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Reduction of Electrostatic Charge in Jet Fuels During Refueler Loading

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13 ABSTRACT

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CONTENTS

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PROBLEM STATUS

This is a final report on this phase of the problem; work is continuing on other phases.

AUTHORIZATION

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REDUCTION OF ELECTROSTATIC CHARGE IN JET FUELS DURING REFUELER LOADING

INTRODUCTION

The generation of electrostatic charge by flowing hydrocarbon fuels has been cited as the source of ignition in more than 100 fires and explosions during refueler and tank truck loadings over a 10-year period (1). While the number of similar accidents involving aircraft has been less (33 incidents from 1956-1969 (2)), two recent low-level explosions within a 7-month period during fueling large commercial jet aircraft have intensified interest in this problem.

It is generally agreed that the primary source of electrostatic charge generation in fuel handling systems is the filter/separator unit which can increase charge density in a flowing fuel by a factor of 100 or more. If the filter/separator also contains fuel monitors, the charge density may be increased even further (3). The level of charge on the fuel when it arrives at the receiving tank, where hazardous discharges may take place, depends on the residence time of the fuel in the line downstream of the filter/separator and on the electrical conductivity of the fuel. The lower the fuel conductivity, the more time is required for the charge to relax.

At present, there are three methods of reducing the level of charge on a fuel and thereby minimizing the possibility of electrostatic discharges:

1. A static dissipator additive which increases the conductivity of the fuel and thereby decreases the time required for the charge to relax.

2. A relaxation tank which provides a minimum of 30 seconds for the charge to relax before the fuel enters the receiving tank, and

3. The static charge reducer (SCR) which produces a corona-type discharge in the fuel to reduce the excess charge.

In this study, the relaxation tank and the SCR were compared for their effectiveness in promoting the dissipation of the electrostatic charge in JP-4 and JP-5 jet fuels. The tests were conducted at a truck fill stand located at the Naval Air Station, Patuxent River, Maryland. Electrostatic charge generation during refueler loading at this same fill stand was discussed in an earlier report (4) in which the voltage on the fuel surface was used as an indicator of electrostatic charge. In the present study, the charge density in the fuel was measured at three points in the system: at the filter, downstream of the relaxation device, and at the point of entry into the refueler. In this manner, the performance of the relaxation devices could be evaluated and the charge generated in the refueling hose could be assessed.

EQUIPMENT

The following equipment was used in this study:

Filter-Separator — Keene Corporation, Filtration Division, model S14-30-40-V-600AL, 600 gpm. This unit has 30 filter elements located in the lower section and 40 Petroguard monitor fuses in the upper section. Fuel is supplied to the filter/separator from underground storage tanks by a 600-gpm deepwell turbine pump.

Relaxation Chamber — 300-gallon capacity. This unit provides a 30-second relaxation time at maximum flow rate.

Static Charge Reducer — A. O. Smith, Meter Systems Division, model SCR-6-36. This unit consists of a 10-inch-diameter pipe, 3 ft in length, containing a 2-inch polyethylene liner through which several rows of sharply pointed electrodes protrude. Passage of highly charged fuel over the grounded electrodes produces a corona discharge which reduces the excess charge within the fuel.

Static Charge Measuring System — A. O. Smith, Meter Systems Division. The measuring system consists of a sensor housing, sensor measuring head, sensor drive, and a Keithley 600B electrometer. In operation, the charge on the fuel flowing past the measuring head is alternately seen by, and shielded from, a stationary plate in the sensor head by the motion of a rotor. This action causes a current to flow to and from ground through the electrometer. Since the current is proportional to the level of charge in the fuel, the current readings from the electrometer can be converted and expressed in terms of the charge density in the fuel. The units used to describe charge density are microcoulombs/cubic meter ($\mu C/m^3$). In these experiments the sensor measuring heads (charge density meters or CDM) were located (a) immediately downstream of the filter/separator, (b) immediately downstream of the charge relaxation devices, and (c) at the dry break or loading connection to the refueler.

Recorder — The output of each electrometer was fed into a strip chart recorder.

Flow Meter — Digital type.

Loading Hose — rubber, O.D. = 2-1/2 or 3 in., length = 13 ft.

Refueler — Two refuelers having capacities of 7050 and 8200 gal. were used.

Figure 1 is a schematic showing the location of the above equipment.

Fuel — Specification-grade JP-4 and JP-5 fuels were used in these tests. The electrical conductivity of the JP-5 fuel was lowered for some tests by clay filtration.

PROCEDURE

The tests were designed to simulate typical refueler loading operations at flow rates of 300 to 540 gpm. During most runs, the charge density in the fuel was monitored continuously at the three locations described previously. Samples were withdrawn after each run for fuel conductivity measurement by either the Shell charged-ball method (5) or, in the later tests, by the proposed ASTM method (6)

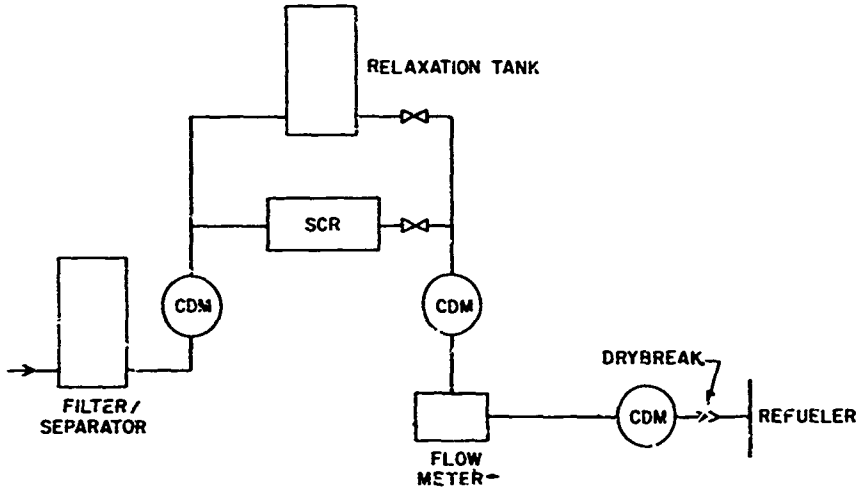

Fig. 1 — Schematic of experimental setup

Three series of runs were conducted with JP-5 fuels having high, normal, and low fuel conductivities. For this purpose, the normal conductivity of JP-5 was assumed to be between 1 and 5 C.U. (1 C.U. = 1×10^{-14} mhos/cm). This assumption is based on the results of a survey of JP-5 fuel conductivity at Lamoore Naval Air Station (7) which showed that of 213 samples of JP-5 fuel, 162 had conductivities between 1 and 5 C.U., 50 were between 0.5 and 1 C.U., and only one sample was above 5 C.U. The JP-4 fuel used in this study had a conductivity of 7.8 C.U. which, based on the authors' experience, is typcial of U.S. military JP-4 fuel.

RESULTS AND DISCUSSION

The results of the fuel conductivity measurements are given in Tables 1 through 3. The data were obtained in the laboratory at 78°F which was approximately the same as the fuel temperature during the first test period (Table 1), but 23-28° higher than during the succeeding test periods (Tables 2 and 3). Since fuel conductivity increases with temperature, the actual fuel conductivities during the second and third test periods were probably about two thirds of the values shown in Tables 2 and 3.

Following run 4 of the first test series (Table 1), new filter elements and fuel monitors were installed in the filter/separator. The new elements and monitors apparently adsorbed sufficient ionic and/or polar material from the fuel to lower the conductivity from 10.9 to 3.3 C.U. Following run 5, the conductivity returned to approximately the same value as in the first four runs indicating that the fuel and the filter had again reached equilibrium. Apparently the JP-4 fuel did not equilibrate with the new filter elements quite as rapidly as the JP-5 fuel since the conductivity of the JP-4 continued to increase during the four runs. Since the JP-4 fuel contains corrosion and icing inhibitor additives whereas the JP-5 fuel does not, it seems quite reasonable that the JP-4 fuel would take more time to equilibrate with the new filters. The conductivity data in Tables 2 and 3, which were obtained by the more precise ASTM method, demonstrate that once the fuel had equilibrated with the filter, the conductivity remained essentially constant for the remainder of the tests.

Table 1
Comparison of Performance of Relaxation Chamber and Static Charge Reducer
Using High-Conductivity JP-5 and Average-Conductivity JP-4 Fuels

Test Period: August 18-21, 1970
Ambient Temperature: 80-86° F
Relative Humidity: 44-77%
Fuel Temperature: 74-78° F

Run No.	Fuel		Relaxation Device	Flow Rate (gpm)	Hose Size (in.)	Charge Density ($\mu C/m^3$)			Time to Reach $30\mu C/m^3$ (sec)	
	Type	Conductivity (C.U.)*				At Filter	Downstream of Relaxation Device	At Dry Break	Downstream of Relaxation Device	At Dry Break
1	JP-5	10.9	RC†	410	3	−216	−9	n.d.**	0	n.d.
2	JP-5		SCR‡	400	3	−209	±8	n.d.	<10	n.d.
3	JP-5		RC	300	3	−130	−7	n.d.	0	n.d.
4	JP-5		SCR	300	3	−146	−5	n.d.	<10	n.d.
New Filter Elements and Bendix Gages Installed										
5	JP-5	3.3	RC	540	3	−292	−6	−14	0	<10
6	JP-5	9.2	SCR	540	3	−285	±8	±8	<10	20
7	JP-5	9.5	RC	400	3	−209	−8	−10	0	0
8	JP-5	9.5	SCR	400	3	−190	±8	±5	<10	<10
Switch to JP-4 Fuel										
9	JP-4	5.0	RC	540	3	−124	−8	−4	0	0
10	JP-4	8.5	SCR	540	3	−124	+12	−8	>10	0
11	JP-4	9.8	RC	300	3	−50	−2	−5	0	0
12	JP-4		SCR	300	3	−42	−1	−5	0	0

*At 78° F, Shell charged-ball method.
†Relaxation chamber.
‡Static charge reducer.
**Not determined.

Table 2
Comparison of Performance of Relaxation Chamber and Static Charge Reducer
Using Normal-Conductivity JP-5 Fuel

Test Period: Dec. 10-11, 1970
Ambient Temperature: 41-54°F
Relative Humidity: 40-89%
Fuel Temperature: 55°F

Run No.	Fuel		Relaxation Device	Flow Rate (gpm)	Hose Size (in.)	Charge Density ($\mu C/m^3$)			Time to Reach 30 $\mu C/m^3$	
	Type	Conductivity (C.U.)*				At Filter	Downstream of Relaxation Device	At Dry Break	Downstream of Relaxation Device	At Dry Break
1	JP-5	n.d.†	RC‡	490	3	−122	−13	−16	0	0
2	JP-5	2.11	SCR**	490	3	−122	±8	±8	<10	<30
3	JP-5	2.33	RC	490	3	−122	−17	−16	0	0
4	JP-5	2.22	SCR	490	3	−118	±15	±8	60	60
5	JP-5	2.14	RC	400	3	−108	−12	−11	0	0
6	JP-5	n.d.	SCR	400	3	−110	±8	0	70	40
7	JP-5	3.00	RC	400	3	−110	−12	−12	0	0
8	JP-5	2.61	SCR	400	3	−103	0	0	60	60
2-1/2-in. Hose Installed										
9	JP-5	2.13	SCR	480	2½	−107	±15	−8	60	60
10	JP-5	2.46	RC	480	2½	−114	−11	−10	0	0
11	JP-5	2.68	SCR	300	2½	−103	±8	±8	60	60
12	JP-5	2.83	RC	300	2½	−107	−6	−8	0	0

*At 78°F, proposed ASTM method.
†Not determined.
‡Relaxation chamber.
**Static charge reducer.

Table 3
Comparison of Performance of Relaxation Chamber and Static Charge Reducer
Using Low-Conductivity JP-5 Fuel

Test Period: Mar. 10-11, 1971
Ambient Temperature: 41-53°F
Relative Humidity: 38-96%
Fuel Temperature: 50°F

Run No.	Fuel		Relaxation Device	Flow Rate (gpm)	Hose Size (in.)	Charge Density ($\mu C/m^3$)			Time to Reach 30 $\mu C/m^3$	
	Type	Conductivity (C.U.)*				At Filter	Downstream of Relaxation Device	At Dry Break	Downstream of Relaxation Device	At Dry Break
1	JP-5	Test equipment								
2	JP-5	n.d.†	RC‡	540	3	−52	−28	−25	120	120
3	JP-5	0.11	SCR**	520	3	−52	−8	0	120	120
4	JP-5	0,14	RC	530	3	−58	−27	−27	60	90
5	JP-5	0.13	SCR	530	3	−60	−8	0	90	120
6	JP-5	0.11	RC	400	3	−58	−23	−20	90	90
7	JP-5	0.18	SCR	400	3	−56	−5	0	130	150
8	JP-5	0.10	RC	400	3	−50	−24	−20	90	120
9	JP-5	0.15	SCR	400	3	−52	−5	0	150	120
Install 2-1/2-in. Hose										
10	JP-5	0.13	SCR	520	2½	−50	0	0	90	90
11	JP-5	0.12	RC	514	2½	−50	−26	−23	90	90
12	JP-5	0.13	SCR	300	2½	−54	−4	0	130	110
13	JP-5	0.11	RC	300	2½	−54	−22	−21	90	60

*At 78°F, proposed ASTM Method.
†Not determined.
‡Relaxation chamber.
**Static charge reducer.

If run 5 of the first series is neglected, since it represents a transitory condition, the average conductivity of the JP-5 fuel was 9.8, 2.45, and 0.13 C.U. respectively for the first, second, and third series, and 7.8 C.U. for the JP-4 fuel which was used in the first series only.

A comparison of the average fuel temperatures during the various test periods with the ambient temperatures given in Tables 1, 2, and 3 indicates that the fuel temperatures were within 10 degrees of ambient for all tests.

Recorder chart tracings showing the charge density in the fuel at the three measuring points, i.e., downstream of the filter, after passing through the relaxation chamber, and at the dry break connection, are shown in Fig. 2 for the normal (2.45 C.U.) fuel. A sharp peak, corresponding to an initial surge of highly charged fuel, can be seen in the tracing obtained from the charge density meter at the filter. This peak is attenuated in the tracings obtained downstream of the relaxation tank and at the dry break. Apparently the highly charged fuel present in the initial surge has sufficient time to dissipate most of this charge in the relaxation chamber, leaving little charge to be detected by the charge density meters downstream of this device. After the initial surge, which lasts about 15 seconds, the charge density at all three measuring points approaches an equilibrium value which usually persists for the remainder of the run. Th decay of charge in the fuel after flow ceases can be seen in the tracings obtained at all three locations.

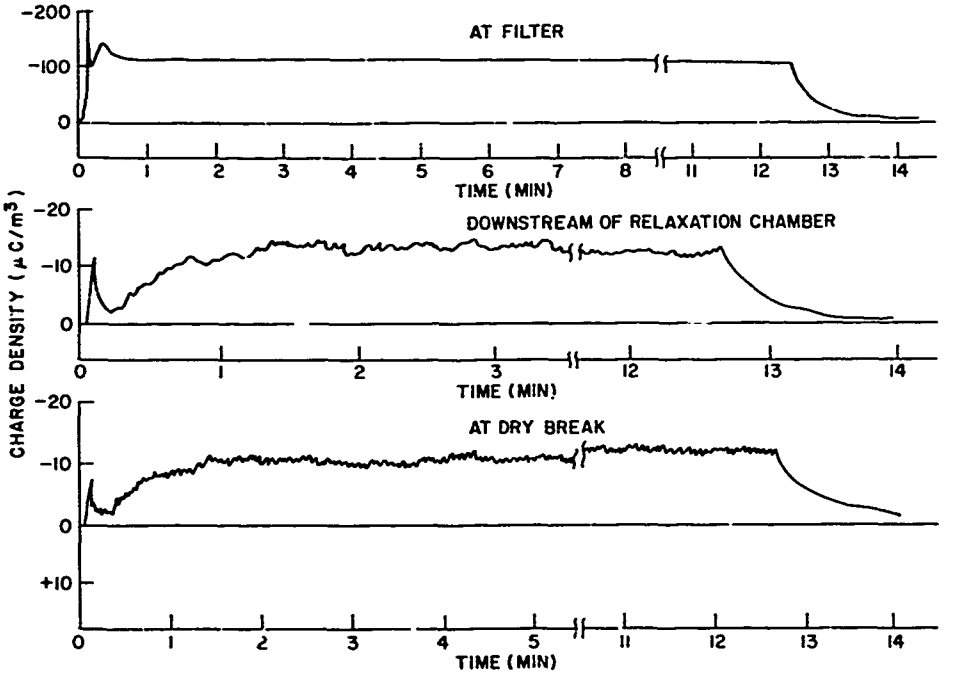

Fig. 2 — Recorder tracings showing charge density in normal-conductivity JP-5 fuel at filter, downstream of relaxation chamber, and at dry break. Time scales (horizontal axes) do not correspond since three different types of recorders were used.

The recorder chart tracings obtained when the SCR was used in place of the relaxation chamber exhibited different characteristics as can be seen by comparing Figs. 2 and 3. The curves in Fig. 3 demonstrate that the initial surge of highly charged fuel passes through the SCR virtually undiminished and appears at the dry break. The reason that the initial charge eludes the SCR but not the relaxation chamber is that a certain finite time (called the "turn-on" time for the SCR) is required for the highly charged fuel to establish a sufficient electric field within the SCR to cause the corona discharge which neutralizes the fuel. Until this field is established, most of the initial surge of highly charged fuel passes through the SCR and appears at the dry break as shown in Fig. 3. However, once the SCR becomes "turned-on," the charge density on the effluent fuel decreases until a final value fluctuating between $\pm 10\ \mu C/m^3$ is attained. The performance of the SCR during the remainder of the run is shown by the expanded-scale drawing in Fig. 3. The oscillatory pattern, which was typical of the SCR, also appears in the tracing obtained at the dry break. The oscillations imply that the corona discharges in the SCR are somewhat intermittent, due, perhaps, to a momentary collapse of the electric field after a sizable portion of the fuel within the SCR has been neutralized. Since the residence time of the fuel in the SCR is so short (about 1 second), the field is quickly reestablished and the discharge process is resumed.

The charge density data from the three series of runs are summarized in Tables 1 through 3. The results show that regardless of conductivity, charge density, or flow rate of the incoming fuel, both the SCR and the relaxation chamber reduce the charge density

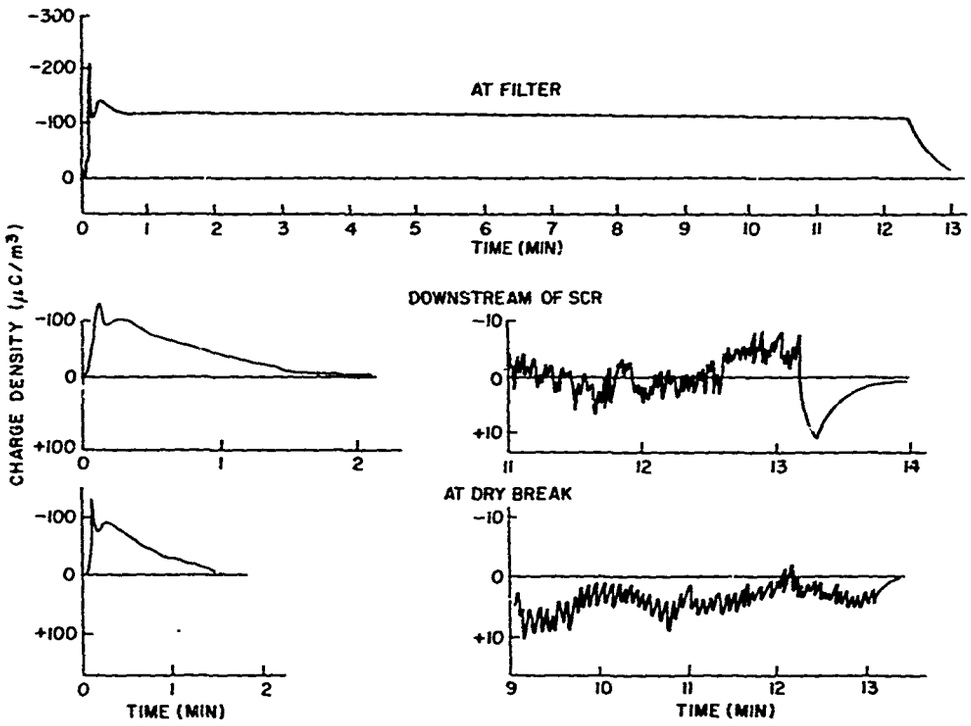

Fig. 3 — Recorder tracings showing charge density in fuel at all three measuring points when SCR is used

of the incoming fuel to less than 30 $\mu C/m^3$, which is considered to be the threshold for incendiary spark discharges (8). Sparking may take place when the charge density is below 30 $\mu C/m^3$, but the energy of these discharges is considered to be insufficient to cause ignition.

The only areas in which the performance of the two relaxation devices differed were with respect to the time required for each device to reduce the charge on the fuel to less than 30 $\mu C/m^3$ and in the degree to which the charge density on the low-conductivity fuel was reduced. At all conductivity levels, the SCR required a certain "turn-on" time to reduce the charge density on the fuel to less than 30 $\mu C/m^3$. This time increased from approximately 10 seconds for the high-conductivity fuel (Table 1) to 150 seconds for the low-conductivity fuel (Table 3). In contrast, when the relaxation chamber was in the system, the charge density on the fuel did not exceed 30 $\mu C/m^3$ until the low-conductivity fuel was used. In this case, the relaxation chamber required approximately the same length of time as the SCR to reduce the incoming charge to less than 30 $\mu C/m^3$.

Although the SCR and the relaxation chamber reduced the charge density on the high- and normal-conductivity fuels to approximately the same degree, there was some difference in performance with the low-conductivity fuel. The relaxation chamber was capable of reducing the charge density on this fuel to about only 25 $\mu C/m^3$ whereas the final value with the SCR was less than 10 $\mu C/m^3$.

In all runs, the charge density at the dry break connection was almost identical to the charge density downstream of the relaxation device, indicating that there was no significant charge generation in the refueling hose. Even when the flow velocity in the refueling hose was increased 50% by switching from the 3-inch to a 2-1/2-inch hose (Tables 2 and 3) there was essentially no increase in the charge density at the dry break, regardless of the conductivity of the fuel. The absence of an increase in the charge density when the flow velocity was increased does not mean, however, that there is no increase in hazard associated with increasing flow velocity. On the contrary, if the charge density remains constant and the flow velocity is increased, more charged fuel enters the receiving tank per unit length of time. It is logical to assume that the voltage on the surface of the fuel in the receiving tank would also increase as the amount of charged fuel entering the receiving tank increases. From the standpoint of initiation of electrostatic discharges, the voltage on the fuel surface is a more realistic criterion of hazard than charge density, since it gives a better picture of the condition existing in the area where discharges could occur. Unfortunately, surface voltage measurements were not made during the present study because suitable equipment was not available. However, it was shown in an earlier study made at the same fill stand (4) that, in some cases, the voltage on the fuel surface tripled when the hose diameter was decreased from 3 to 2-1/2 inches.

Effect of Fuel Conductivity and Flow Rate

The effect of flow rate on the charge density in the fuel coming out of the filter/separator is shown in Fig. 4 for the high-, normal-, and low-conductivity JP-5 fuels. The data show that at low conductivities ($K < 1.0$ C.U.) the charge density is essentially independent of flow rate. As explained above, this does not mean that when handling low-conductivity fuels the flow rate can be increased without increasing the electrostatic hazard. This is particularly true of systems which lack relaxation devices and have rather short residence times downstream of the filter/separator. Since low-conductivity fuels

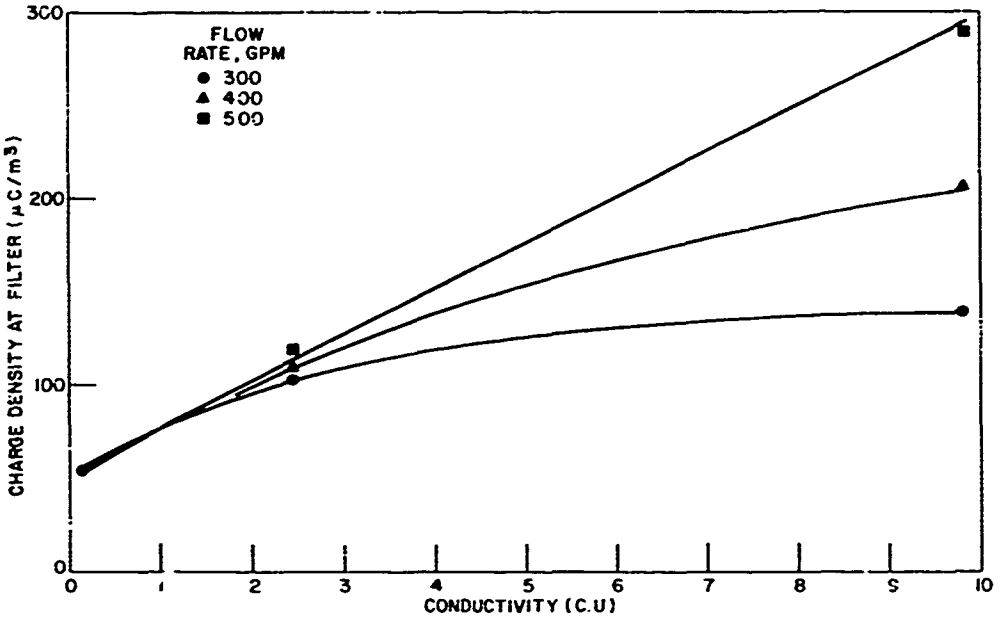

Fig. 4 — Charge density at filter at various flow rates vs conductivity of fuel

retain an appreciable amount of their charge for as long as 30 seconds, increasing the flow rate of these fuels in such systems could cause a significant increase in the level of charge arriving at the receiving tank. This statement would apply particularly in the case of aircraft fueling from hydrant carts and refuelers where the residence time of the fuel downstream of the filter is of the order of a few seconds. According to the data in Fig. 4, no significant reduction in charge density is realized at lower rates until the conductivity of the fuel exceeds 2 to 3 C.U.

A comparison of the charging tendencies of JP-4 and JP-5 fuels of approximately the same conductivity (K = 7.8 C.U. for the JP-4 fuel vs 9.8 C.U. for the JP-5) is given in Fig. 5. The results, which were obtained on successive days using the same filter elements and fuel monitors, demonstrate that fuel conductivity by itself is not a sufficient criterion for predicting the charging tendency of fuels. Other factors, such as the nature of the additives and impurities in the fuels and the age and previous history of the filter elements, are involved. Although other JP-4 and JP-5 fuels would be expected to follow curves similar to those shown in Figs. 4 and 5, the displacement of the curves along the y axis could be quite different.

The data in Table 3 show that the charge density on the low-conductivity fuel was reduced from approximately 54 to 25 $\mu C/m^3$ by passing through the relaxation chamber. Since this represents a reduction of only 46%, it could be inferred that if the charge density on the incoming fuel were higher (>70 $\mu C/m^3$), the relaxation chamber would not be capable of reducing the charge density below 30 $\mu C/m^3$. Although a reduction of this magnitude with low-conductivity fuel may be beyond the capabilities of the relaxation chamber, it is doubtful that very high charge densities would be encountered with low-conductivity fuels due to the inherently poor charging characteristics of these fuels. Also,

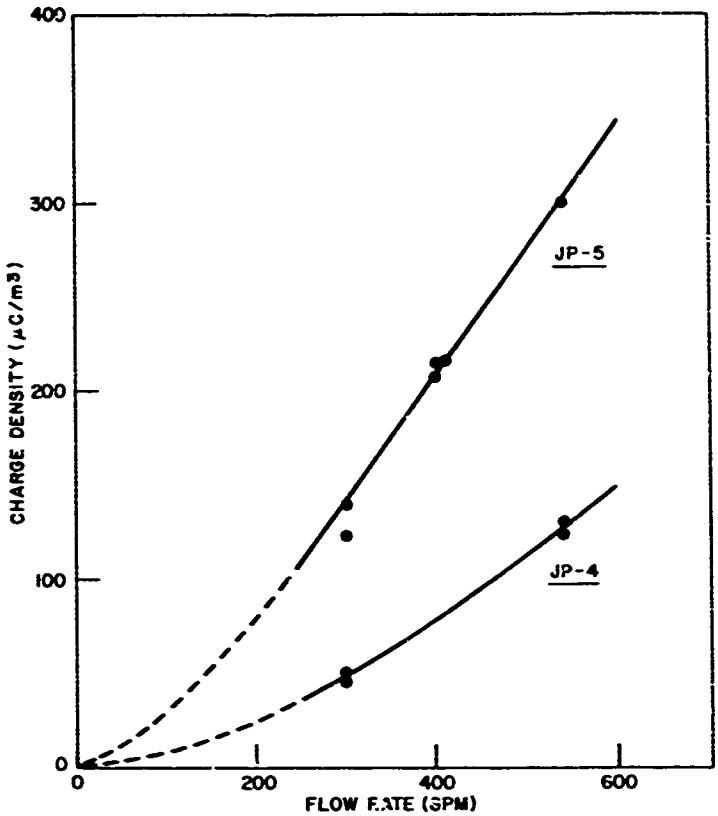

Fig. 5 — Charge density as a function of flow rate for JP-5 and JP-4 fuels

there is other experimental evidence (9) to indicate that 30 seconds of relaxation is adequate for very low-conductivity fuels.

Charge Decay

At the end of each test, the pump was turned off and the charge density meters allowed to run for an additional 2 to 3 minutes to record the decay of charge in the fuel as shown in Figs. 2 and 3. Semilog plots showing the decay of charge in the fuel for the normal- and low-conductivity fuels are presented in Figs. 6 and 7. With the high-conductivity fuel the charge relaxed so rapidly that satisfactory charge decay plots could not be obtained. The curves shown in Fig. 6 indicate that the decay of charge for the normal-conductivity JP-5 fuel is exponential and follows the general expression

$$q = q_0 e^{-tK_e/\epsilon\epsilon_0}$$

where

q_0 = initial charge (coulombs)

q = charge at time t (coulombs)

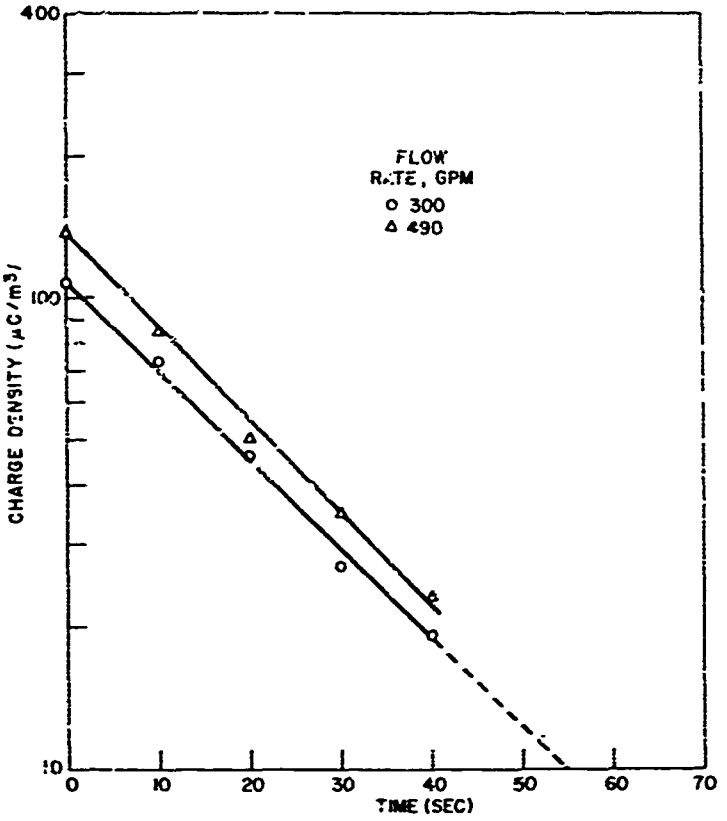

Fig. 6 — Charge decay curves for normal-conductivity JP-5 fuel

t = elapsed time (sec)

K_e = effective conductivity (mho/cm)

ϵ = liquid dielectric constant

$\epsilon_0 = 8.85 \times 10^{-14}$ (sec/ohm cm).

The effective conductivity is a measure of the ability of the charged fuel to relax. As such, it differs from the rest conductivity (Tables 1 through 3), which is obtained by impressing a low voltage on the uncharged fuel. The effective conductivity can be calculated from the above equation by letting $q/q_0 = 0.368$, which makes

$$K_e = \frac{\epsilon \epsilon_0}{\tau},$$

where τ is the time required for the charge to decay to 36.8% of its original value.

Calculation of the effective conductivity from the curves in Fig. 6 yields a value of 0.84 C.U. from the low-flow-rate data and 0.88 C.U. at the high flow rate. The rest conductivity of this fuel at the test temperature (55°F), as estimated from the data in Table 2, is about 1.6 C.U. Thus, the effective conductivity of this fuel is about 1/2 of the estimated rest conductivity. Consequently, the charge on this fuel relaxes more slowly

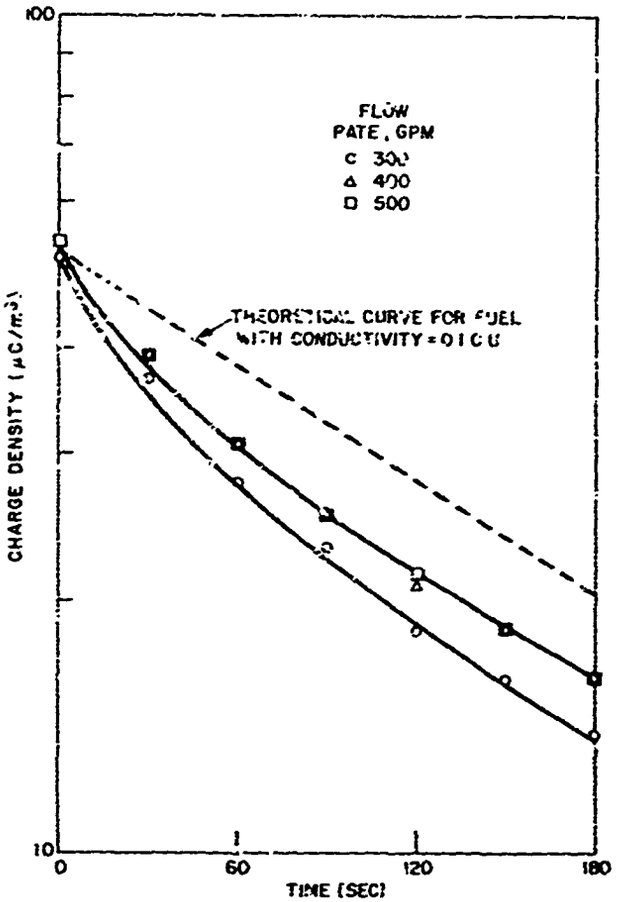

Fig. 7 — Charge decay curves for low-conductivity JP-5 fuel

under actual field conditions than would be predicted from its rest conductivity. Similar discrepancies between rest and effective conductivities have been reported by other workers (10), indicating that accurate predictions of charge relaxation times cannot be made from rest conductivity data.

The residence time of the fuel in the relaxation chamber at a flow rate of 300 gpm is 60 seconds and at 490 gpm, 37 seconds. As indicated by the curves in Fig. 6, the fuel should emerge from the relaxation tank with a charge density of -8 $\mu C/m^2$ at 300 gpm and -25 $\mu C/m^3$ at 490 gpm. The actual charge densities, as indicated in Table 2 for runs 12 and 3, were -6 $\mu C/m^3$ at 300 gpm and -17 $\mu C/m^3$ at 490 gpm which are in fair agreement with the predicted values.

The charge decay curves obtained with the low-conductivity JP-5 are shown in Fig. 7. The dashed-line represents the calculated curve for a fuel having a conductivity of 0.1 C.U., assuming that the decay is exponential. The data show that for the low-conductivity fuel, the charge decays faster than predicted by the exponential law during the critical first 120 seconds. Beyond this point, the curves begin to straighten out and become parallel

with the calculated curve. These results are in agreement with findings of other investigators (9), who have reported that if conductivity of the fuel is below 1 C.U. the charge decays faster than predicted from Ohm's law.

CONCLUSIONS

The following conclusions were developed from the results of this investigation:

1. Regardless of the conductivity, charge density, or flow rate, both the static charge reducer (SCR) and the relaxation chamber reduced the level of charge on the incoming fuel to less than 30 $\mu C/m^3$, which is considered to be the threshold for incendiary discharges.

2. The SCR required an initial "turn-on" time at the beginning of each run before it began to reduce the charge density on the fuel. The time required for the SCR to reduce the charge density to less than 30 $\mu C/m^3$ increased from 10 seconds with the high-conductivity fuel to 150 seconds for the low-conductivity fuel. Once "turned-on," the SCR continued to reduce the charge density during the remainder of run until a final value of about ± 10 $\mu C/m^3$ was reached.

3. With both normal- and high-conductivity fuels, the charge density downstream of the relaxation chamber remained well below 30 $\mu C/m^3$ throughout the entire run. However, with low-conductivity fuel, the relaxation chamber required slightly less time (60 to 120 seconds) than the SCR to reduce the charge density to less than 30 $\mu C/m^3$. The final value was about -25 $\mu C/m^3$, which is higher than values obtained with the normal- and high-conductivity JP-5.

4. In all runs, the charge density at the dry break connection was almost identical to the charge density downstream of the refueling hose, indicating that there was essentially no charge generation in the refueling hose.

5. With low-conductivity JP-5 fuel ($K < 1.0$ C.U.) the charge density on the fuel coming out of the filter was found to be independent of flow rate. This does not mean, however, that the flow rate of such fuels can be increased without increasing the electrostatic hazard. On the contrary, if the charge density remains constant and the flow rate is increased, more charged fuel enters the receiving tank per unit length of time. This finding is of particular importance in systems which lack relaxation devices and have very short residence times for the fuel downstream of the filter/separator. These conditions are often found in aircraft refueling from hydrant service carts where short lengths of small-diameter hose provide the only relaxation between the filter/separator and the skin of the aircraft. The residence time of the fuel in such hoses at high flow rates may be less than 1 second. Increasing the flow rate of low-conductivity fuels in such systems could cause a considerable increase in the amount of charge on the fuel entering the aircraft despite the fact that the charge density remained constant.

RECOMMENDATIONS

Since the purpose of a relaxation device is to reduce electrostatic charge on fuel before it enters the receiving tank, it is essential that the length of pipe downstream of the relaxation device be kept to an absolute minimum. For top loading, the manufacturer

of the SCR (11) suggests that the total run of pipe in the loading assembly be limited to 22 feet. The same restriction would apply for bottom loading or for a relaxation chamber since the object is to prevent buildup of static charge downstream of the relaxation device. It is further recommended when an SCR is used that a static charge sensor housing and measuring head be installed downstream of the SCR as shown in the manufacturer's literature (11) to permit periodic evaluation of the effectiveness of the SCR. This evaluation would detect any diminution in performance of the SCR that might occur if the surface of the plastic lining of the SCR were to become conductive as a result of adsorbing impurities from the fuel. Since the successful operation of the SCR depends on the insulation properties of this liner, increasing the surface conductivity could seriously impair the effectiveness of the SCR with resultant loss in protection from electrostatic hazards.

In a typical installation in which the SCR is located immediately downstream of the filter/separator and the length of pipe downstream of the SCR is reduced to a minimum, failure of the SCR would mean that most of the charge generated at the filter/separator would arrive at the receiving tank undiminished since the relaxation time provided by the pipe would be rather short (ca. 1-2 sec). Periodic evaluation of the effectiveness of the SCR would permit prompt remedial action in the event of any loss of performance of the SCR (solvent washing of liner to restore high surface resistivity) and thereby prevent failures.

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