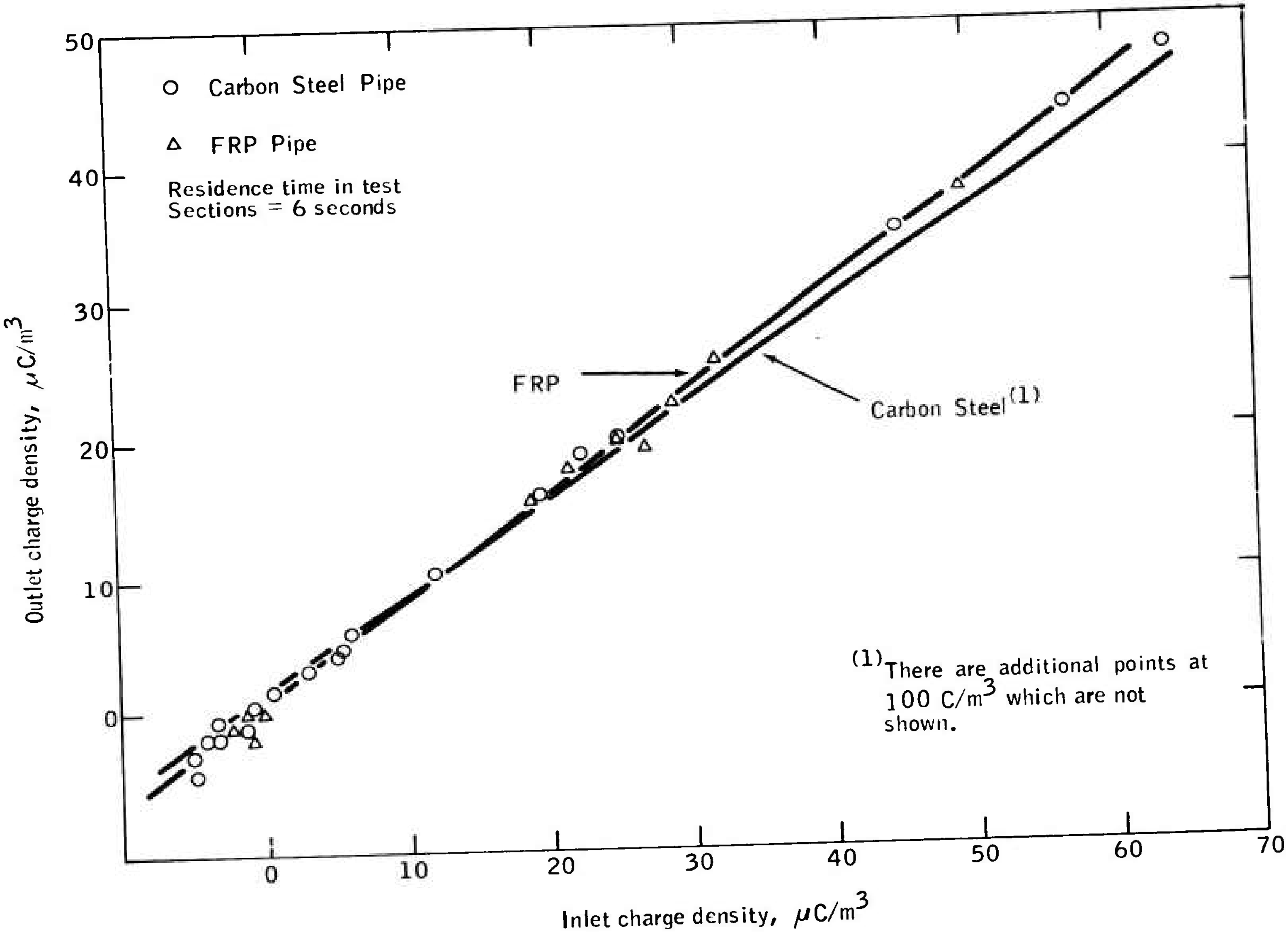

Figure 31 - Outlet Charge Density as a Function of Iniet Charge Density for 1200 gpm and Short Pipe Configuration

6 per cent. (Note that the carbon steel line does not seem to fall through the plotted points very well. This is because the calculated line includes several more points above 100 $\mu C/m^3$ which have not been plotted on the figure.) From the plotted points the slope of the line is a measure of the relaxation rate and the intercept of the line at zero inlet charge density is the charge generation in the pipe. The equation for the rate of charge relaxation is

$$Q_t = Q_o \quad e^{-\frac{tk}{\varepsilon\varepsilon_o}}$$

where

Q_t = charge or charge density after time t ($\mu C/m^3$)
Q_o = initial charge ($\mu C/m^3$)
t = elapsed time (seconds)
k = fuel conductivity (siemens/meter)
ε = relative dielectric constant, a dimensionless quantity with a value about 2.
ε_o = absolute dielectric constant of a vacuum (8.854×10^{-12} ampere seconds/volt meter)

The relationship between Q_t and Q_o is linear (the relationship between Q and t or k are exponential but at constant t and k, Q_t and Q_o are linearly related). The data obtained in this program are in agreement with this equation in that a linear relationship was found for Q_t and Q_o. The goodness of fit (r^2) to the linear least squares line was greater than 0.90 and frequently better than 0.99.

The slope (m) of the line relating Q_t and Q_o is equal to

$$m = e^{-\frac{tk}{\varepsilon\varepsilon_o}}$$

Taking the natural logarithm of both sides of the equation gives

$$\ln [m] = -\frac{tk}{\varepsilon\varepsilon_o}$$

Furthermore

$$T = \frac{\varepsilon\varepsilon_o}{k} = \frac{t}{-\ln [m]}$$

where T is the relaxation time in seconds for the fuel. The relaxation time is defined as the time for charge on the fuel to decay to 36.8 per cent of its original value. Since t (the residence time in the pipe) is constant for the two types of pipe, comparison of the relaxation times is equivalent to comparison of the slopes of the lines of inlet versus outlet charge densities. The following comparison of FRP and carbon steel pipes has been made on the basis of the slopes of the charge density relationships. This differs from the comparison in the previous work (AFWL-TR-72-90)

TABLE XXX. CHARGE RELAXATION - STEEL VERSUS FRP PIPES

Pipe Length		Long		Short	
Flow Rate Gal/Min	Pipe Type	Slope $[Q_{out}/Q_{in}]$	$\Delta^{(1)}(\%)$	Slope $[Q_{out}/Q_{in}]$	$\Delta^{(1)}(\%)$
1200	Steel	0.65850	+19	0.71157	-6
	FRP	0.54433		0.75531	
600	Steel	0.30494	+2	0.56699	0
	FRP	0.29165		0.565464	
300	Steel	0.077377	-16	0.35792	+7
	FRP	0.090870		0.33404	

Analysis of Variance

Source of Variation	df	Sum of Squares	Mean Squares	$F_{x,2}$ (2)	$F_{x,7}$ (3)
Pipe Length	1	0.145999	0.145999	56.6	53.9
Pipe Type	1	0.000762	0.000762	0.3	0.3
Flow Rate	2	0.409503	0.204751	79.4	75.6
Length x Rate	2	0.011788	0.005894	2.3	-
Length x Type	1	0.001459	0.001459	0.6	-
Type x Rate	2	0.000560	0.000280	0.1	-
Length x Type x Rate	2	0.005159	0.002580	-	-

(1) $$\Delta = \frac{\text{Steel} - \text{FRP}}{\frac{\text{Steel} + \text{FRP}}{2}} \times 100\%$$

(2) Assume L x T x R is insignificant and is equivalent to error. Therefore, the F ratio for L x T x R cannot be determined.

(3) Assume all interactions, L x T x R, T x R, L x T & L x R, are insignificant and their sum is equivalent to the error. Therefore, F ratios cannot be determined for these interactions. Where blanks appear calculations were not possible.

which was done using relaxation time. The conclusions do not depend on which variable is used for the comparison.

Table XXX gives the slopes of the charge density relations for each pipe type, pipe length, and flow rate and a summary of the analysis of variance. The analysis of variance procedure determines F ratios which measure the significance of variables. The F ratios of 53.9 and 75.6 for pipe length and flow rate, respectively, indicate they are significant variables. Pipe type with an F ratio = 0.3 is not significant. The previous report (AFWL-TR-72-90) has found that the relaxation rate did depend on the type of pipe in which the fuel was flowing. Furthermore, with positively charged fuel, it had been found that fuel in FRP pipe relaxed slower than in steel pipe. Ignoring the analysis of variance, the best estimate of the difference between FRP and steel is a 1 per cent difference in relaxation rate with charged fuel relaxing faster in FRP pipe than in carbon steel pipe. The analysis of the variance test indicates that 1 per cent is not significantly different from zero.

The result is not in agreement with the results from the previous work where it was found that, in general, positively charged fuel relaxed slower in FRP than in carbon steel pipe. Negatively charged fuel relaxed faster in FRP than in steel pipe. Possible explanations for the variation between this work and the previous work are discussed in a later section.

A corresponding Table XXXI summarizes the calculations for the determination of charge generation in pipe.

TABLE XXXI. CHARGE GENERATION - STEEL VERSUS FRP PIPE

Flow Rate Gal/Min	Pipe Type	Value of Intercept ($\mu C/m^3$) Long	Short
1200	Steel	1.2	1.2
	FRP	2.2	0.8
600	Steel	0.2	0.4
	FRP	1.9	1.0
300	Steel	1.4	0.0
	FRP	1.6	0.9

In general, the charge generation increases with increasing flow rate and also with increasing length of pipe. FRP pipe generates more charge than steel but all the results are very low.

Further details of the results of the least squares analysis of the raw data are given in Table XXX and Appendix B.

d. Discussion of Results

The differences between the previous program and this effort are (1) temperature, (2) fuel, (3) additives, and (4) accuracy of determination of the slope.

The previous work was done at about 40°F whereas in this program the fuel was maintained at 77°F. It is possible that the differences between the FRP and carbon steel pipes are exaggerated at lower temperatures and that a significant difference at 40°F disappears at higher temperature. There is no information with respect to the effect of temperature on the difference between the pipes.

The previous program used Jet A while this effort used JP-4. It is possible that this factor caused the difference in the results. A more likely reason for the difference is the presence of additives in the JP-4 of the current program. The corrosion inhibitor could coat the walls of either the steel or FRP pipe and change its surface conductivity. If the corrosion inhibitor coated the metal wall, it would probably reduce its conductivity slightly. If on the other hand, it coated the wall of the FRP pipe, it would probably enhance its conductivity. Therefore, if absorption took place on either material it could tend to make the materials more nearly alike in surface conductivity. This is an interesting hypothesis, but unfortunately it was not possible to devise a method to measure the expected small changes in surface conductivity.

The last hypothesized reason for the difference between the results of the two programs is the method by which the slope of the lines for the FRP and carbon steel pipes was determined. As described earlier, although the previous program calculated and used relaxation times for comparison, it was the equivalent of using the slope of the line. The previous program used one point and the origin to determine the slope of the line. The assumption that the line goes through the origin is equivalent to saying that charge generation is zero. It is known that charge generation is not zero. The charge generation was measured but not at the same temperature as the relaxation rate was measured; therefore, the data cannot be used to determine the intercept. Only one data point was used to determine the slope; therefore, the precision of the determination of the slope cannot be determined. In the current program, the slope was determined from a minimum of six points and as many as 41 points in one case.

The determination of which factor was the main cause of the difference between the two results cannot be made.

The conclusions resulting from this test program are that with JP-4 containing corrosion inhibitors there is no significant difference between the rate of relaxation of charged fuel in FRP and carbon steel pipe. The charge generation was low in both types of pipes. The first conclusion differs from a conclusion in previous work (AFWL-TR-72-90) but the reason for that difference has not been resolved.

5. EFFECT OF TANK COATINGS ON CHARGE RELAXATION

a. Introduction

Epoxy-lined tanks and tank trucks are part of the so-called sanitary fuel systems. These systems prevent contamination of aviation fuels. Metal tanks rust and produce particulate in the fuel. Fiberglass reinforced plastic (FRP) pipe and epoxy-lined tanks do not expose aviation fuels to this type of contamination. However, there was some

TABLE XXXII. CHARGE RELAXATION AND GENERATION - FRP VERSUS CARBON STEEL PIPE (RESULTS OF LEAST SQUARES ANALYSIS)

Flow Rate	Pipe Configuration	Pipe Type	No. of Data Points	Range in Inlet Charge Density ($\mu C/m^3$) Maximum	Minimum	Slope	Intercept	Goodness of Fit (r^2)
1200	Short	Steel	14	119	-2.15	0.71157	1.167	0.998
1200	Short	FRP	24	64	-10.0	0.75531	0.827	0.998
1200	Long	Steel	9	28.2	-0.7	0.65850	1.214	0.995
1200	Long	FRP	6	62.0	-0.95	0.54433	2.186	0.998
600	Short	Steel	15	83	-0.9	0.56699	0.406	0.995
600	Short	FRP	41	52.5	-10.5	0.56564	1.048	0.988
600	Long	Steel	10	28.5	-0.5	0.30494	0.186	0.972
600	Long	FRP	11	58	-1.2	0.29165	1.935	0.994
300	Short	Steel	13	45	-0.3	0.35792	0.025	0.972
300	Short	FRP	18	33	-11.0	0.33404	0.877	0.943
300	Long	Steel	9	21.7	-0.2	0.77377	1.373	0.910
300	Long	FRP	7	36.5	-0.6	0.090870	1.620	0.997

concern that the rate of charge relaxation or dissipation might be slower in a lined tank than in a bare metal (or rust-coated) tank. This concern is certainly logical since the epoxy lining would be much less conductive than carbon steel and electrical charge on the fuel inside an epoxy-lined tank would theoretically have a more resistive path to ground. If the rate of charge relaxation were significantly slower in lined tanks, then regulations would have to be changed. For example, if charge relaxed slower, it would be necessary to wait a longer time between filling and gauging a tank. To quantify risks and assess the needs for changing regulations, a task involving the measurement of the rate of relaxation of charge in tanks of different coatings was undertaken. It had been decided to build a small test rig to allow side-by-side comparison of different coated identical drums. Coated 55-gallon drums were used as test receivers rather than full-size tanks because of their uniformity and ease of coating.

b. Experimental Set Up and Test Procedures

(1) Test Rig

A schematic of the test rig which was built for this task is shown in Figure 32. The test fuel is kept in a 55-gallon epoxy-lined storage reservoir. During tests, the fuel is pumped through a control valve, a rotameter, and a filter-monitor (Part No. 043589-52). The monitor is rated at 50 gpm. Most of the tests were carried out at 34 gpm which was maximum capacity of the pump. The monitor was used to produce a charge on the fuel. It was isolated from ground with Teflon® connectors. Therefore, a Keithley Electrometer could be used to measure the current off the filter housing. From the fuel monitor, the fuel was either circulated back to the fuel reservoir or directed into one of the test drums. The test drum was electrically isolated from the test rig and connected to ground only through another Keithley Electrometer. An electrostatic voltmeter was placed on a platform on the top of the test drum to allow measurement of surface voltage. At the completion of a test, the fuel was allowed to flow by gravity back to the test reservoir. The vapor space in both the test drum and reservoir were filled with nitrogen to prevent the possibility of explosion if incendiary sparks occurred. The piping in the system was 1-1/2 inches in diameter.

(2) Coated Drums

The tops were removed from three 55-gallon metal drums. A 1-1/2 inch female pipe coupling was welded to the side of each drum. The coupling was welded as close to the bottom as possible. Two of the drums were sandblasted. One of the drums was used as is after the cleaning by sandblasting. The second drum was coated with a two-coat epoxy. The primer coat was No. 578-R-1 and the finish coat was 578-C-1, both manufactured by the Chemical Coatings Division of Mobil Chemical Company. The coatings were prepared and applied by the manufacturer's directions and the specification MIL-C-4556D, for coating the interior of steel fuel tanks.

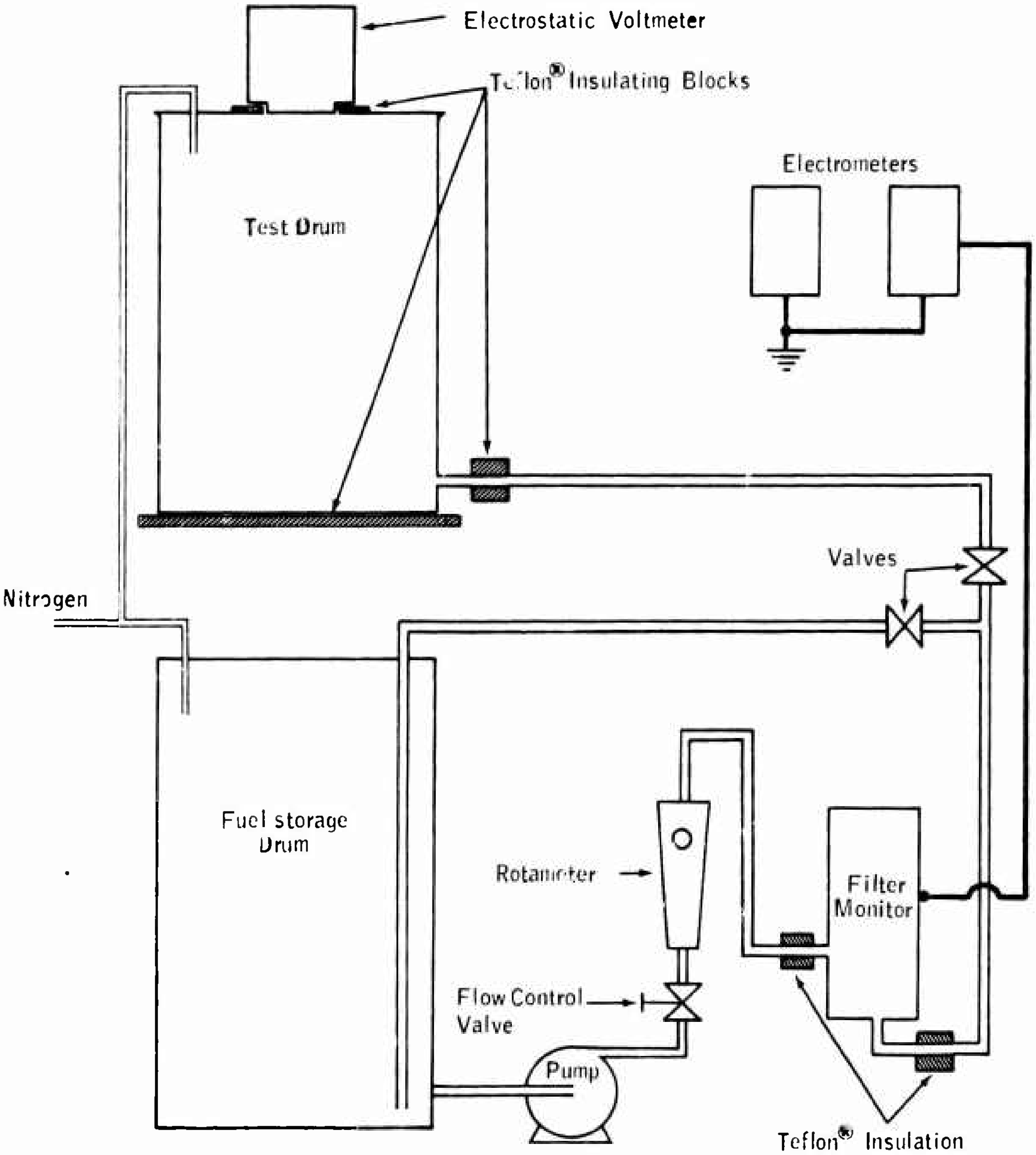

Figure 32 - Schematic of Test Rig for Testing Relaxation in Coated Drums

The third drum was coated with a Teflon® - like material, Halar®, by Applied Coating, Inc. of Pequannock, New Jersey. The drum was sand-blasted before the coating was applied. Halar® was used as the insulative coating instead of Teflon® since no supplier could be found that would guarantee a nonporous thin coating of Teflon®. Teflon® coating is very difficult to apply. Halar® is relatively easy to obtain in nonporous coatings. The resistivity of Halar® is only 1/10 that of Teflon® but it is still 1000 times that of the epoxy coating. Therefore, the comparison of bare metal, epoxy with a conductivity similar to jet fuel, and a very resistive coating, Halar® , could be made. The coating was spark tested by Applied Coating, Inc. to assure a pinhole-free coating.

(3) Test Procedure

Before beginning each series of runs, the vapor spaces above the fuel and in the receiver drum were purged with nitrogen. The fuel was then pumped through the filter and back to the storage reservoir to establish equilibrium. The conductivity of the fuel was measured. All meters and recorders were warmed up and zeroed just before use.

A run consisted of pumping the fuel from the storage reservoir into the test drum. The currents off the filter and the test drum were measured. The field strength meter was allowed to remain untouched until the surface voltage had decayed to a constant value. The distance from the fuel surface to the field strength meter was measured. The fuel was allowed to drain by gravity back into the storage reservoir while nitrogen was purging the vapor space of the drum. The run was repeated or the hose was switched to another test drum and the procedure was duplicated on the other drum. The conductivity of the fuel was measured after every second or third run during the day.

(4) Test Fuel

Several different Jet A type aviation turbo fuels were used in this program. First, a commercial Jet A with no additives and a rest conductivity of 30 pS/m was used. The test rig was then cleaned by running with clay-treated low conductivity fuels. A JP-4 additive package was added to the Jet A fuel to simulate the effect of using JP-4 fuel. Finally, a prostatic additive was added to increase the conductivity and the charging tendency.

c. Results and Discussion

About one hundred runs were made in the test rig to compare relaxation rates of charged fuel in the different drums. These runs are summarized in Table XXXIII. Each run produced a recorder trace (Figure 35 is an example of a typical trace) which showed field strength rising to a maximum when flow stopped and the drum was filled. It then decayed to either zero or a non-zero level. The initial field strength is the maximum value observed adjusted for a non-zero base line. The raw data are treated in the following manner:

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TABLE XXXIII. EFFECT OF TANK COATINGS ON CHARGE RELAXATION

Run No.	Drum Type	Conductivity[(1)] (pS/m @ (°C))	Current (μA) Off Filter	Current (μA) Off Drum	Ambient Temp(°C)	Distance From Meter to Fuel Surface (m)	Maximum Field Strength (kV/m)	Maximum Surface Voltage (kv)	Approximate Time to Decay (Sec)	Slope of Relaxation Line
2	E	29.7 (25)	-2.5	-	25	0.36	1.94	0.70	10	-0.177
3	E	-	-3.0	+0.5	25	0.37	2.74	1.03	10	-0.222
4	E	-	-3.0	+0.5	25	0.38	2.18	0.83	10	-0.292
5	E	-	-3.0	+0.6	25	0.38	2.74	1.04	10	-0.252
6	BM	-	-3.0	+0.7	25	0.38	3.56	1.35	10	-0.252
7	BM	30.1 (25)	-3.0	+0.7	25	0.38	4.11	1.56	10	-0.272
8	H	-	-3.0	+0.69	25	0.38	3.40	1.29	10	-0.210
9	H	-	-2.4	+0.6	25	0.38	2.81	1.07	10	-0.138
10	H	-	-3	+0.6	25	0.38	----------	----------Void	Recorder Malfunctioned	----------
Test Fuel Changed										
11	E	6.6 (29)	-1.1	+0.65	29	0.24	74.9	17.98	60	-0.0620
12	E	-	-1.1	+0.62	29	0.24	82.9	19.90	60	-0.0529
13	BM	-	-1.0	+0.65	29	0.24	113.	27.12	60	-0.0568
14	BM	-	-1.0	+0.60	29	0.24	500.	120.00	60	-0.0526
15	H	5.0 (29)	-1.0	+0.60	29	0.24	153	36.72	50	-0.0532
16	H	4.8 (28.5)	-1.0	+0.60	29	0.245	127	31.12	50	-0.0461
Numbers 17-19 Unintentionally Skipped.				Clay-treated fuel placed in Test Rig.						
20	E	-	-0.25	+0.18	32	0.245	28.4	6.96	90	-0.0431
21	E	3.2 (30.5)	-0.30	+0.24	32	0.245	36.2	8.87	80	-0.0386
22	E	-	-0.33	+0.26	32	0.25	36.9	9.22	80	-0.0375
23	BM	-	-0.33	+0.28	32	0.25	41.96	10.49	90	-0.0310
24	BM	2.9 (31)	-0.32	+0.26	32	0.25	42.96	10.74	90	-0.0312
25	BM	-	-0.32	+0.26	32	0.25	39.96	9.99	80	-0.0295
26	H	-	-0.34	+0.26	32	0.25	51.57	12.89	60	-0.0409
27	H	3.4 (31.5)	-0.46	+0.36	32	0.25	99.7	24.92	90	-0.0374
28	H	-	-0.43	+0.34	32	0.245	84.5	20.70	70	-0.0317
29	BM	-	-0.42	+0.33	32	0.25	91.9	22.98	90	-0.0349
30	BM	5.5 (29)	-0.75	+0.45	29	0.25	39.04	9.76	50	-0.0558
31	BM	-	-0.9	+0.65	29	0.25	126.09	31.52	60	-0.0473
32	BM	4.4 (29)	-0.8	+0.60	29	0.25	131.08	32.77	60	-0.0431
33	H	-	-0.85	+0.60	29	0.26	146.6	38.12	60	-0.0471
34	H	4.4 (31)	-0.80	+0.60	29	0.255	145.9	37.20	60	-0.0260
35	H	-	-0.75	+0.55	29	0.255	150.8	38.45	60	-0.0307

LEGEND: E = Epoxy, BM = Bare Metal, H = Halar®, R = 1/4" Al Rod.

(1) Where blanks appear, measurements were not made.

TABLE XXXIII. EFFECT OF TANK COATINGS ON CHARGE RELAXATION (CONTINUED)

Run No.	Drum Type	Conductivity (pS/m @ (°C))	Current (uA) Off Filter	Current (uA) Off Drum	Ambient Temp (°C)	Distance From Meter to Fuel Surface (m)	Maximum Field Strength (kV/m)	Maximum Surface Voltage (kv)	Approximate Time to Decay (sec)	Slope of Relaxation Line
36	E	4.9 (32)	-0.9	+0.60	29	0.255	142.12	36.24	70	-0.0427
37	E	-	-0.8	+0.60	29	0.255	142.14	36.25	70	-0.0379
38	E	4.4 (32)	-0.75	+0.55	29	0.255	131.14	33.44	70	-0.0383
New Fuel - Jet A containing JP-4 Type Additive Package (DCI-4A + Methyl Cellosolve)										
39	E	6.6 (26)	-0.5	+0.35	27	0.255	32.70	8.34	40	-0.0759
40	E	-	-0.7	+0.50	27	0.26	45.04	11.71	40	-0.0770
41	E	6.0 (27)	-0.72	+0.50	27	0.26	44.04	11.45	40	-0.0755
42	E	-	-0.72	+0.50	27	0.26	44.32	11.52	40	-0.0779
43	H	-	-0.75	+0.50	27	0.26	78.50	20.41	30	-0.0927
44	H	5.8 (28)	-0.75	+0.50	27	0.26	93.00	21.58	30	-0.0960
45	H	-	-0.75	+0.50	27	0.255	75.0	19.12	30	-0.0927
46	BM	-	-0.75	+0.50	27	0.26	45.26	11.77	50	-0.0631
47	BM	6.0 (28.5)	-0.75	+0.50	27	0.26	45.26	11.77	40	-0.0662
48	BM	-	-0.75	+0.50	27	0.26	51.24	13.32	40	-0.0663
New Fuel - Clay Treated Jet A										
49	E	-	-0.26	+0.24	18	-	235	-	440	-0.00952(?) (Valve Not Closed)
50	E	1.1 (23.5)	-0.29	+0.27	18	0.21	235	49.35	440	-0.00690
51	E	-	-0.31	+0.28	18	0.21	218	45.78	440	-0.00713
52	BM	-	-0.30	+0.28	18	0.215	218	46.87	440	-0.00775
53	BM	1.1 (24)	-0.28	+0.26	18	0.215	218	46.87	440	-0.00801
54	BM	-	-0.20	+0.18	18	0.22	310	68.2	480	-0.00528
55	BM	1.0 (21)	-0.20	+0.19	18	0.22	340	74.8	480	-0.00549
56	BM	-	-0.22	+0.20	18	0.215	225	50.52	480	-0.00723
57	BM	-	-0.21	+0.19	18	0.35	63	23.8	480	-0.00397 (Drum half filled)
58	BM	1.1 (23)	-0.13	+0.11	18	0.215	235	50.52	450	-0.00627 (Drum filled @ 1/2 flow rate)
59	E	-	-0.23	+0.21	18	0.215	355	76.32	280	-0.0113
60	E	1.05 (23.5)	-0.22	+0.20	18	0.215	355	76.32	290	-0.00990
61	E	-	-0.22	+0.20	18	0.355	57.0	20.24	280	-0.0109
62	H	1.1 (24)	-0.22	+0.20	18	0.21	400	84	200	-0.0189
63	H	-	-0.22	+0.20	18	0.21	3.50	0.74	[illegible]	-0.0151 (Field Strength Meter rezeroed on empty Halar© drum

LEGEND: E = Epoxy, BM = Bare Metal, H = Halar©, R = 1/4" Al Rod.

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TABLE XXXIII. EFFECT OF TANK COATINGS ON CHARGE RELAXATION (CONCLUDED)

Run No.	Drum Type	Conductivity (pS/m @ (°C))	Current (μA) Off Filter	Current (μA) Off Drum	Ambient Temp (°C)	Distance From Meter to Fuel Surface (m)	Maximum Field Strength (kV/m)	Maximum Surface Voltage (kv)	Approximate Time to Decay (Sec)	Slope of Relaxation Time
	Bare Metal Drum was sandblasted to remove rust layer.									
65		1.9 (19)	-0.23	+0.20	19	0.24	104	24.96	240	-0.0147
66			-0.27	+0.24	19	0.24	78	18.72	240	-0.0148
67	BM	-	-0.30	+0.26	19	0.24	83.2	19.97	260	-0.0159
68	BM	2.2 (23)	-0.27	+0.24	19	0.24	137	32.88	240	-0.0179
69	E	-	-0.28	+0.24	19	0.24	87	20.88	180	-0.0189
70	E	-	-0.27	+0.24	19	0.25	104	26.00	180	-0.0164
71	E	2.2 (23.5)	-0.28	+0.25	19	0.24	98	23.52	180	-0.0175
72	H	-	-0.30	+0.26	19	0.23	103	23.69	100	-0.0178
73	BM	2.0 (23.5)	-0.28	+0.24	19	0.24	83	19.92	180	-0.0202
74	BM	-	-0.22	+0.18	17	0.255	53	13.52	120	-0.0233
75	BM	2.1 (19)	-0.25	+0.21	17	0.25	63	15.75	120	-0.0221
76	BM&R	-	-0.27	+0.22	17	0.25	65	16.25	120	-0.0225
77	BM&R	1.9 (19)	-0.28	+0.23	17	0.25	104	26.00	120	-0.0233
78	E&R		-0.27	+0.23	17	0.255	63.5	16.19	120	-0.0254
79	E&R	2.0 (19)	-0.26	+0.22	17	0.255	57.5	14.66	120	-0.0240
80	E	-	-0.26	+0.22	17	0.255	65.3	16.65	120	-0.0250
81	E	2.1 (19.5)	-0.25	+0.21	17	0.255	57.3	14.61	120	-0.243
82	H	-	-0.26	+0.21	17	0.25	74.7	18.68	80	-0.0211
83	H	2.0 (19)	-0.25	+0.20	17	0.24	97	23.28	80	-0.0173
84	H&R	-	-0.26	+0.21	17	0.24	46	11.04	80	-0.0217
85	H&R	2.1 (19)	-0.24	+0.20	17	0.24	38.7	9.29	70	-0.0225
86	BM&R	-	-0.25	+0.20	17	0.25	37.6	9.40	80	-0.0263
87	BM	2.2 (19)	-0.24	+0.19	17	0.24	39.6	9.50	80	-0.0268
	DCI-4A added to fuel									
88	BM	-	-0.15	+0.10	17	0.245	17.6	4.31	50	-0.0478
89	BM	3.1 (19)	-0.14	+0.10	17	0.24	18.3	4.39	50	-0.0396
90	BM&R		-0.14	+0.10	17	0.245	17.7	4.34	50	-0.0445
91	E&R	3.1 (19)	-0.15	+0.10	17	0.24	16.6	3.98	50	-0.0536
92	E		-0.12	+0.08	17	0.24	12.5	3.00	50	-0.0539
93	E		-0.12	+0.08	17	0.24	13.3	3.19	50	-0.0527
94	H		-0.13	+0.09	17	0.24	12.0	2.88	30	-0.0556
95	BM	3.1 (19.5)	-0.13	+0.09	17	0.24	16.4	3.94	50	-0.0358
										(Hitec E-515 + No. 6 fuel oil added to increase conductivity)
96*	BM		-4.5	+2.8	17	0.21	68.5	14.38	10	-0.164
97	BM	66. (18.5)	-4.2	+2.5	17	0.21	68.5	14.38	10	-0.200
98	BM&R		-3.9	+2.5	17	0.21	75.5	15.86	10	-0.168
99	E&R		-4.3	+2.6	17	0.21	57.5	12.08	10	-0.181
100	E	49.5 (19)	-3.9	+2.5	17	0.205	63.2	12.96	10	-0.174
101	E		-3.7	+2.4	17	0.205	68.2	13.98	10	-0.152
102	H	46.7 (19.5)	-3.7	+2.4	17	0.20	36.8	7.36	10	-0.152

LEGEND: E = Epoxy, BM = Bare Metal, H = Halar©, R = 1/4" Al Rod.

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The recorder trace of the decay curve was converted to a relaxation rate by selecting several (2 up to 10) points of field strength versus time. Field strength at time (t) was measured as the difference in the recorder values at time (t) and the final base line. A plot of the logarithm of the ratio of the field strength at time (t) to the initial field strength was made for each run. A line was drawn through the points and the slope of the line was calculated. This method of data analysis gave a straight line and gave consistent numbers even when the initial field strength varied.

Comparisons among the three drums were made at rest conductivity levels which ranged from 1 to 50 pS/m. Fuel temperatures varied from 17 to 32°C. The fuel was positively charged by the filter in all cases.

Figure 33 is a plot of the relaxation rate for the epoxy and bare metal drums. The numbers plotted are actually the averages of the several runs made each day with each drum type. From the figure, it can be seen that the results at low conductivities, i.e., less than 10 pS/m, seem to fall along a straight line. Most of the averages for the epoxy drum lie above the averages for the bare metal drum. That is, the charged fuel relaxes faster in the epoxy drum than in the bare metal drum. At high conductivity (30 and 50 pS/m) the reverse is true, fuel relaxes faster in bare metal. It is also apparent from the graph that if a straight line represents the function of relaxation rate and conductivity, the variability at high conductivities is very large. It is true that the variability in this region is large because the relaxation is so fast that only two points can be read off the recorder trace. The error in the determination of the slope can in these cases be large. If the numbers are accurate, the function of relaxation rate versus conductivity is certainly not linear. Multiple linear regression analysis was carried out on the total set of points. Fuel temperature, rest conductivity, and drum type were used as the independent variables. The result of the analysis was that drum type, epoxy versus bare metal (Teflon® will be discussed later), is not a significant variable. This means that epoxy-lined vessels are equivalent to bare metal ones with respect to charge relaxation.

No attempt was made to fit the points of relaxation rate versus conductivity to nonlinear equations.

Instead the high conductivity points were ignored as being subject to considerable error, and the analysis rerun on only the data below 10 pS/m conductivity. In this case, drum type was a significant variable, as were fuel conductivity and temperature. Figure 34 is an expanded plot of the low conductivity data points. The relaxation rates that are plotted here have been corrected to a temperature of 25°C using the temperature dependence determined by the regression analysis. At the two points which are plotted at a relaxation rate of $-0.052\ sec^{-1}$, the conductivity varied over the three runs. From this plot there appears to be a linear dependence of relaxation rate on conductivity but the relaxation rate may also depend on something other than conductivity and temperature.

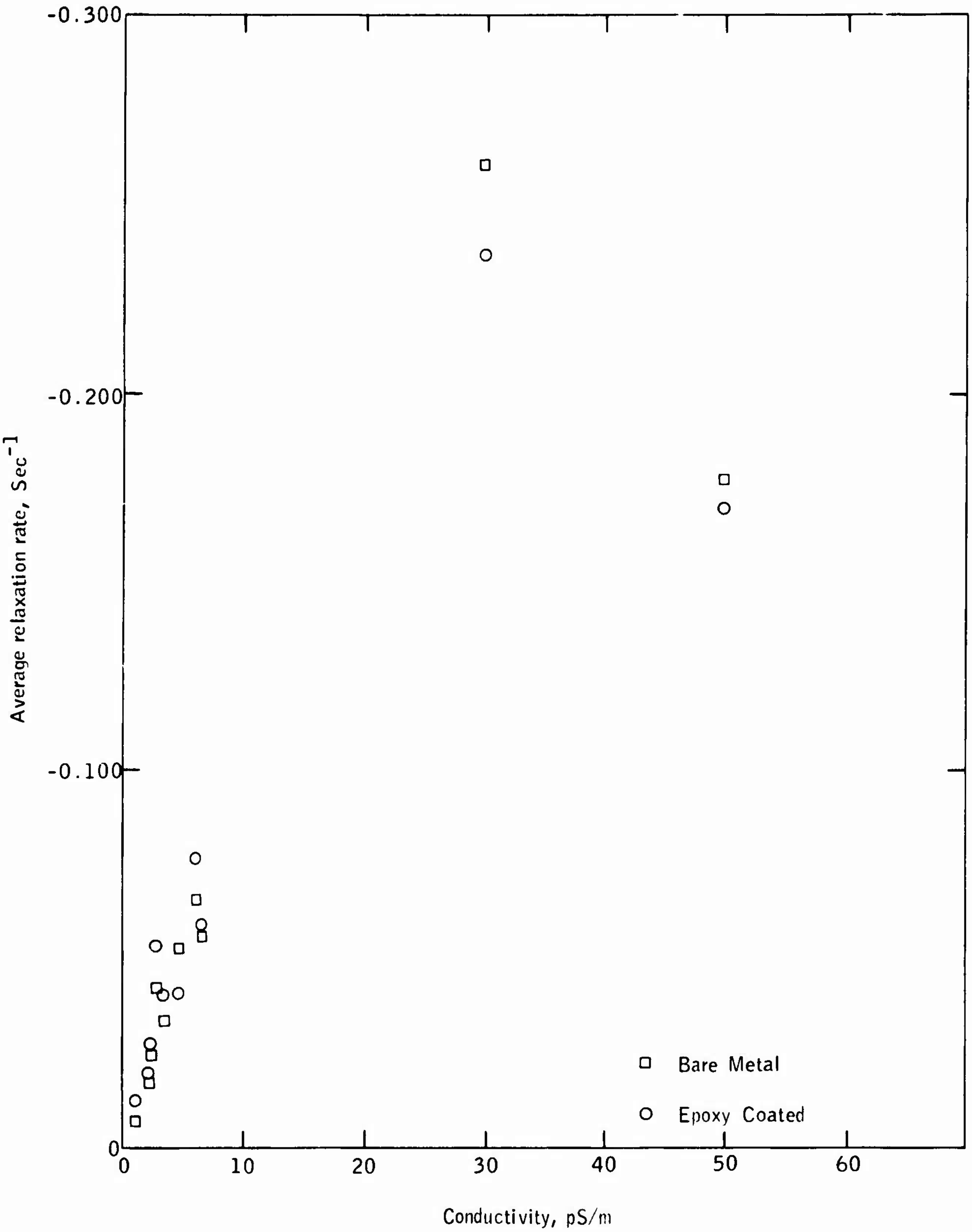

Figure 33 - Fuel Relaxation Rate versus Conductivity
(Steel versus Epoxy Drums)

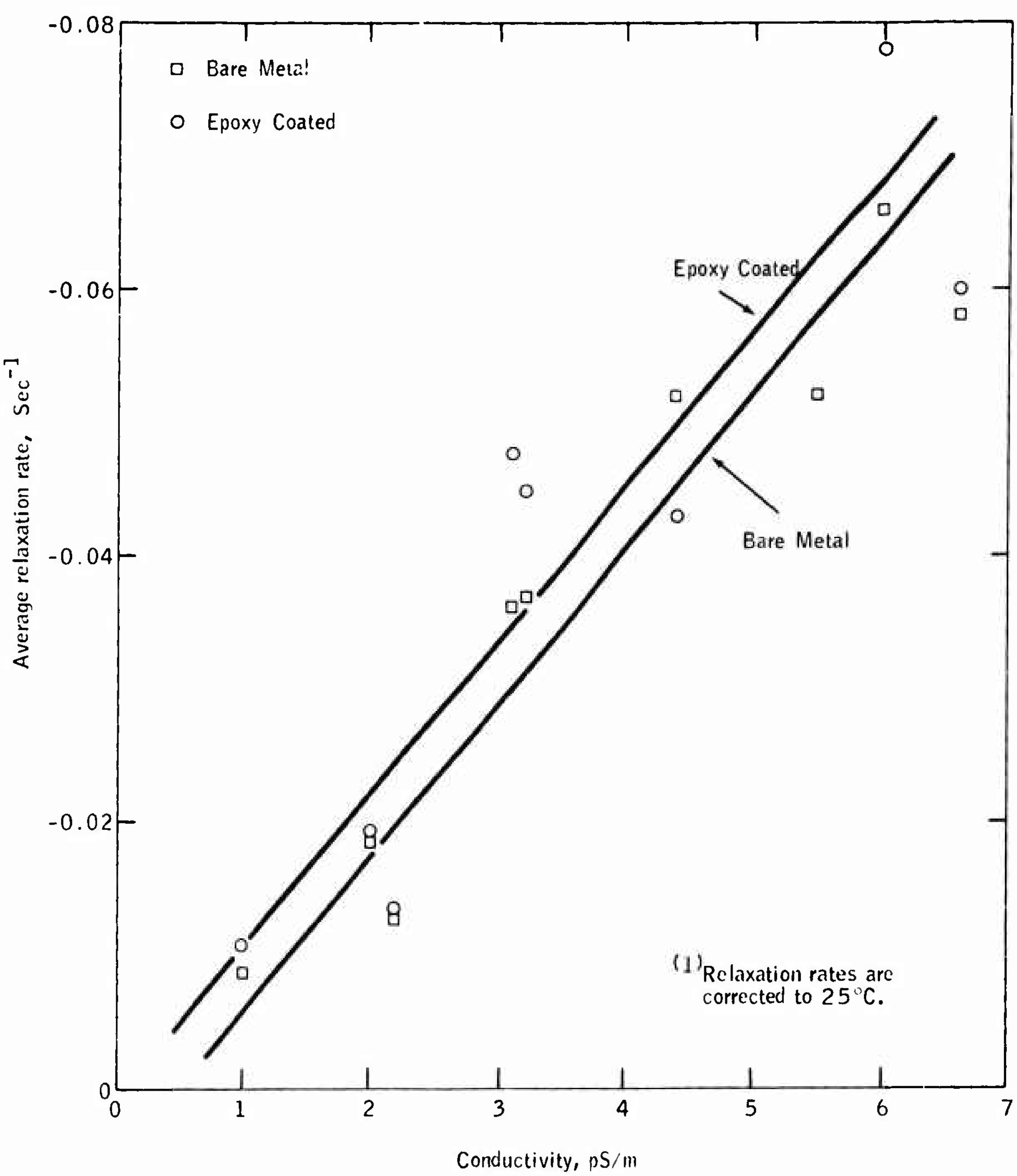

Figure 34 - Relaxation Rate[1] versus Conductivity (Fuel Conductivity < 10PS/m) Steel versus Epoxy Drums

In this region of rest conductivity, the fuel relaxes faster in the epoxy drum than in the bare metal drum. This was contrary to expectations of slower or equal relaxation rates. At a temperature of 25°C and a fuel conductivity of 3 pS/m the fuel in an epoxy-coated drum would relax 16 per cent faster than fuel in a bare metal drum.

The Halar® -coated drum was different from the other two in that the field strength in the drum never returned to zero after once filling it with charged fuel. The field strength meter fell to about 75 per cent of the maximum field strength and remained constant. The charge was in the Halar® layer since draining the fuel from the drum had very little effect on the measured field strength. The charge in the coating did not especially decay even over a weekend. Repeatedly filling the drum with the same fuel to the same charge level did not change the base line. In other words, the charge did not continually build up on the coating but reached a nonzero equilibrium point. The base line did shift with fuel changes. Because of this base line shift for the Halar® -coated drum, the relaxation rates are measurement of the rate of decay toward the final base line. For the epoxy and bare metal drums the final base line was always very close to zero.

The rates of relaxation of charged fuel in the Halar® -coated drum was erratic but similar to that for the other drums. In general, there was a strong dependence on rest conductivity.

These effects are shown dramatically in Figure 35 where tracings of the field strength output of three runs have been made. The first half of the curves show the increase in field strength as the charged fuel enters the drums. The maximum height of the curve is dependent on the fillrate, incoming charge density, conductivity and fill depth. When these are all controlled, the maximum field strength is very consistent. The field strength in the epoxy and bare metal drums decays nicely to essentially zero. Although the initial rate of decay for the Halar® -coated drum is similar to the other two drums, the charge relaxation stops long before the field strength reaches zero. The relaxation rates listed in the data table are those for the initial rate of relaxation. Since the amount of decay was less than for the other drums and the field strength meter is less accurate at the higher field strength levels, the rates for the Halar® -coated drum are less precise than for the other drums. The initial relaxation rates were similar for the Halar® -coated and the other two drums. As found for the other drums, the dominant effect on relaxation rate was the rest conductivity of the fuel.

Cleaning the bare metal drum by sandblasting had essentially no effect on the rate of relaxation of charged fuel. This was done to find out whether rust accounted for the apparent slower relaxation rate of the metal drum.

Addition of a 1/4-inch-diameter aluminum rod as a ground wire in the fuel also had no effect on the relaxation rate. No other metal

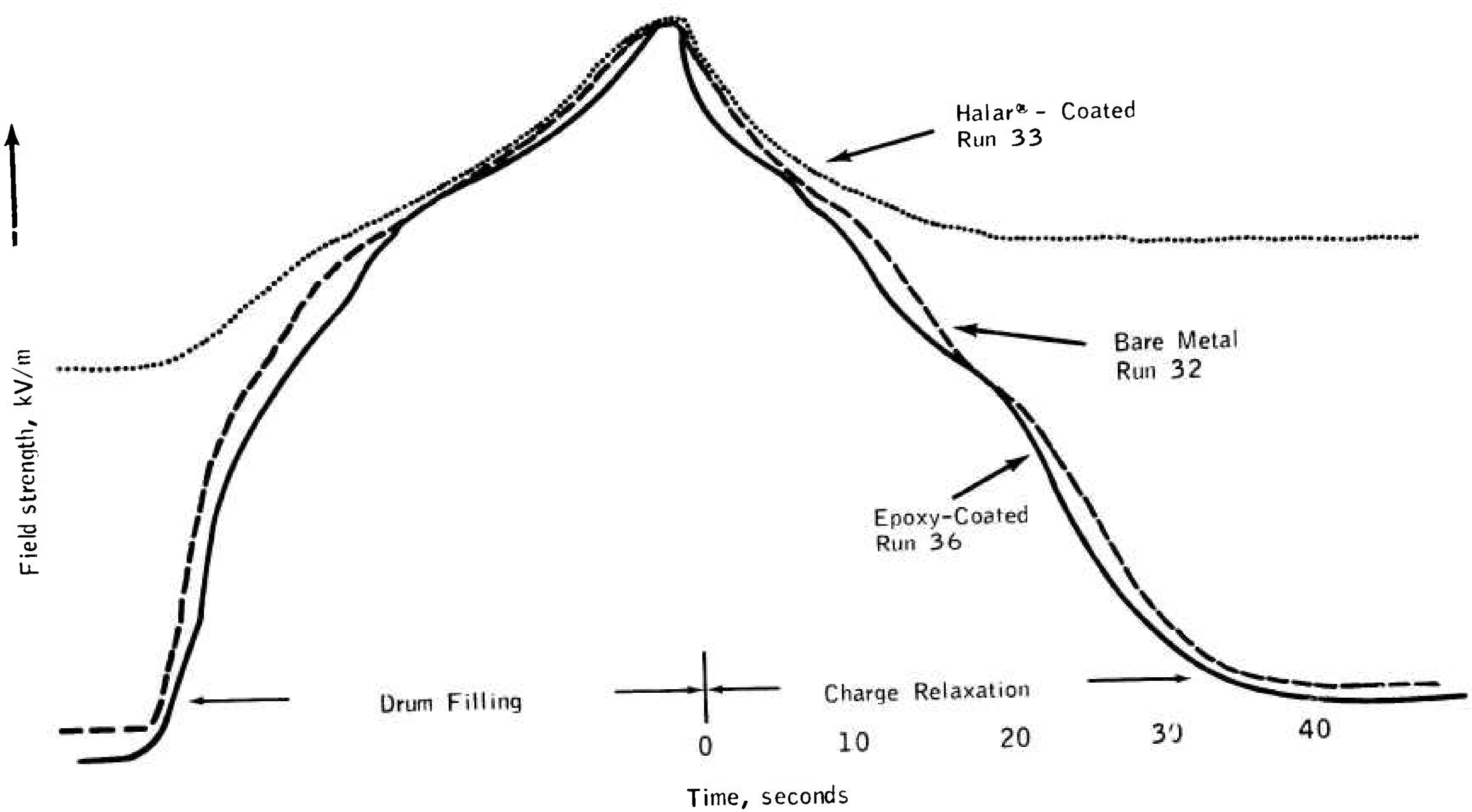

Figure 35 - Field Strength Relaxation Curves - Epoxy versus Halar®

devices were tested because the results on epoxy-coated drums were so persuasive that it was apparent that additional charge relaxation devices were unnecessary.

d. Summary of Results

Although the results of this test program were surprising, the conclusion can be made that no more stringent safety standards are required with epoxy-coated vessels than are currently in effect for unlined metal tanks. It had been expected that charged fuel would relax at a slower or equal rate in an epoxy-lined vessel compared to an unlined vessel. The result that fuel relaxes 16 per cent faster in epoxy has not been explained. One possible explanation which has not been tested is that the difference is a measure of drum-to-drum variability. The test program made no measurement of this factor.

The conclusion is the acceptance of the null hypothesis, epoxy-lined tanks are no worse than bare metal ones with respect to charge relaxation.

However, the fact that the electrical properties of the coating are important is apparent from the comparison of the charge relaxation behavior in Halar® versus epoxy-lined drums. It would be desirable therefore to require that epoxy coating materials exhibit an electrical conductivity no lower than fuel, 10 pS/m, for example. The volume resistivity of epoxy pipe [paragraph 3. b. (2)] is reported to be 5×10^{14} ohm-cm. A maximum value of 10^{14} ohm-cm for epoxy coatings would appear to be consistent with observed values for plastic pipe.

SECTION IV

CONCLUSIONS

1. Based on field tests at two air bases with a limited number of JP-4 fuels, present design DOD filter-separators used in either hose carts or fueler trucks deliver to aircraft a low level of electrostatic charge.

2. The low levels of static charge observed in fueling with JP-4 are the result of a combination of factors that make military fueling with JP-4 less critical than commercial fueling with Jet A - greater relaxation volume in DOD filter-separator units, greater fuel conductivity and lower average fueling rate.

3. When field data on JP-4 static charge generation is compared with the field data on Jet A static charge generation collected by the Coordinating Research Council in terms of a probability distribution, it is possible to conclude that the probability of a high charging condition when fueling aircraft with JP-4 is lower than with Jet A.

4. Tests on JP-4 fuels made to Military Specification MIL-T-5624J show no relationship between fuel conductivity and charging tendency; however, these properties appear to be related to the type of corrosion inhibitor used and qualified to MIL-I-25017.

5. Tests on DOD filter-separators show that new filter-elements exhibit a high initial charge before reaching a lower equilibrium value which then tends to increase in charging tendency with fuel thruput. Teflon® - coated screen separators charge at about half the level of paper separators.

6. The combination shrouded element type of DOD filter-separator (MH-2B) exhibits a lower static charge output than the older two-stage type (MH-2A) mainly because of internal case design.

7. Examination of the charge decay exhibited by the most critical of the tests conducted in the field shows that the 30 seconds of residence time provided in fixed facilities downstream of a filter as a new design criterion is still a valid rule.

8. Field data and test rig data on hose carts are consistent when compared in terms of charge levels versus flow rate. While charge density tends to level off at or above rated flow, the current delivered into aircraft rises exponentially, i.e., doubling the flow rate increases streaming current carried with the fuel four times.

9. Tests on different POL hydrant systems indicate a lower charging tendency for the aluminum system compared with carbon steel pipe, probably because of the corrosion products present in the latter.

10. Charge levels were too low in the field to measure surface voltages in an R-9 fueler truck being filled with JP-4 fuel charged through a DOD filter-separator unit. However, in the Exxon Full-Scale Facility, tests in a tank truck using the JP-4 additive package showed that surface voltage was directly related to incoming charge density and fuel conductivity.

11. It was not possible to measure the efficiency of the Static Charge Reducer (SCR) in the field because of low input charge level. However, in the Exxon Full-Scale Facility, tests with the SCR showed that surface voltage in a tank was determined by the input charge density whether or not the SCR was in the circuit. This result is different than when delivering fuel from the SCR into plastic pipe where high surface voltages can develop with fuel averaging zero net charge.

12. The SCR required several minutes of start-up time to function as a charge reducer and the efficiency of reduction was related to fuel polarity and charge level; both factors had been observed in earlier work. Deposits from the field SCR were analyzed and found to contain metal debris typical of fuel system materials.

13. Spark discharges were observed when bottom filling a tank truck with charged fuel at a surface voltage as low as 1 kv when an unbonded charge collector was present. In the absence of these sources of spark energy, no discharges were observed up to a surface voltage of 28 kv.

14. JP-4 fuel of MIL-T-5624J quality showed the same charge relaxation characteristics when pumped through FRP pipe as through steel pipe regardless of the polarity of the input charge. This result is contrary to the earlier data obtained with Jet A fuel and may be related to the presence of corrosion inhibitor in JP-4 which would adsorb on pipe walls and lower their surface resistivity.

15. In drum filling tests under controlled conditions, epoxy coatings cause charged fuel to relax in surface voltage at the same rate or higher rate than bare metal without coatings. However, a fluorinated coating with a resistivity several orders of magnitude greater than epoxy held charges on its surface for several days.

16. The presence of a rod or cable does not affect the rate at which a charged fuel relaxes regardless of whether a coating was used.

SECTION V

RECOMMENDATIONS

1. Consideration should be given in design specifications for DOD filter-separators to provide maximum charge relaxation volume after the final elements. Operating manuals should draw attention to the importance of relaxation volume in fuel handling systems, particularly in aircraft fueling.

2. Special precautions should be observed in filling an empty filter vessel after installing new elements due to their high initial charging tendency. Slow filling, preferably by gravity, is recommended during the air bleed period to avoid vapor space discharge.

3. Continued use of low charging Teflon® - coated screens in preference to paper separator elements is recommended until a procedure has been developed for qualifying other types of low charging elements.

4. Further investigation should be made of the operating procedures needed to meet the break-in requirements of new filter elements. In addition, the thruput limits of filter elements in terms of increasing charging tendency should be investigated.

5. Additives specified in MIL-I-25017 for control of pipeline corrosion should be tested for electrical conductivity and charging tendency response in reference fuels using laboratory procedures.

6. A wider survey of JP-4 fuels in the field is desirable to measure electrical conductivity and charging tendency in MIL-T-5624J fuels in order to relate these properties to the type of corrosion inhibitor used.

7. The continued use of the Static Charge Reducer should be discouraged unless a monitoring program is adopted.

8. Aluminum, stainless steel, FRP or coated metal as materials for POL hydrant systems are preferable to carbon steel because of their lower charging tendency and freedom from corrosion deposits.

9. Epoxy coatings for vessels should be required to satisfy a maximum resistivity requirement of 10^{14} ohm-cm.

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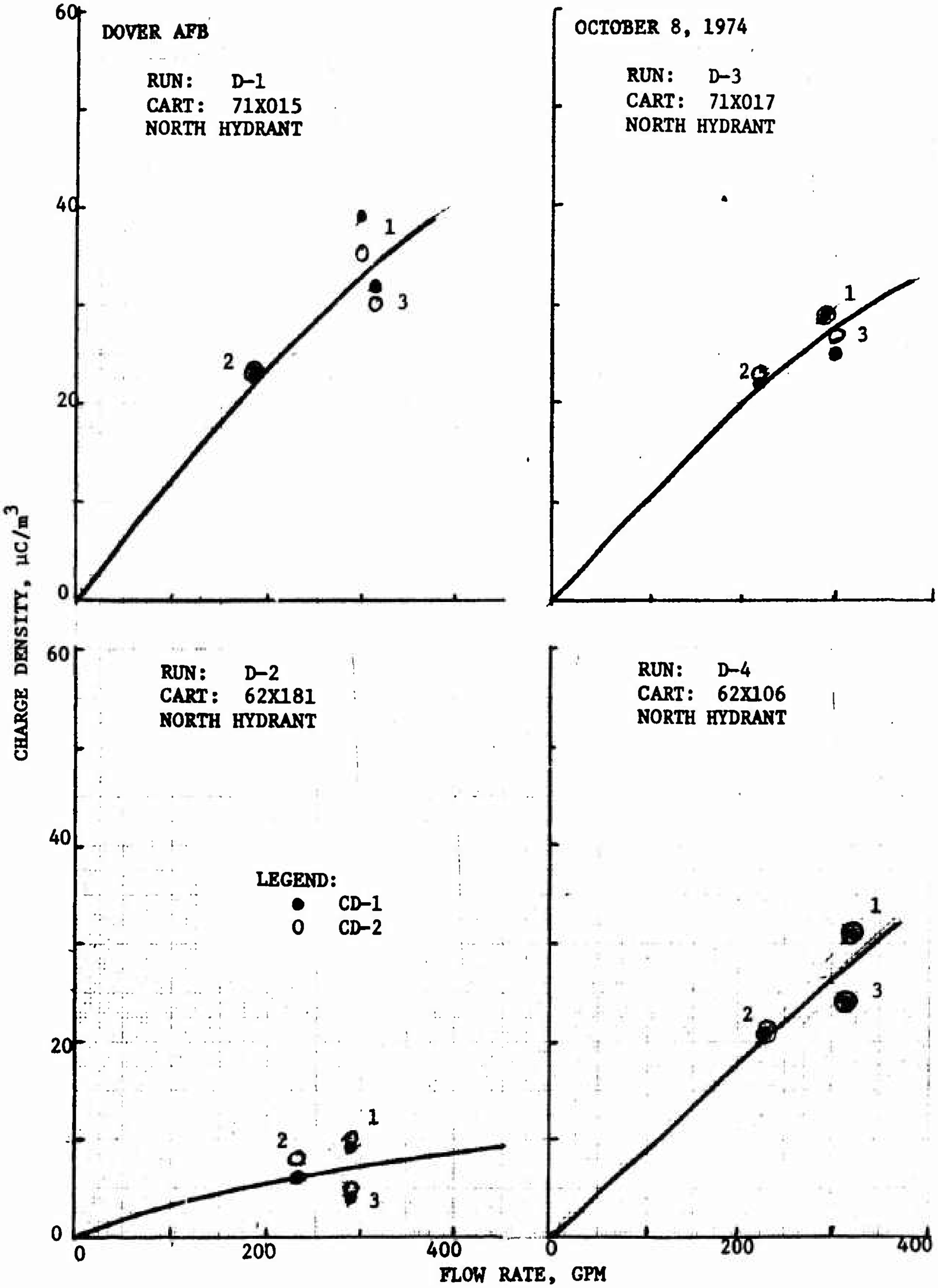
APPENDIX A

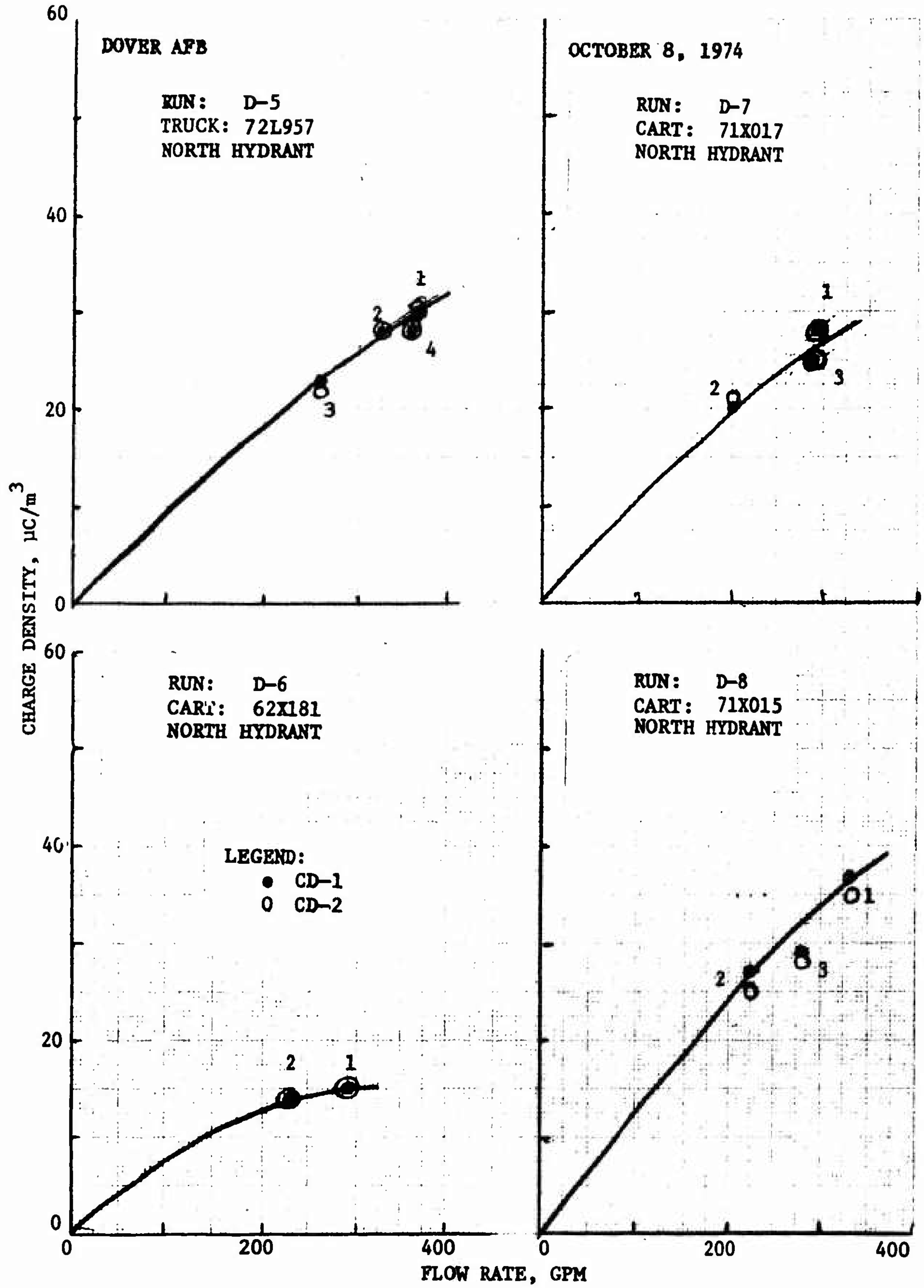
CHARGE DENSITY FIELD DATA - INDIVIDUAL RUNS

DOVER AFB - KELLY AFB

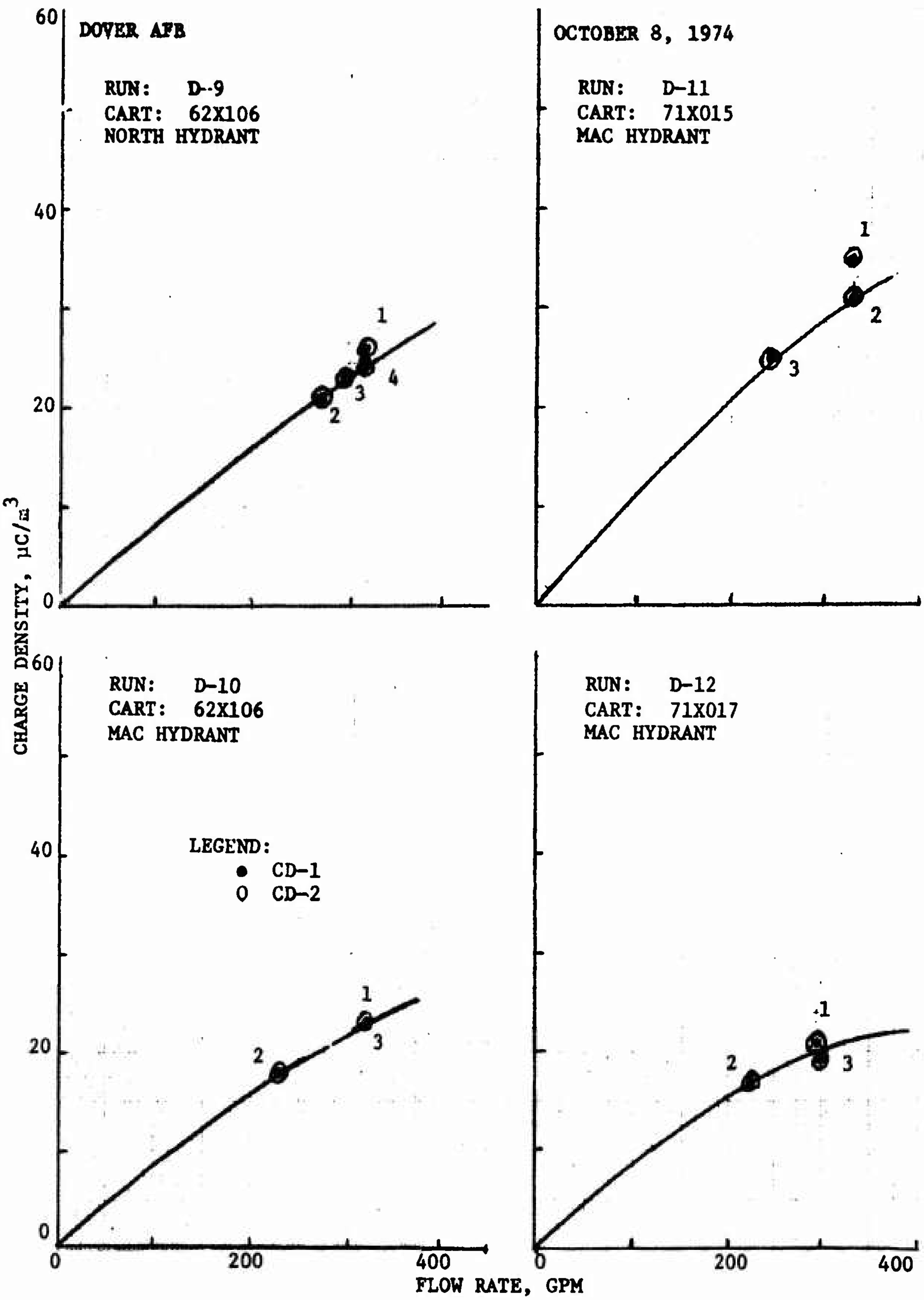
Data contained in Appendix A figures represent charge density measurements obtained over a range of fuel flow rates starting at the maximum flow rate obtainable on each vehicle. Measurements were made in two to four descending increments after allowing charge density equilibrium to be reached at each point. Repeats of charge density were obtained by returning to maximum flow in similar flow increments. The numbers where given beside the data points represent the succession of readings.



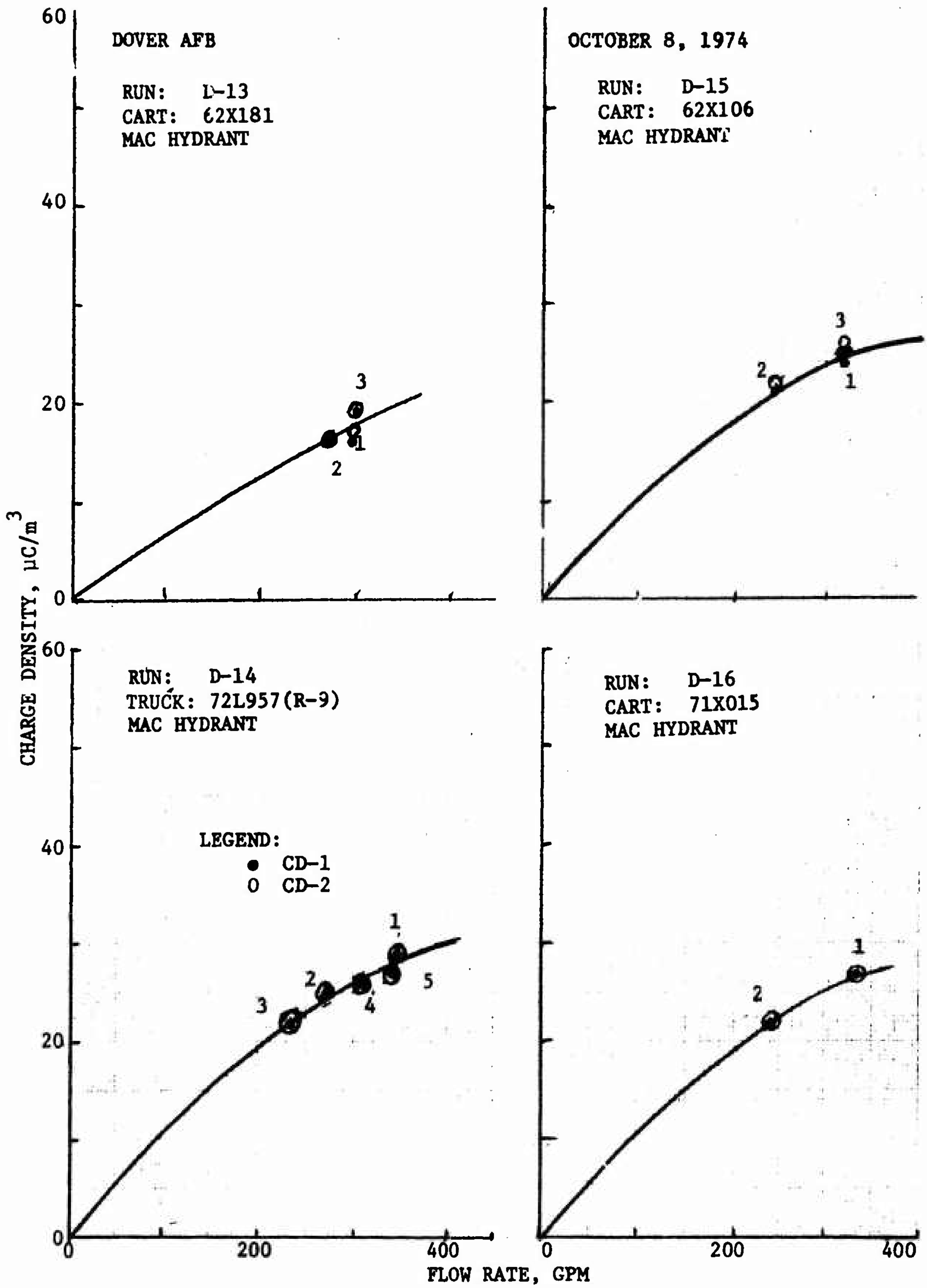
DOVER AFB
OCTOBER 8, 1974
RUN: D-1
CART: 71X015
NORTH HYDRANT
RUN: D-3
CART: 71X017
NORTH HYDRANT
RUN: D-2
CART: 62X181
NORTH HYDRANT
RUN: D-4
CART: 62X106
NORTH HYDRANT
LEGEND:
● CD-1
O CD-2
CHARGE DENSITY, μC/m³
FLOW RATE, GPM
0
20
40
60
200
400
1
2
3



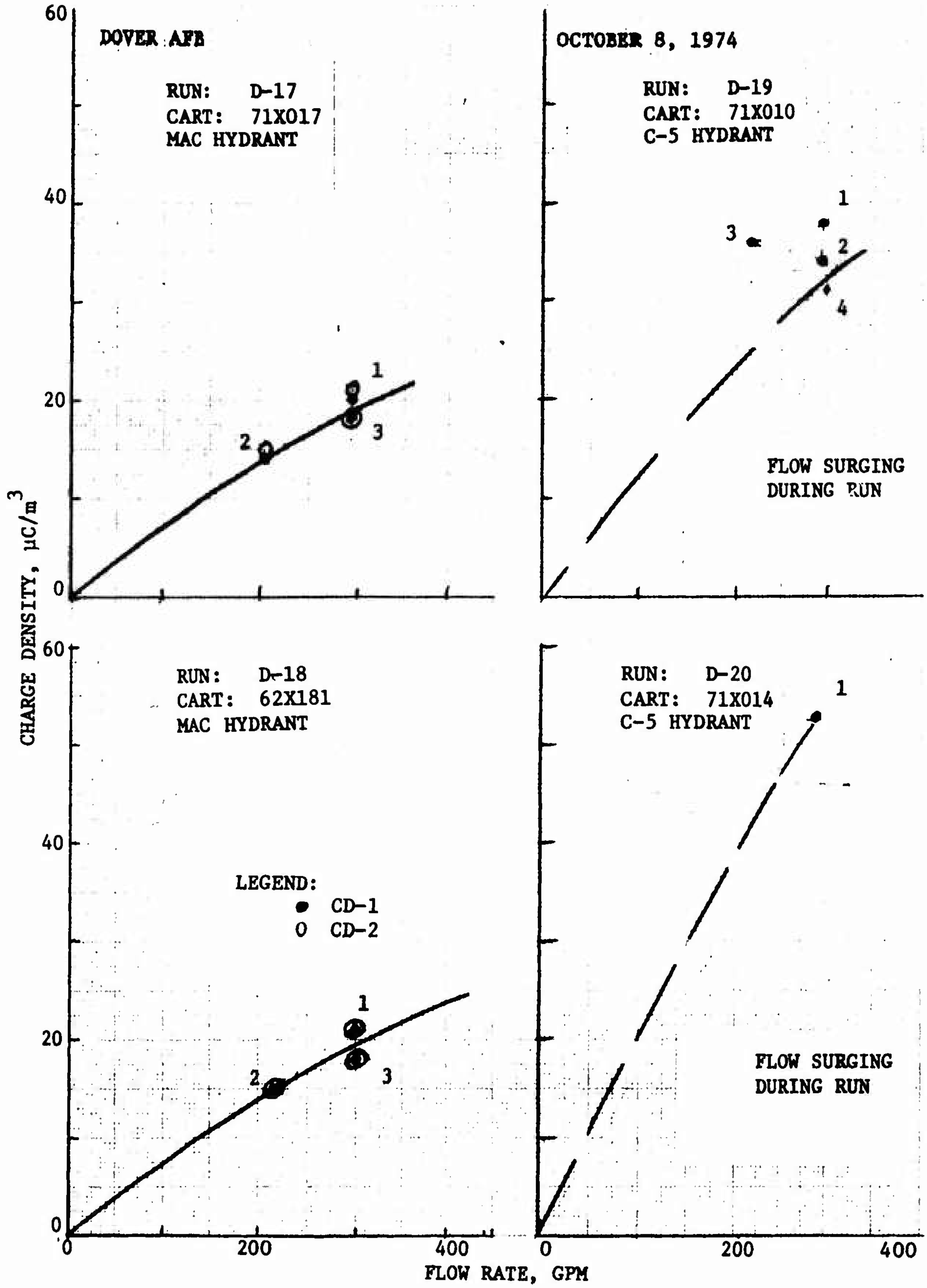
DOVER AFB
OCTOBER 8, 1974
RUN: D-5
TRUCK: 72L957
NORTH HYDRANT
RUN: D-7
CART: 71X017
NORTH HYDRANT
RUN: D-6
CART: 62X181
NORTH HYDRANT
RUN: D-8
CART: 71X015
NORTH HYDRANT
LEGEND:
● CD-1
O CD-2
CHARGE DENSITY, μC/m³
FLOW RATE, GPM
0
20
40
60
200
400
1
2
3
4

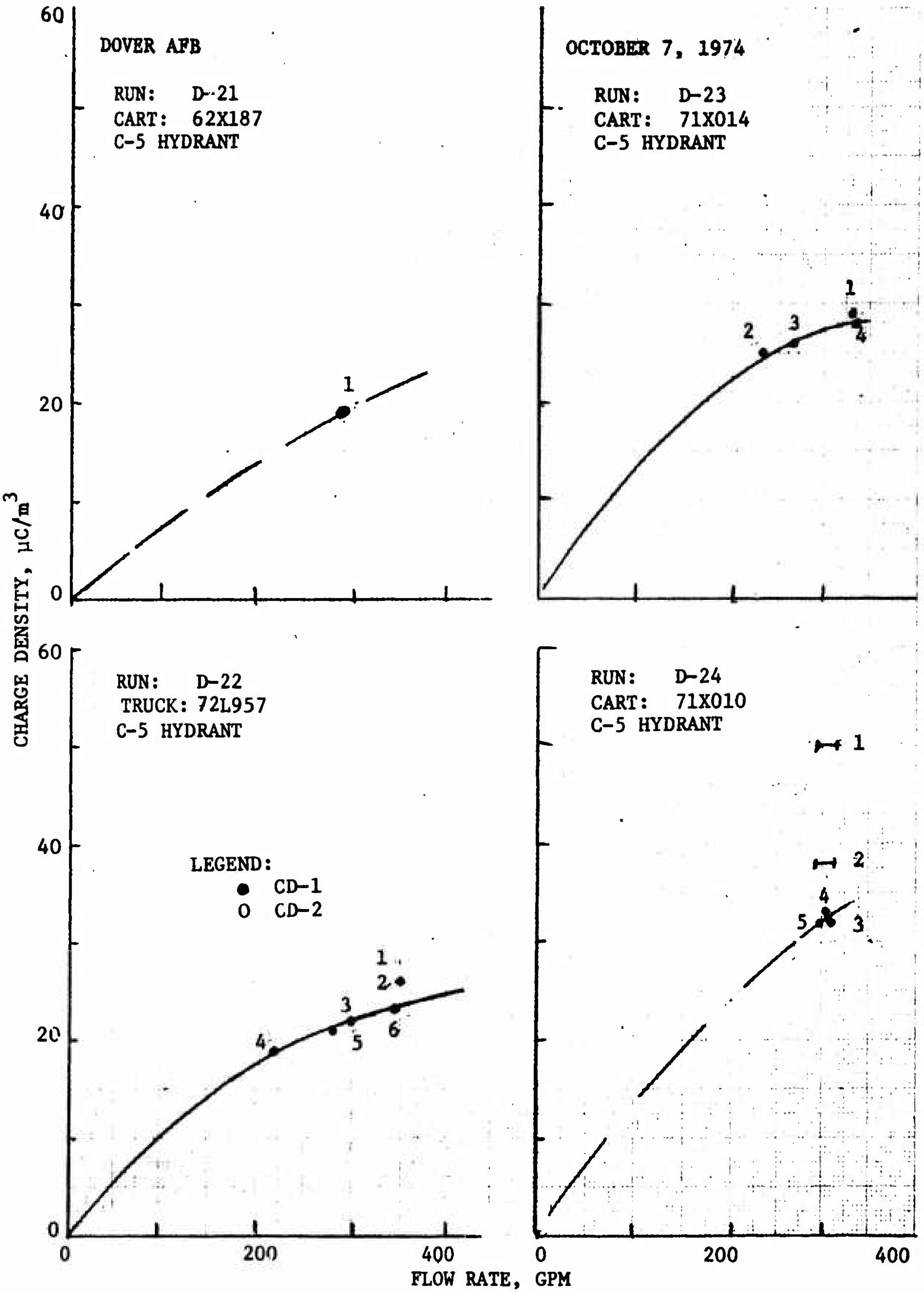


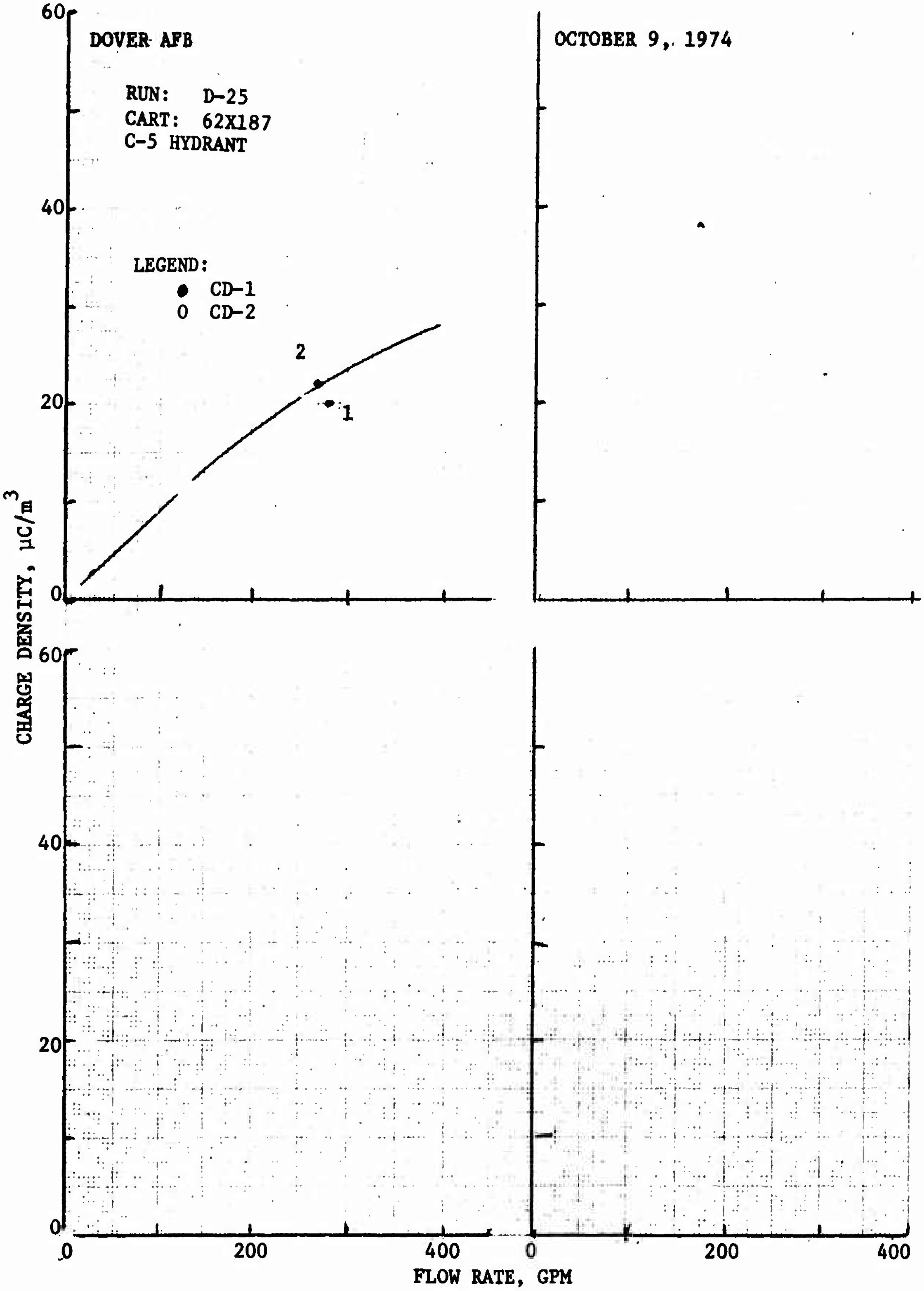
DOVER AFB
OCTOBER 8, 1974
RUN: D-9
CART: 62X106
NORTH HYDRANT
RUN: D-11
CART: 71X015
MAC HYDRANT
RUN: D-10
CART: 62X106
MAC HYDRANT
RUN: D-12
CART: 71X017
MAC HYDRANT
LEGEND:
● CD-1
O CD-2
CHARGE DENSITY, μC/m3
FLOW RATE, GPM
0
20
40
60
200
400
1
2
3
4

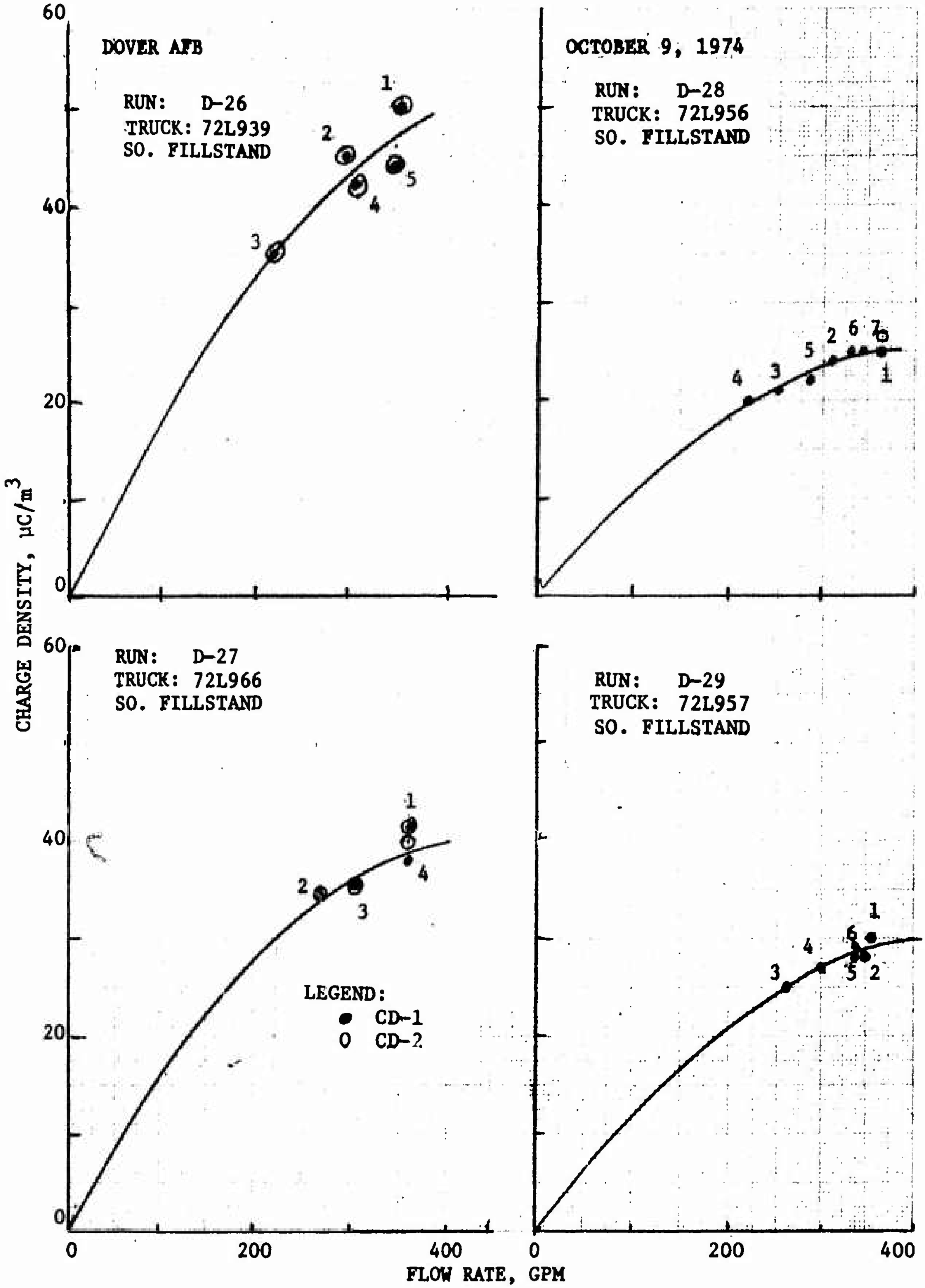


DOVER AFB
OCTOBER 8, 1974
RUN: D-13
CART: 62X181
MAC HYDRANT
RUN: D-15
CART: 62X106
MAC HYDRANT
RUN: D-14
TRUCK: 72L957(R-9)
MAC HYDRANT
RUN: D-16
CART: 71X015
MAC HYDRANT
LEGEND:
● CD-1
O CD-2
CHARGE DENSITY, μC/m3
FLOW RATE, GPM
0
20
40
60
200
400


DOVER AFB
OCTOBER 8, 1974
RUN: D-17
CART: 71X017
MAC HYDRANT
RUN: D-19
CART: 71X010
C-5 HYDRANT
FLOW SURGING DURING RUN
RUN: D-18
CART: 62X181
MAC HYDRANT
LEGEND:
● CD-1
O CD-2
RUN: D-20
CART: 71X014
C-5 HYDRANT
FLOW SURGING DURING RUN
CHARGE DENSITY, μC/m3
FLOW RATE, GPM
0
20
40
60
200
400
1
2
3
4


DOVER AFB
RUN: D-21
CART: 62X187
C-5 HYDRANT
OCTOBER 7, 1974
RUN: D-23
CART: 71X014
C-5 HYDRANT
RUN: D-22
TRUCK: 72L957
C-5 HYDRANT
LEGEND:
● CD-1
O CD-2
RUN: D-24
CART: 71X010
C-5 HYDRANT
CHARGE DENSITY, μC/m3
FLOW RATE, GPM
0
20
40
60
200
400

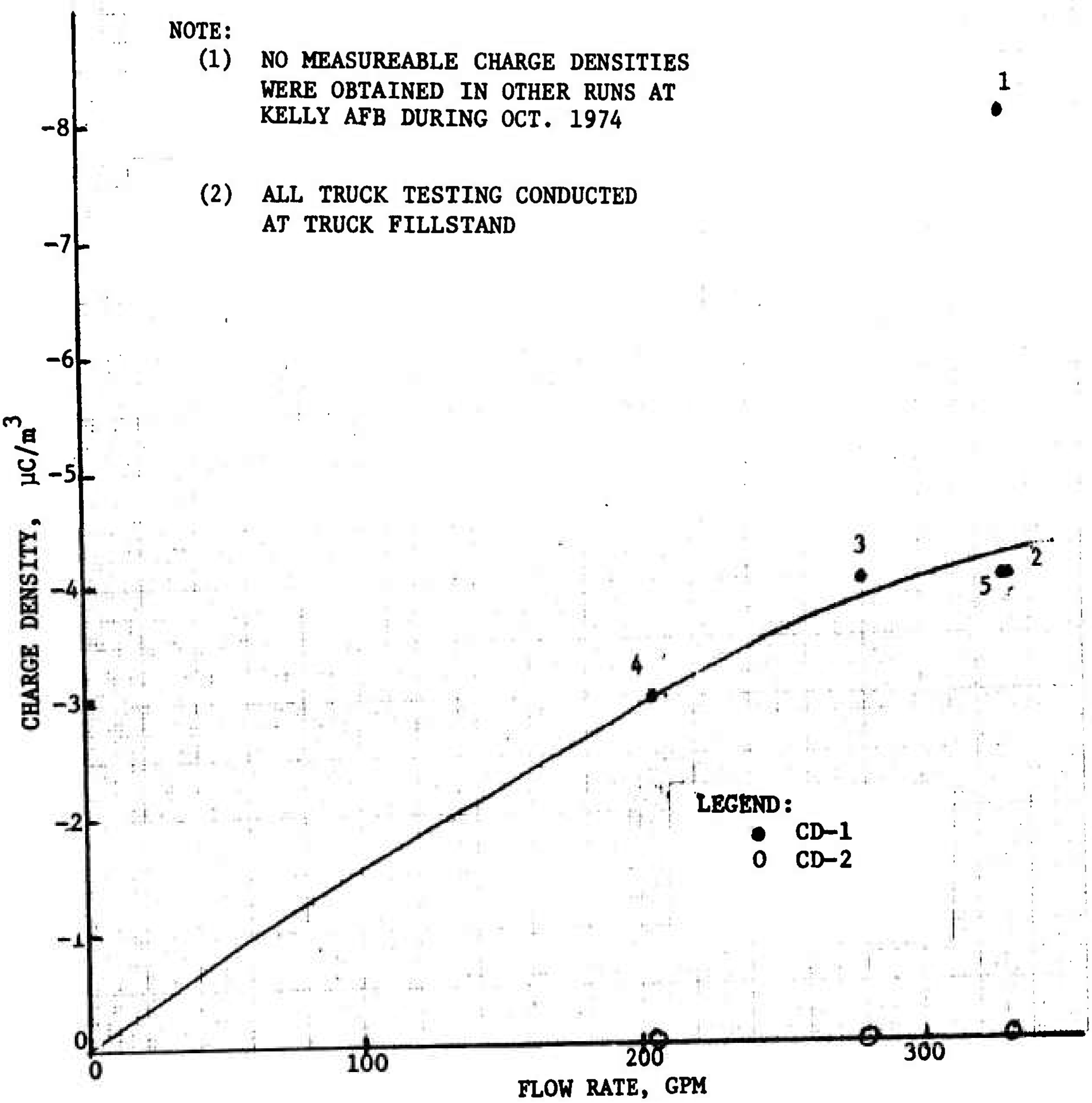

DOVER AFB
OCTOBER 9, 1974
RUN: D-25
CART: 62X187
C-5 HYDRANT
LEGEND:
● CD-1
0 CD-2
2
1
CHARGE DENSITY, μC/m3
FLOW RATE, GPM
0
20
40
60
0
200
400

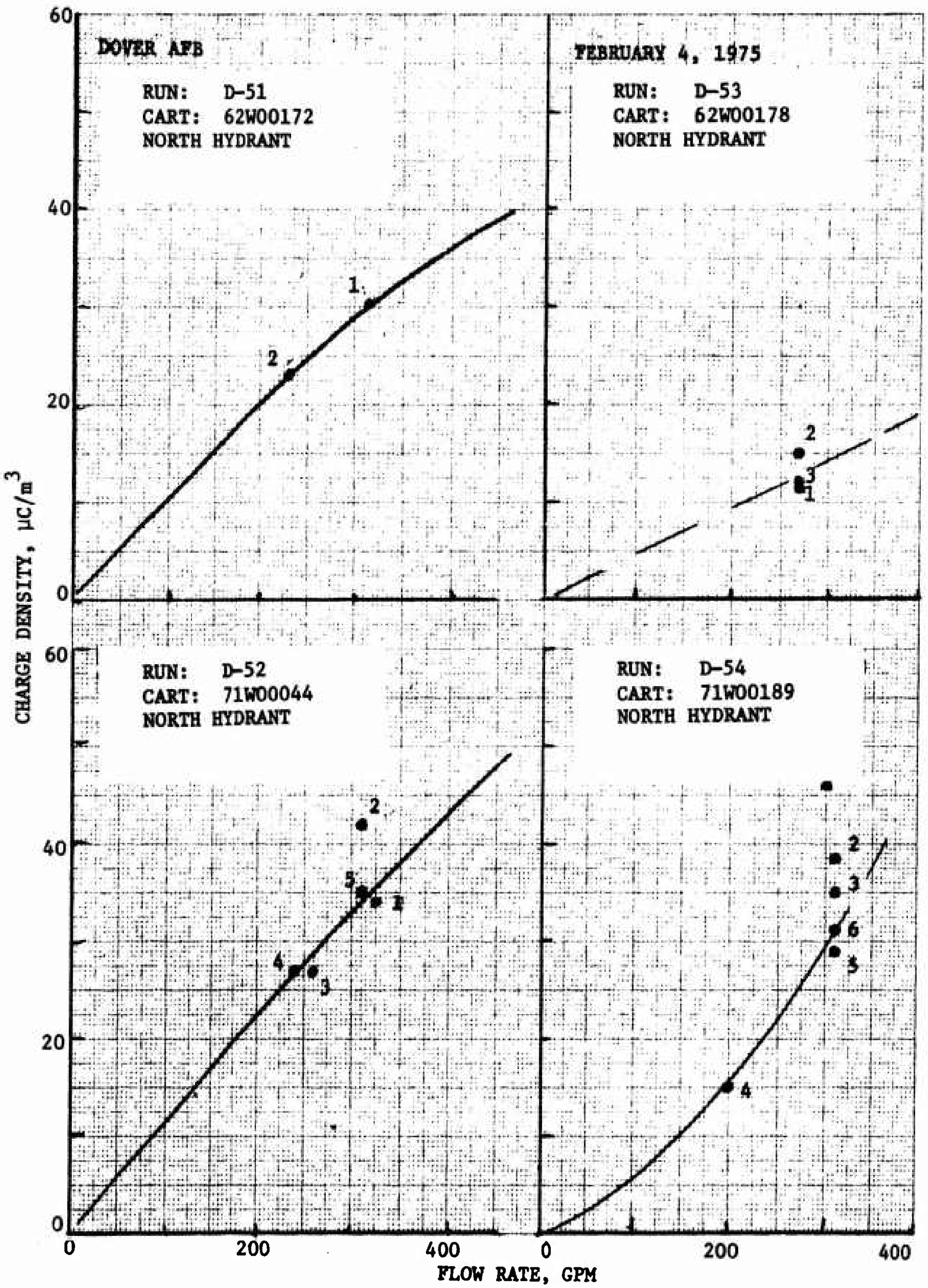


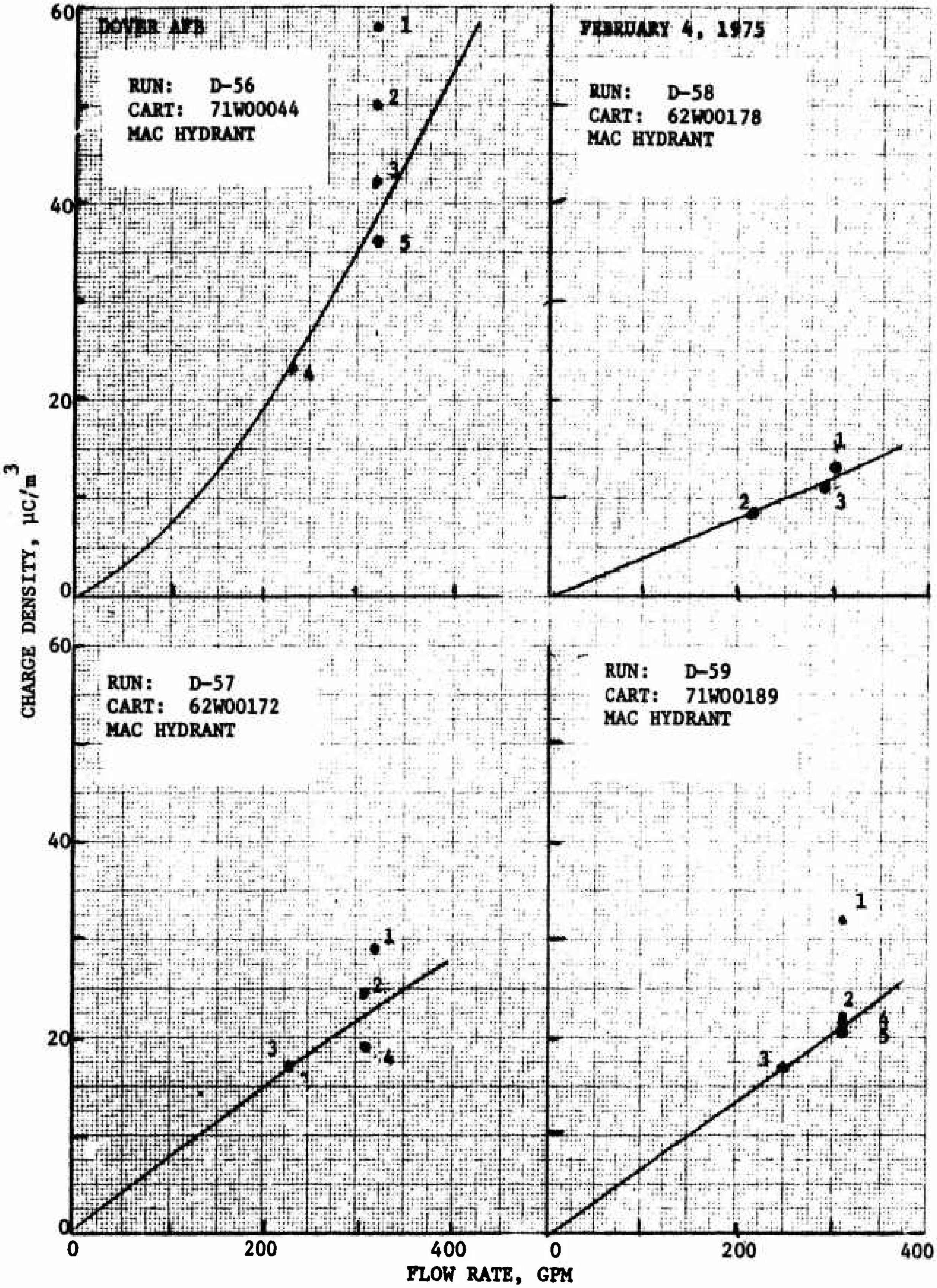
DOVER AFB
OCTOBER 9, 1974
RUN: D-26
TRUCK: 72L939
SO. FILLSTAND
RUN: D-28
TRUCK: 72L956
SO. FILLSTAND
RUN: D-27
TRUCK: 72L966
SO. FILLSTAND
RUN: D-29
TRUCK: 72L957
SO. FILLSTAND
LEGEND:
● CD-1
O CD-2
CHARGE DENSITY, μC/m3
FLOW RATE, GPM
0
20
40
60
0
200
400

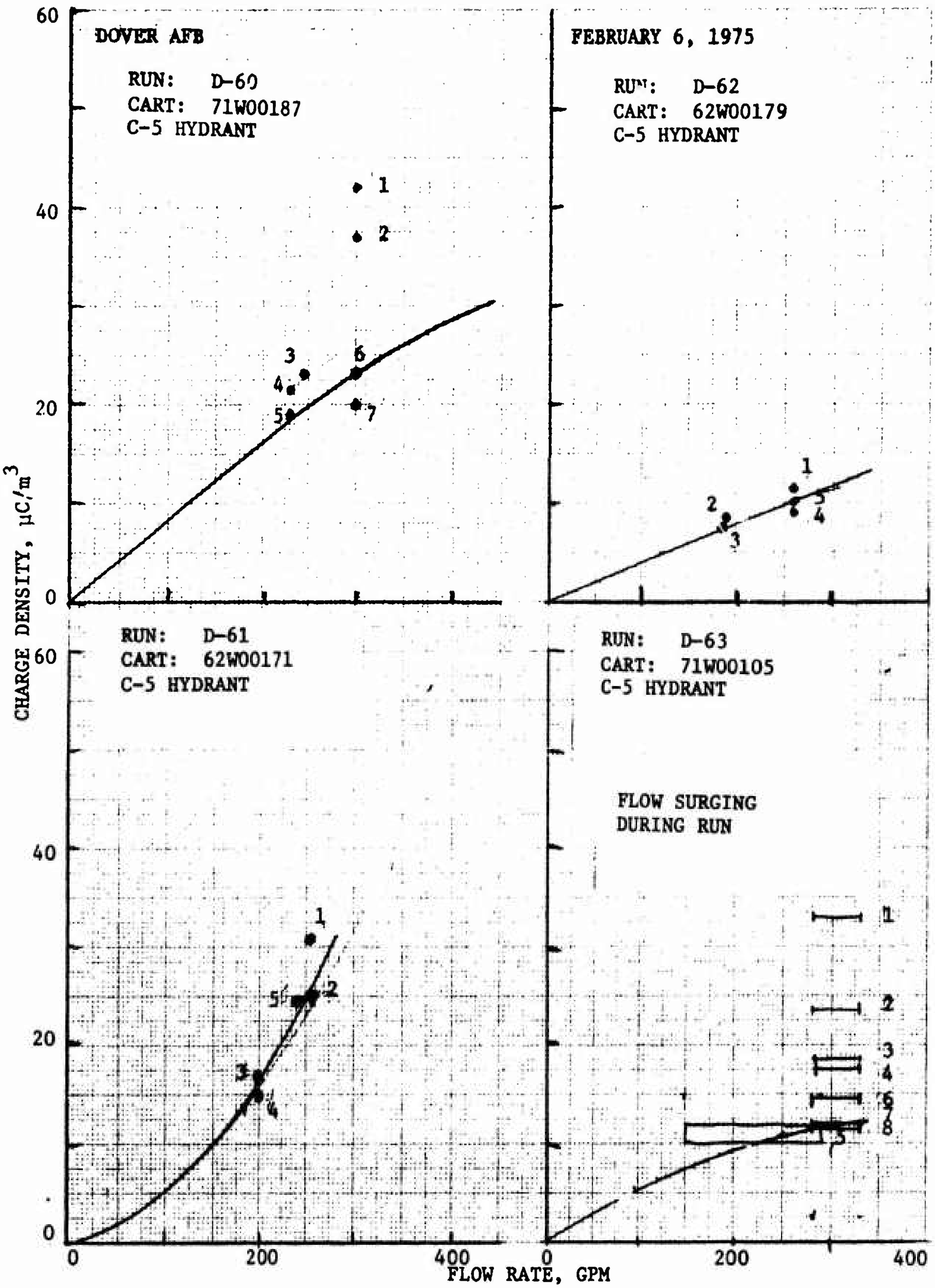
KELLY AFB[1]　　　　　　　　　　　　　　　　OCTOBER 22, 1974

RUN: K-5
TRUCK: 67L578




DOVER AFB
FEBRUARY 4, 1975
RUN: D-51
CART: 62W00172
NORTH HYDRANT
RUN: D-53
CART: 62W00178
NORTH HYDRANT
RUN: D-52
CART: 71W00044
NORTH HYDRANT
RUN: D-54
CART: 71W00189
NORTH HYDRANT
CHARGE DENSITY, μC/m³
FLOW RATE, GPM
0
20
40
60
200
400


DOVER AFB
FEBRUARY 4, 1975
RUN: D-56
CART: 71W00044
MAC HYDRANT
RUN: D-58
CART: 62W00178
MAC HYDRANT
RUN: D-57
CART: 62W00172
MAC HYDRANT
RUN: D-59
CART: 71W00189
MAC HYDRANT
CHARGE DENSITY, μC/m³
FLOW RATE, GPM
0
20
40
60
0
200
400


DOVER AFB
FEBRUARY 6, 1975
RUN: D-60
CART: 71W00187
C-5 HYDRANT
RUN: D-62
CART: 62W00179
C-5 HYDRANT
RUN: D-61
CART: 62W00171
C-5 HYDRANT
RUN: D-63
CART: 71W00105
C-5 HYDRANT
FLOW SURGING
DURING RUN
CHARGE DENSITY, μC/m3
FLOW RATE, GPM
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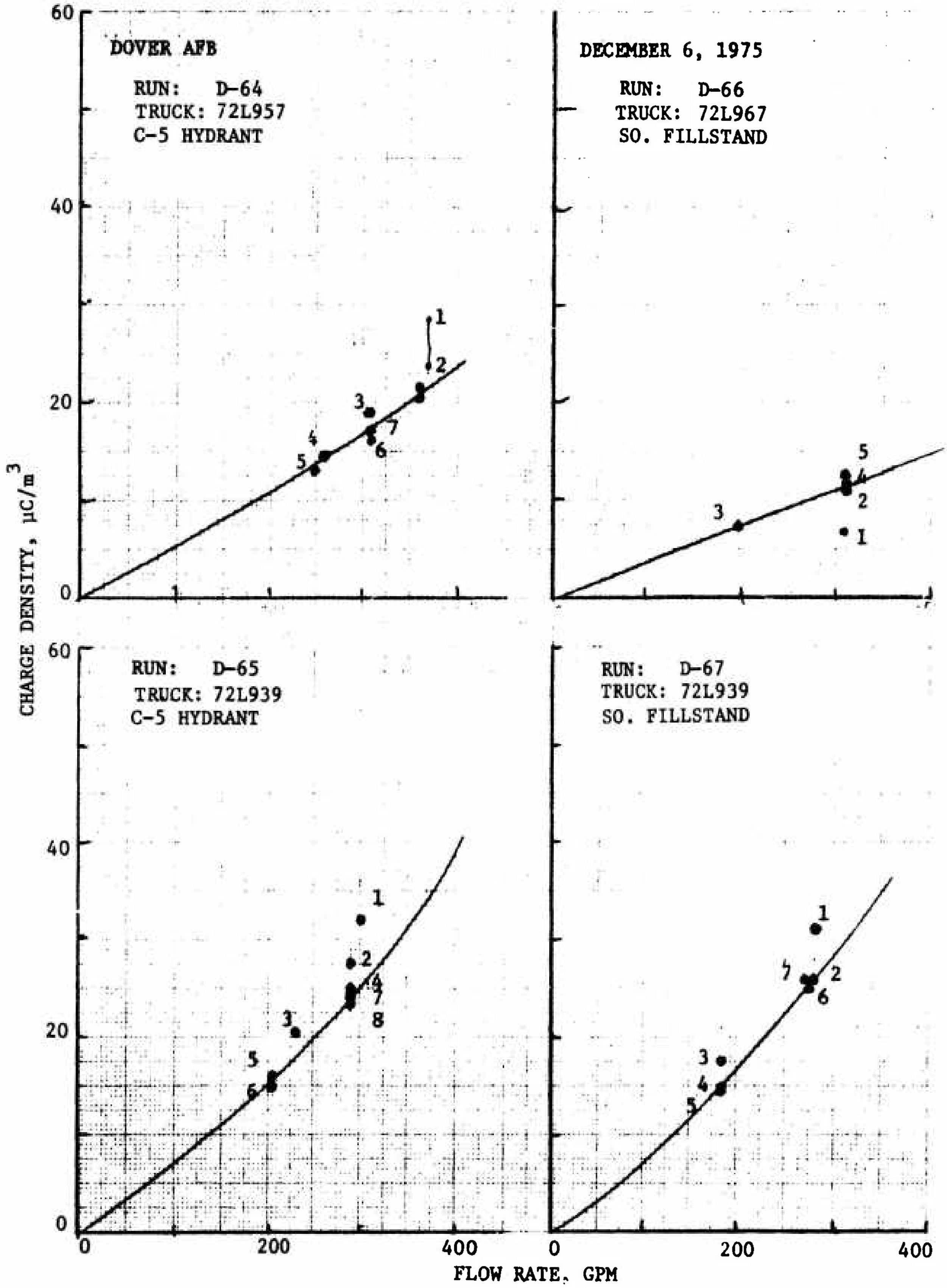
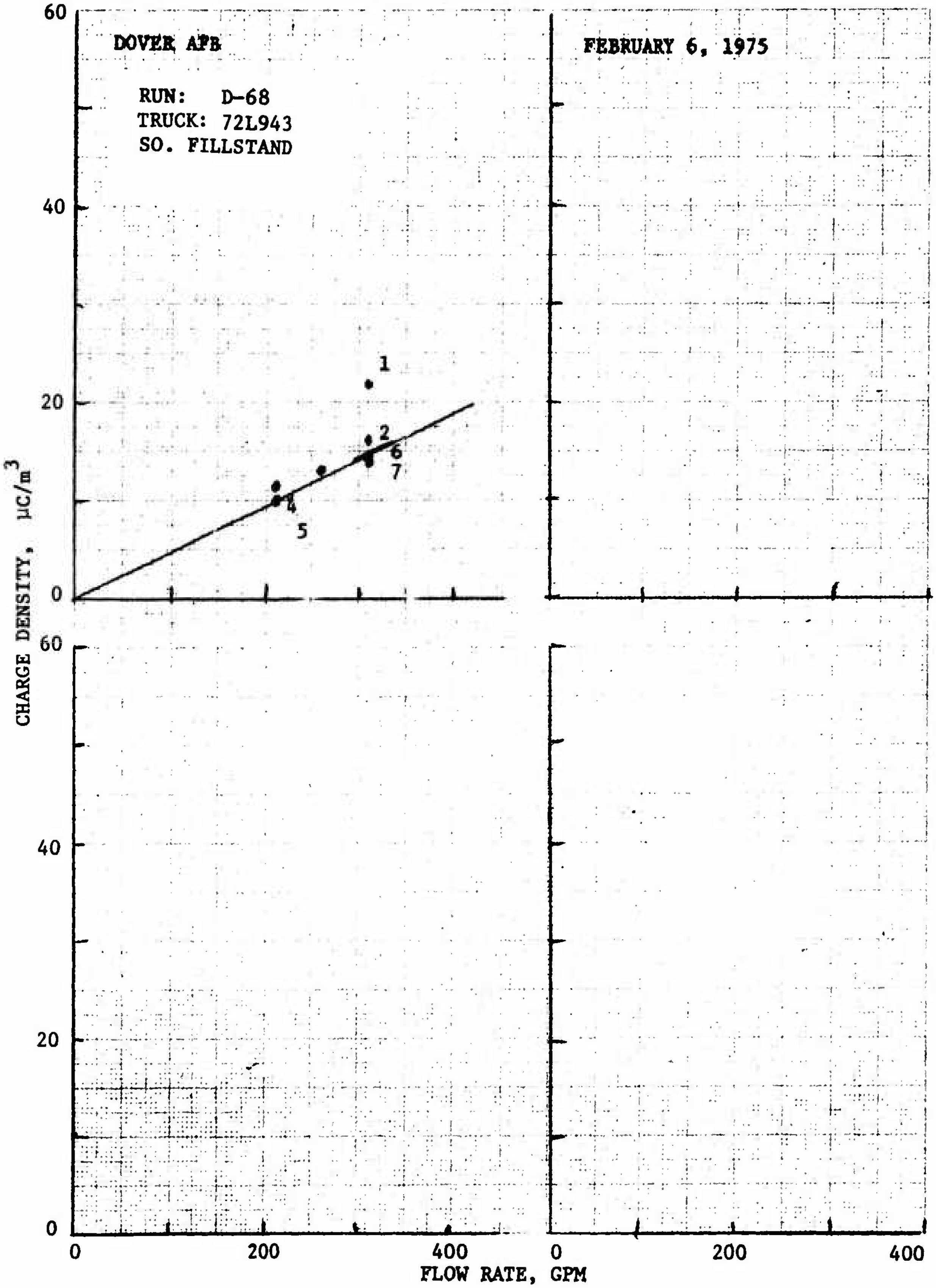
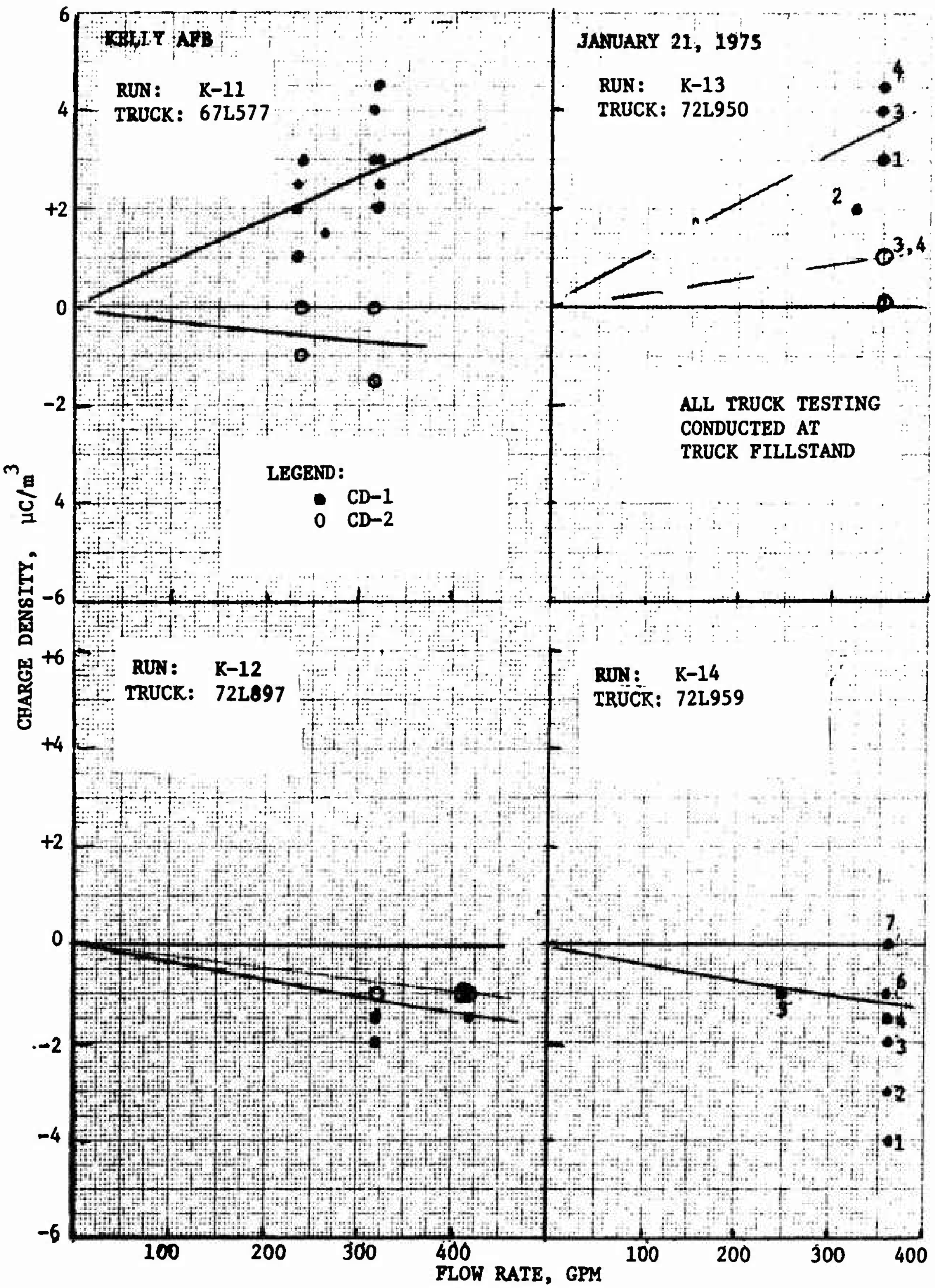
20
40
60
200
400

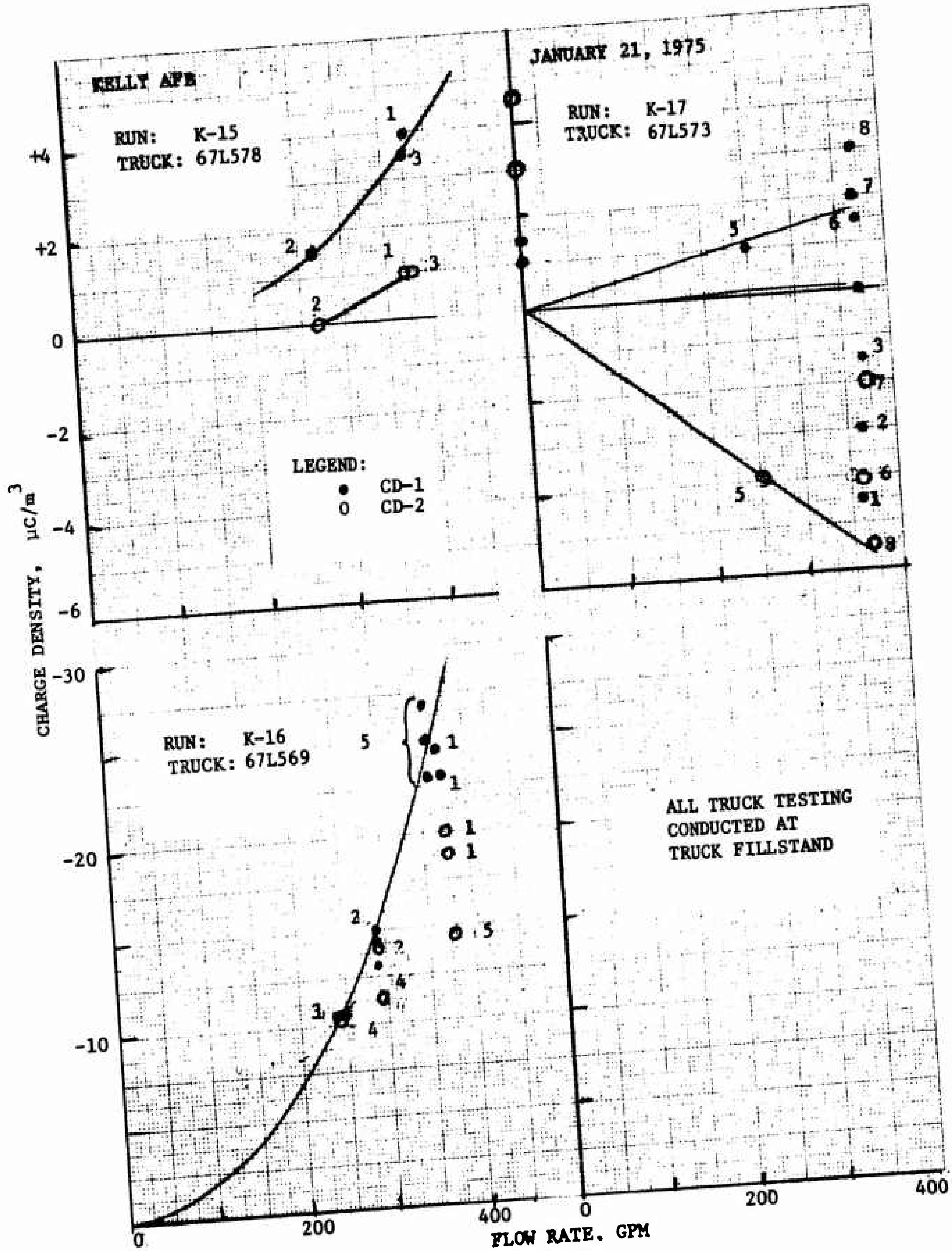

DOVER AFB
RUN: D-64
TRUCK: 72L957
C-5 HYDRANT
DECEMBER 6, 1975
RUN: D-66
TRUCK: 72L967
SO. FILLSTAND
RUN: D-65
TRUCK: 72L939
C-5 HYDRANT
RUN: D-67
TRUCK: 72L939
SO. FILLSTAND
CHARGE DENSITY, μC/m3
FLOW RATE, GPM
0
20
40
60
0
200
400



DOVER AFB
FEBRUARY 6, 1975
RUN: D-68
TRUCK: 72L943
SO. FILLSTAND
CHARGE DENSITY, μC/m3
FLOW RATE, GPM
60
40
20
0
200
400
1
2
4
5
6
7



KELLY AFB
JANUARY 21, 1975
RUN: K-11
TRUCK: 67L577
RUN: K-13
TRUCK: 72L950
ALL TRUCK TESTING
CONDUCTED AT
TRUCK FILLSTAND
LEGEND:
● CD-1
O CD-2
RUN: K-12
TRUCK: 72L897
RUN: K-14
TRUCK: 72L959
CHARGE DENSITY, μC/m3
FLOW RATE, GPM



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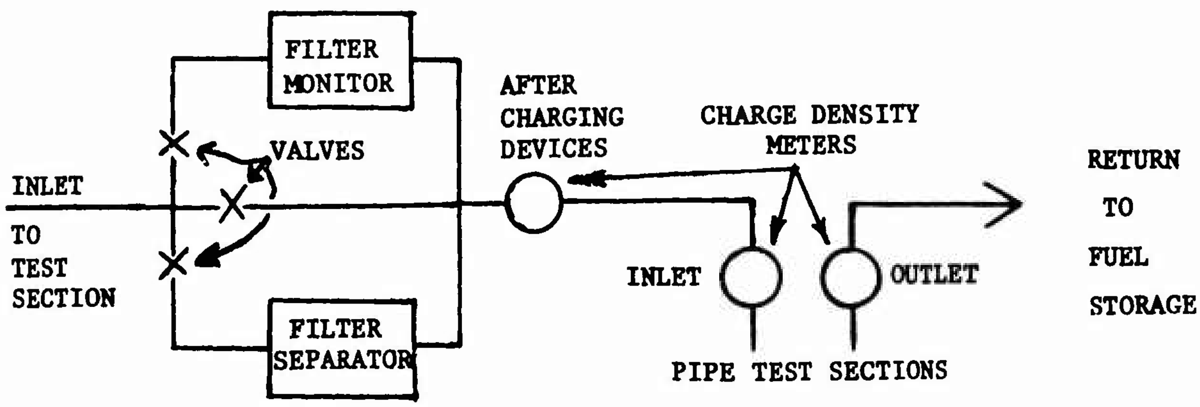
APPENDIX B

TEST DATA ON FRP VERSUS STEEL PIPE - INDIVIDUAL RUNS

Piping Description



The valves allow undetermined but reproducible flows through either the straight pipe, the filter-separator, or the filter-monitor or a combination of them.

TABLE B-1. CHARGE RELAXATION AND GENERATION
CARBON STEEL VERSUS FRP PIPE
(JP-4 - 1.2 pS/m at 22°C)

Flow Rate (gal /min)	Piping Description	Temp (°C)	Charge Density ($\mu C/m^3$) After Charging	Inlet	Outlet
600	100 str pipe	25.0	0	-0.5	+0.8
300	100 str pipe	25.0	0	-0.2	+0.8
1200	100 str pipe	25.0	0	-0.4	+1.0
1200	100 monitors	25.5	+20.7	+20.4	+16.0
600	100 monitors	25.0	+23.7	+22.0	+8.6
300	100 monitors	25.0	+23.7	+20.4	+2.8
300	100/F-S	25.5	+23.7	+19.4	+2.8
600	100 F-S	25.0	+28.7	+26.5	+9.9
1200	100 F-S	25.0	+28.7	+28.0	+19.6
300	100 str pipe	25.5	0	0	+1.6
300	100 F-S + 100 str pipe	25.5	0	-0.2	+1.5
300	100 F-S + 6 notch str pipe	25.5	0.7	-0.2	+1.5
300	100 F-S + 4 notch str pipe	25.5	+7.7	+3.7	+1.7
300	100 F-S + 2 notch str pipe	25.0	+18.0	+13.5	+2.5
300	100 F-S	25.0	+27	+21.7	+3.2
600	100 str pipe	25.0	-0.2	-0.5	+1.6
600	100 F-S + 100 str pipe	25.0	+1.0	-0.5	+1.7
600	100 F-S + 6 notch str pipe	25.5	+4.7	+1.0	+2.4
600	100 F-S + 4 notch str pipe	25.0	+17.0	+9.7	+5.7
600	100 F-S + 2 notch str pipe	25.0	+23.5	+20.0	+8.6
600	100 F-S	25.0	+30.0	+27.0	+10.6
1200	100 str pipe	25.5	-0.4	-0.7	+0.6
1200	100 F-S + 100 str pipe	25.5	+4.0	+1.2	+1.8
1200	100 F-S + 6 notch str pipe	25.0	+12.0	+4.8	+4.3
1200	100 F-S + 4 notch str pipe	25.0	+20.0	+13.7	+10.3
1200	100 F-S + 2 notch str pipe	24.5	+24.0	+22.0	+15.5
1200	100 F-S	25.0	+29.0	+28.2	+19.0
600	100 F-S	25.0	+30.5	+28.5	+9.3

NOTE:

100 F-S - All flow goes through the filter-separator.

100 F-S + str pipe - Both valves to the filter-separator and the straight pipe section are fully open.

100 F-S + 4th Notch str pipe - The valve to the filter-separator is completely open and the valve to the straight pipe is open to the fourth notch.

100 F-S + 100 SCR - All flow goes through the filter-separator and then the SCR as shown in Figure 29.

TABLE B-2. CHARGE RELAXATION AND GENERATION CARBON STEEL VERSUS FRP PIPE (JP-4 - 1/3 pS/m at 24°C)

Flow Rate (gal /min)	Piping Description	Temp (°C)	Charge Density ($\mu C/m^3$) After Charging	Inlet	Outlet
300	100 str pipe	25.5	-1	-0.6	+1.6
300	100 gages + 100 str pipe	25.5	-0.8	-0.6	+1.6
300	100 gages + 100 F-S	25.5	-0.8	-0.6	+1.6
300	100 F-S + 6 notch str pipe	25.5	0.0	-0.5	+1.6
300	100 F-S + 4 notch str pipe	25.5	+10.5	+5.5	+2.0
300	100 F-S + 2 notch str pipe	25.5	+27.0	+21.5	+3.5
300	100 F-S	25.5	+37.0	+36.5	+5.0
600	100 str pipe	25.5	-1.1	-1.2	+2.0
600	100 F-S + 100 str pipe	25.5	0.0	-0.9	+2.0
600	100 F-S + 6 notch str pipe	25.5	+5.2	+1.35	+2.3
600	100 F-S + 4 notch str pipe	25.5	+25.0	+17.0	+7.5
600	100 F-S + 2 notch str pipe	25.5	+45	+40	+14.0
600	100 F-S	25.5	62	+58	+19
600	100 F-S	25.5	55	53	18
600	100 str pipe	25.5	-0.5	-0.7	+1.6
1200	100 str pipe	25.5	-0.5	-0.95	+1.5
1200	100 F-S + 100 str pipe	25.5	+5.5	+1.5	+2.5
1200	100 F-S + 6 notch str pipe	25.5	+18	+7.2	+6.1
1200	100 F-S + 4 notch str pipe	25.0	+40	+28	+18.4
1200	100 F-S + 2 notch str pipe	25.0	+50	+49	+29.5
1200	100 F-S	25.0	+64	+62	+35.0
600	100 F-S	25.0	+55	+52	+16
600	100 F-S + 5 notch str pipe	25.0	+18	+9	+4
600	100 F-S + 100 SCR	25.0	57	6	3

TABLE B-3. CHARGE RELAXATION AND GENERATION
CARBON STEEL VERSUS FRP PIPE
(JP-4 - 1.54 pS/m at 22°C)

Flow Rate (gal /min)	Piping Description	Temp (°C)	Charge Density ($\mu C/m^3$) After Charging	Inlet	Outlet
600	100 str pipe	26	-1.2	+0.15	-1.3
1200	100 str pipe	26	-2.4	-1.2	-2.2
1200	100 F-S	25	+98.0	+100.0	+72.0
600	100 F-S	25	+76.0	+75.0	+42.0
300	100 F-S	25	+51.0	+45.0	+14.0
1200	100 F-S + 100 SCR	25	+94.0	+27.0	+19.5
600	100 F-S + 100 SCR	25	+73.0	+16.5	+8.0
300	100 F-S + 100 SCR	25	+50.0	+8.0	+1.4
300	100 F-S + 100 SCR	25.5	+50.0	+6.0	+2.8
600	100 F-S + 100 SCR	25.5	+70.0	+13.0	+8.0
1200	100 F-S + 100 SCR	25.5	+81.0	+21.5	+18.0
1200	100 F-S + 3 notch str pipe	25.5	+56.0	+49.5	+38.0
600	100 F-S + 3 notch str pipe	25.5	+41.0	+29.5	+20.0
300	100 F-S + 3 notch str pipe	25.5	+21.0	+15.0	+6.0
300	100 F-S + 4 notch str pipe	26.5	+13.0	+6.7	+3.0
600	100 F-S + 4 notch str pipe	26.5	+31.0	+19.7	+12.8
1200	100 F-S + 4 notch str pipe	26.5	+46.0	+32.0	+25.5
1200	100 F-S + 5 notch str pipe	26.5	+34.0	+19.0	+15.8
600	100 F-S + 5 notch str pipe	26.5	+17.5	+9.0	+6.3
300	100 F-S + 5 notch str pipe	26.0	+5.5	+2.7	+1.5
300	100 str pipe	26.0	-1.3	-0.3	+0.6
600	100 str pipe	26	-1.5	-0.9	-0.2
1200	100 str pipe	26	-2.5	-2.15	-1.3
1200	100 F-S	25.5	+110.0	+119.0	+85.0
600	100 F-S	25.5	+85.0	+83.0	+47.0
300	100 F-S	25.5	+54.0	+45.0	+17.0
1200	100 F-S	25.5	+107.0	+109.0	+7[illegible].0
600	100 F-S	25.5	+80.0	+78.0	+45.0
300	100 F-S	25.5	+51.0	+44.0	+16.5
1200	100 F-S + 100 SCR	25.5	+104.0	+29.0	+22.5
600	100 F-S + 100 SCR	25.5	+77.0	+17.0	+10.5
300	100 F-S + 100 SCR	26.0	+51.0	+8.0	+3.0
300	100 F-S	26.0	+51.0	+43.0	+16.5
300	100 F-S + 3 notch str pipe	26.0	+21.0	+14.0	+3.0
600	100 F-S + 3 notch str pipe	26.0	+44.0	+34.0	+19.5
600	100 F-S + 4 notch str pipe	26.5	+35.0	+25.0	+14.0

TABLE B-3. CHARGE RELAXATION AND GENERATION CARBON STEEL VERSUS FRP PIPE (JP-4 - 1.54 pS/m at 22°C) (CONCLUDED)

Flow Rate (gal /min)	Piping Description	Temp (°C)	Charge Density (μC/m³) After Charging	Inlet	Outlet
600	100 F-S + 5 notch str pipe	26.5	+20.0	+12.0	+7.5
1200	100 F-S + 5 notch str pipe	26.5	+44.0	+25.0	+20.0
1200	100 str pipe	26.5	-1.8	-0.4	+0.0
600	100 str pipe	26.5	-1.5	+0.0	+0.0
300	100 str pipe	26.5	-1.1	+0.3	+0.0
1200	100 str pipe	26.5	-1.8	-1.0	+0.0

TABLE B-4. CHARGE RELAXATION AND GENERATION
CARBON STEEL VERSUS FRP PIPE
(JP-4 - 1.43 pS/m at 22°C)

Flow Rate (gal /min)	Piping Description	Temp. (°C)	Charge Density (μC/m) After Charging	Inlet	Outlet
300	100 gages	25		-11.0	-4.0
300	100 gages + 4 notch str pipe	25		-7.0	-1.6
600	100 gages	25		-6.5	-4.0
1200	100 gages	25		-5.0	-4.5
1200	100 F-S + 100 SCR	25		+5.5	+4.5
1200	100 F-S + 5 notch str pipe	25		+5.0	+4.0
600	100 F-S	25		+19.0	+13.0
600	100 F-S	25		+18.5	+13.0
600	100 F-S + 100 SCR	25		+3.0	+2.0
600	100 F-S + 4 notch str pipe	25		+5.5	+4.0
600	100 F-S + 5 notch str pipe	25		+2.5	+1.8
300	100 F-S pipe	25.5		+0.4	-0.5
600	100 str pipe	25.5		-0.5	-0.5
1200	100 str pipe	25.5		-1.5	-1.0
1200	100 F-S	25.5		+64.0	+48.0
600	100 F-S	25.5		+51.0	+29.0
300	100 F-S	25.5		+33.0	+11.0
300	100 F-S + 2 notch str pipe	26.0		+23.0	+7.0
300	100 F-S + 4 notch str pipe	26.0		+7.3	+2.5
300	100 F-S + 6 notch str pipe	26.0		+1.2	+1.0
600	100 F-S	26.0		+42.5	+30.0
600	100 F-S + 2 notch str pipe	25.5		+40.5	+23.5
600	100 F-S + 4 notch str pipe	25.5		+18.5	+10.5
600	100 F-S + 6 notch str pipe	25.5		+3.0	+2.7
1200	100 F-S	26.0		+57.0	+44.0
1200	100 F-S + 2 notch str pipe	26.0		+45.0	+35.0
1200	100 F-S + 4 notch str pipe	26.0		+25.0	+20.0
1200	100 F-S + 6 notch str pipe	26.0		+6.0	+5.8
1200	100 F-S + 100 str pipe	26.0		+0.3	+1.2
600	100 F-S + 100 SCR	25.0	+41.0	+8.3	+6.0
600	100 F-S + 5 notch str pipe	25.0	+15.0	+7.5	+5.8
600	100 F-S + 4 notch str pipe	25.0	+25.0	+13.0	+9.3
600	100 F-S + 100 str pipe	25.0	+5.0	-0.5	+1.3
600	100 F-S + 6 notch str pipe	25.0	+7.0	+1.0	+2.3
600	100 F-S + 5 notch str pipe	25.0	+15.0	+5.5	+5.0
600	100 F-S + 100 str pipe	26	+3.0	-0.7	+1.3
600	100 F-S + 6 notch str pipe	26	+8.0	+1.0	+1.8
600	100 F-S + 4 notch str pipe	26	+20.0	+12.0	+8.3
600	100 F-S + 5 notch str pipe	26	+15.0	+6.5	+5.3

TABLE B-4. CHARGE RELAXATION AND GENERATION
CARBON STEEL VERSUS FRP PIPE
(JP-4 - 1.43 pS/m at 22°C)(CONTINUTED)

Flow Rate (gal /min)	Piping Description	Temp (°C)	Charge Density (μC/m³) After Charging	Inlet	Outlet
600	100 F-S + 6 notch str pipe	26	+9.0	+1.7	+1.3
600	100 F-S + 5 notch str pipe	26	+13.0	+5.0	+3.3
600	100 F-S + 4 notch str pipe	26	+20.0	+11.5	+7.8
600	100 F-S + 2 notch str pipe	26	27.0	+22.5	+15.3
600	100 F-S str pipe	26	+35.0	+29.0	+15.0
1200	100 F-S + 100 str pipe	26	+5.0	-0.5	+0.8
1200	100 F-S + 6 notch str pipe	26	+14.0	+3.0	+3.0
1200	100 F-S + 5 notch str pipe	26	+20.0	+7.7	+7.0
1200	100 F-S + 4 notch str pipe	26	+23.0	12.0	+10.3
1200	100 F-S + 2 notch str pipe	26	+25.0	+19.3	+16.0
1200	100 F-S	26	+25.0	+22.5	+19.0
300	100 gages + 100 str pipe	25.5	-2.7	-1.1	+0.9
300	100 gages + 6 notch str pipe	25.5	-3.7	-2.0	+0.5
300	100 gages + 4 notch str pipe	25.5	-6.7	-5.8	-0.5
300	100 gages + 2 notch str pipe	25.5	-9.7	-8.5	-2.0
300	100 gages	25.5	-8.7	-8.5	-2.3
300	100 F-S + 6 notch str pipe	25.5	-0.2	-0.5	+1.0
300	100 F-S + 5 notch str pipe	25.5	+2.3	+0.7	+1.5
300	100 F-S + 4 notch str pipe	25.5	+7.0	+3.7	+2.7
300	100 F-S + 3 notch str pipe	25.5	+12.0	+7.8	+4.4
300	100 F-S + 2 notch str pipe	25.5	+15.0	+12.0	+6.2
300	100 F-S	25.5	+18.0	+16.7	+8.5
600	100 str pipe	25.0	-2.2	-3.8	-0.2
600	100 gages + 100 str pipe	25.0	-3.5	-3.1	-1.0
600	100 gages + 6 notch str pipe	25.0	-6.7	-4.5	-1.8
600	100 gages + 4 notch str pipe	25.0	-11.0	-7.5	-3.7
600	100 gages + 2 notch str pipe	24.5	-9.7	-9.7	-5.3
600	100 gages	24.5	-10.7	-10.5	-6.3
600	100 F-S + 100 str pipe	24.5	-1.2	-1.8	-0.5
600	100 F-S + 6 notch str pipe	24.5	+2.0	-0.5	+0.5
600	100 F-S + 5 notch str pipe	24.5	+7.0	+2.0	+2.3
600	100 F-S + 4 notch str pipe	25.0	+9.0	+4.5	+4.2
600	100 F-S + 3 notch str pipe	25.0	+9.0	+6.5	+5.7
600	100 F-S + 2 notch str pipe	25.0	+9.0	+8.0	+6.7

TABLE B-4. CHARGE RELAXATION AND GENERATION CARBON STEEL VERSUS FRP PIPE (JP-4 - 1.43 pS/m at 22°C) (CONCLUDED)

Flow Rate (gal/min)	Piping Description	Temp (°C)	Charge Density (μC/m³) After Charging	Inlet	Outlet
600	100 F-S	25	+10.0	+9.5	+7.7
600	100 str pipe	25	-2.8	-2.2	-0.3
1200	100 str pipe	25	-4.3	-3.5	-1.8
1200	100 gages + 100 st. pipe	25	-6.5	-5.0	-2.9
1200	100 gages + 6 notch str pipe	25	-9.0	-6.0	-3.6
1200	100 gages + 4 notch str pipe	25	-9.0	-7.0	-4.5
1200	100 gages + 2 notch str pipe	25	-9.0	-8.0	-5.5
1200	100 gages	25	-11.0	-10.0	-7.0
1200	100 str pipe	25	-5.0	-4.2	-2.2
1200	100 F-S + 100 str pipe	25	-4.0	-3.2	-0.8

REFERENCES

1. "Electrostatic Charging Survey of Airport Fueling Systems" Coordinating Research Council, Report No. 473, December 1974

2. "A Survey of Electrical Conductivity and Charging Tendency Characteristics of Aircraft Turbine Fuels 1973/74" Coordinating Research Council, Report No. 478, April 1975

3. Martel, C. R.,"An Evaluation of the Static Charge Reducer for Reducting Electrostatic Hazards in the Handling of Hydrocarbon Fuels" AFAPL-TR-70-22, July 1970

4. Bachman, K. C., and Munday, J. C., "Evaluation of the Hazards of Static Electricity in Non-Metallic POL Systems" - AFWL-TR-72-90, June 1973

5. Dukek, W. G., Strauss, K. H., and Leonard, J. T. "Charge Generation by U.S. Commercial Aircraft Fuels and Filter-Separators" - Summary Report of Coordinating Research Council Studies on Static - Lightning & Static Conference, Culham Lab., England, April 1975

6. Bachman, K. C., "Variables Which Influence Spark Production Due to Static Electricity in Tank Truck Loading" - Lightning & Static Conference, Culham Lab., England, April 1975

7. "Electrostatic Discharge in Aircraft Fuel Systems - Phase II" Coordinating Research Council, Report No. 355, August 1961.

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GLOSSARY OF TERMS

Charge Density - Concentration of charged species in a fuel expressed in terms of $\mu C/m^3$. The charge density at any point in a fuel handling system can be measured by placing a device such as the A. O. Smith Charge Measuring System in the line. Charge density may also be calculated by electrically isolating a section of the system, e.g., the filter or a section of pipe, and measuring the current (filter current or streaming current) by means of an electrometer. The charge density may then be calculated from the equation:

$$Q = \frac{i}{V}$$

where:

Q = charge density, microcoulombs/meter^3, $\mu C/m^3$

i = streaming current, microamps, μA

V = volumetric flow rate, $\frac{\text{meters}^3}{\text{sec}}$, $\frac{m^3}{\text{sec}}$

Charge Flow - The streaming current usually measured in microamps, μA. It is the product of charge density and volumetric flow rate.

Charging Tendency - Ability of a fuel to generate electrostatic charge in a standard apparatus such as the Shell Charging Tendency Apparatus or the ESSO Mini-Static Tester. In either case, the charge in the flowing fuel is measured as a current which may then be converted to charge density as described above.

Coalescer - Coalescer is the first stage of a filter-separator where water droplets are coalesced and solid particles are removed. Separator is the second stage where remaining free water droplets are stripped.

Conductivity, Rest - The conductivity of uncharged fuel in the absence of ionic depletion or polarization. It is, in effect, the conductivity at the initial instant of a direct current measurement. In the ASTM procedure D 3114, fuel conductivity is measured by impressing 1.5 volts across a set of concentric cylindrical electrodes immersed in the fuel and recording the instantaneous current.

Conductivity, Effective - Conductivity of a charged fuel as inferred from the rate at which the charge decays. Depending upon the nature and amount of charged species in a fuel, the charge may decay at a faster or slower rate than predicted from its rest conductivity. To measure effective conductivity, it is necessary to place a charge density meter in the line or to position a field meter in the vapor space of the receiving tank. The fuel is allowed to flow through the system long enough to establish equilibrium and then the flow is shut off and the decay of charge recorded as a function of time. The effective conductivity is then calculated from the equation:

$$Q_t = Q_o e^{-tk_e/\varepsilon\varepsilon_o}$$

where:

Q_t = charge at time t, $\mu C/m^3$
Q_o = initial charge, $\mu C/m^3$
t = elapsed time, seconds
k_e = effective conductivity, siemens/m
ε = relative dielectric constant, dimensionless for fuels, $\varepsilon \simeq 2.0$.
ε_o = absolute dielectric constant of a vacuum.
$\varepsilon_o = 8.854 \times 10^{-12}$ ampere seconds/volt meter.

Alternatively, the effective conductivity can be measured under conditions of constant flow by the simultaneous observation of two charge density meters located in series. In this case, the elapsed time is the residence time of the fuel in the line between the two charge density meters.

Conductivity Unit (CU) - a term used to describe the electrical conductivity of fuels.

$1CU = 10^{-12}$ Siemens/m = 1 picoSiemens/m (pS/m)

Also $1CU = 10^{-12}$ mhos/m - 1 picomho/m - 10^{-14} mhos/cm

Field Strength - The strength of the electric field in the vapor space above a charged fuel. The magnitude of the field strength depends on the charge density in the fuel, the dimension of the tank, the fuel conductivity and the presence of projections within the tank.

Filter-Monitor - a special device in which a filter is used to trigger rapid system shutdown in the event of fuel contamination.

Filter-Separator - the designation for the entire filtration unit containing coalescers and separators.

Millijoule (mJ) - a unit of energy.

1 mJ - 10^{-3} Joules = 10^4 Ergs

Pico - An abbreviation for 10^{-12}

Picomho - See Conductivity Unit

PicoSiemen - See Conductivity Unit

Relaxation Time - The time required for the charge on fuel to decrease to 36.8 per cent of its original value, which is equivalent to setting the exponent of the equation for effective conductivity (above) equal to -1. In other words,

$$\tau = \frac{\varepsilon\varepsilon_o}{k} = \frac{17.7 \times 10^{-12}}{K}$$

where τ = relaxation time (sec)
k = conductivity (pS/m)

Residence Time of System - Time required for fuel to flow from the filter-separator to the receiving tank.

Siemen (S) - Unit of conductance

$$1 \text{ Siemen (S)} -1 \text{ mho} = 1 \text{ ohm}^{-1}$$

Streaming Current - Current resulting from entrainment of charged species in a flowing hydrocarbon stream. See Charging Tendency.

Surface Voltage -- The potential at the surface of the liquid (usually expressed in kilovolts (kV) calculated from a field strength reading (usually expressed in kV/m) and a knowledge of distance between meter and surface. Since the surface voltage of a charged fuel in a grounded container would peak in the center and reach zero at the container walls, surface voltage calculated from field strength is an average or integrated value.

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