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ELECTROSTATIC CHARGING OF JP-4 FUEL ON POLYURETHANE FOAMS.(U)

MAR 78 J T LEONARD, W A AFFENS

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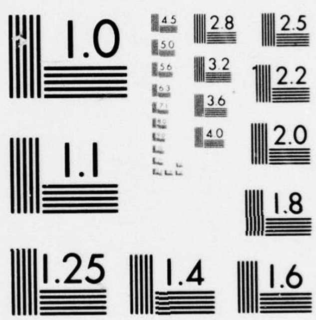

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NRL Report 8204

Electrostatic Charging of JP-4 Fuel on Polyurethane Foams

J. T. LEONARD and W. A. AFFENS

Combustion and Fuels Branch
Chemistry Division

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The electrostatic charge generating characteristics of JP-4 fuel were determined on both polyester- and polyether-type polyurethane foams. Eleven samples of JP-4 fuel, covering a range in electrical conductivity of 0.65 to 10.27 picosiemens/m (pS/m) were tested. The conductivity of one sample was increased incrementally to 200 pS/m by use of a static dissipator additive (ASA-3). The charging tendency of the fuels was determined by measuring the filter current developed by the passage of 50 ml of fuel through a cylindrical section of foam held in an electrically isolated filter holder. The charging tendencies

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20. Abstract (Continued)

of all fuel samples were also determined using a reference paper filter. It was found that JP-4 fuels can become charged electrostatically by flowing through polyurethane foam. However, the magnitude of the charge cannot be predicted from the electrical conductivity of the fuel nor on the basis of its charging tendency on the reference paper filter. The charging tendencies on the polyether foams were about six times greater than on the polyester foams.

CONTENTS

ELECTROSTATIC CHARGING OF JP-4 FUEL ON POLYURETHANE FOAMS

INTRODUCTION

Over the past three years, seven Air Force aircraft (two helicopters and five fixed wing) experienced minor fires or low-level explosions while refueling with JP-4 fuel. In another incident, a ball of flame was observed at the filler opening of the fuel tank of an F-5E aircraft while the tank, which previously contained JP-4 fuel, was being purged with a mixture of JP-5 fuel and 1010 oil. Because the tanks of all eight aircraft were filled with polyurethane foam for explosion suppression, damage to the aircraft was minimal. However, since jet fuels are known to generate static electricity when passing over paper and fiberglass filters, it was considered that the polyurethane foam possibly could have contributed to the accidents by serving as a static-charge-generating surface for the fuel. The objective of this project was to investigate electrostatic-charge-generating characteristics of JP-4 fuel on different types of polyurethane foams to determine if any fuel—foam combinations produce unusually high electrostatic charges.

EXPERIMENTAL PROCEDURE

The study was conducted in three phases. In the initial phase, the charging tendency of silica-gel-treated (SGT) *n*-heptane was investigated on a variety of polyurethane foams including the three polyester types (Type I, orange; Type II, yellow; and Type III, red) approved in the military specification [1], and three polyether foams. The foams are listed in Table 1. The used sample of orange foam was taken from an Army OV-1 after five years of service and the used yellow foam was from an F-5E aircraft that was involved in an electrostatic fueling incident. SGT *n*-heptane was used to determine the charging characteristics of a pure hydrocarbon (i.e., free from the polar and ionic constituents and/or additives normally found in fuels) on the foams. The silica gel treatment consisted of passing *n*-heptane (Phillip Pure Grade, 99 mol. % minimum) through a column containing Drierite and silica gel.

The apparatus used to study charging tendency, the Exxon Mini-Static Tester, is shown in Fig. 1 [2]. In this test, the current is measured as a 50-ml sample of the fuel is passed at a constant flow rate of 1.67 cc/s through an electrically isolated filter holder containing a 1.3-cm-diam filter. The filter current is divided by the flow rate to express the charging tendency of the fuel in terms of charge density in microcoulombs per cubic meter ($\mu C/m^3$). The repeatability of the test is 7% [3].

The charging tendencies of all fuels were determined with the Exxon apparatus using the standard (Type 10) paper filter [2]. To measure the charging tendencies of the fuels on the foams, we expanded the filter holder to accommodate a 1.3- × 7.5-cm section of the

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Table 1 — Polyurethane Foams

Sample No.	Foam	Description
Polyester Type		
2	Orange, used*	5 years of service in U.S. Army OV-1 (SN 68-15941)
3	Orange, new*	Run W769K (16-2), produced 1975
4	Yellow, used*	From static discharge incident, Dec. 1974, F-5E Aircraft (SN 74-01369)
5	Yellow, new*	Run W852K (2-3), produced 1975
6	Red, new*	Run W881K (2-5A), produced 1975
Polyether Type		
7	Blue, coarse, new	Run W906K (3-1), produced 1975
8	Blue, fine, new	Run W906K (8-3), produced 1975
9	Charcoal, fine	Run L-319, produced 1974

*Conforms to Military Specification MIL-B-83054A [1].

foam. Test samples were cut from a block of foam using a No. 9 cork borer on a drill press. For each fuel, charging tendency measurements were also made on a "blank" fuel sample (no foam in the filter holder). All foam-charging tendency values that are shown in the tables and figures have had the blank value subtracted from the measured value. As an additional check on electrostatic properties of the fuels, the electrical conductivity was measured by the ASTM method [4]. Conductivity is expressed in picosiemens per meter (pS/m).

In the second phase, the charging tendencies of 11 samples of JP-4 fuels, 10 of which had been involved in foam-related incidents, were compared. Sample 23 was from a static-related, refueler loading incident at McGuire AFB, N.J. The remainder were from incidents involving aircraft equipped with foam-filled tanks. The fuels are listed in Table 2.

In the final phase, the conductivity of a composite sample of JP-4 fuels (No. 32) was increased by adding Shell Static Dissipator Additive (ASA-3) to determine the effect of high fuel conductivity on charging of the foams.

RESULTS AND DISCUSSION

The data obtained by measuring the charging tendency of two samples of SGT *n*-heptane on Type 10 paper are given in Table 3. Sample 2 was passed through the silica gel

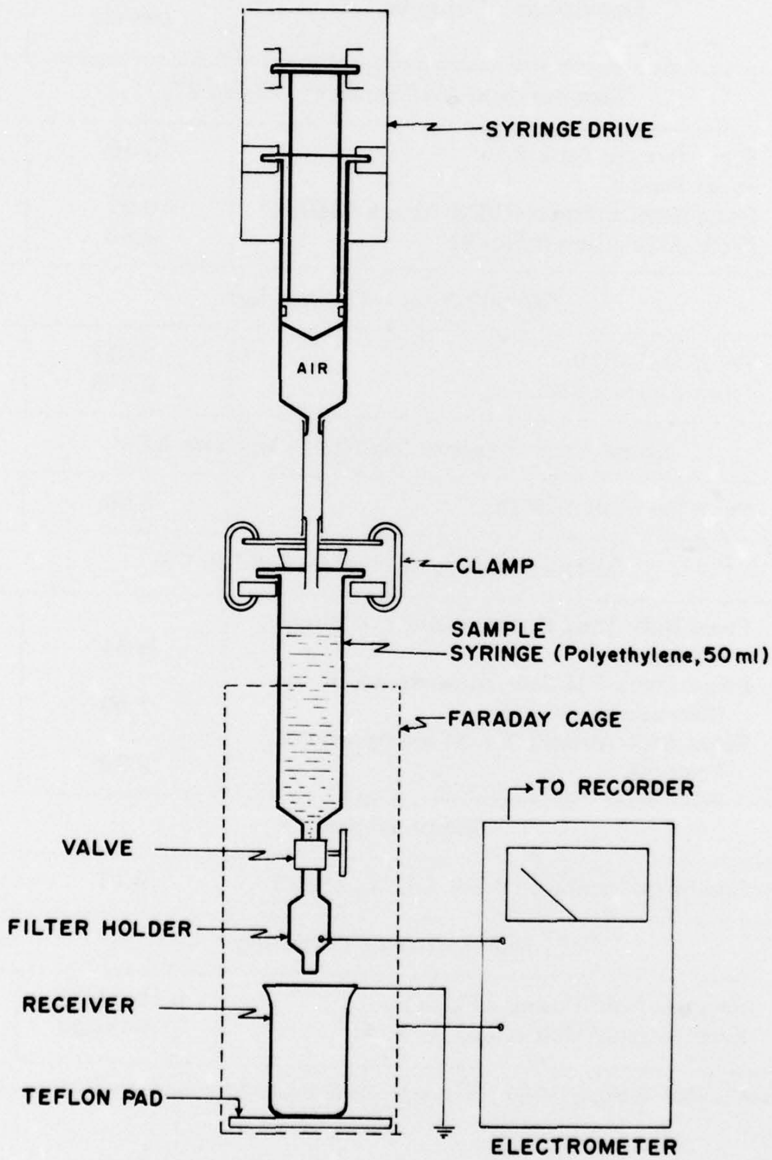

Fig. 1 — Exxon Mini-Static Tester [2]

Table 2 — Electrical Conductivity and Charging Tendency of JP-4 Fuels

Sample No.	Description of Sample	Conductivity (pS/m)	Charge Density ($\mu C/m^3$)
	Samples from A-10 Incident (12 Jan 77)		
15	From Storage Tank 2	2.60	939
16	From Tank 1	4.65	1170
17	From Service Truck (USAF Truck 438091)	10.27	2190
18	From A-10 Aircraft No. 31	6.85	2370
	Samples from F-105 Incident		
19	From Trailer 20	0.651	5800
20	From Aircraft 8365	0.759	4440
	Sample from Refueler Incident at McGuire AFB*		
23	From Hosecart 74W71	5.00	266
	Samples from A-10 Incident (18 Feb 77)		
26	From Bulk Tank 2, downstream of filter-separator	6.54	1480
28	From Truck 68L-192, downstream of filter-separator	7.30	3040
30	From A-10 Aircraft No. 37, composite of bottoms	9.98	1780
	Combined Sample		
32	Combined Samples 19, 20, 23, 26, 28, 30	9.13	4580
	Samples from CRC Survey		
	Samples from Loring AFB (4)	4.19–15.70	930–4290
	Samples from Homestead AFB (4)	2.70–34.20	555–3675

*Sample involved in static-related, refueler loading incident. Foam-filled tanks were not involved.

Table 3 — Electrical Conductivity and Charging Tendency of Silica-Gel-Treated n-Heptane on Polyurethane Foams

Sample	SGT n-Heptane 1	SGT n-Heptane 2
Electrical Conductivity, pS/m	0.111	0.027
Filter	Charge Density, $\mu C/m^3$	
Type 10 Paper	128	3
Polyester Foam		
No. 2 Orange, used	5	-
No. 3 Orange, new	2	<1
No. 4 Yellow, used	1	-
No. 5 Yellow, new	-1	<1
No. 6 Red, new	-1	<1
Polyether Foam		
No. 7 Blue, coarse	-4	2
No. 8 Blue, fine	-4	-
No. 9 Charcoal, fine	-2	<1
Blank, i.e., no foam in filter holder	-2	0

column twice and hence had a lower conductivity and a lower charging tendency on the Type 10 paper. The charge levels developed by the n-heptanes on the foam barely exceed the values obtained with no foam in the filter holder. The results confirm the conclusions from a previous study [5], in which it was found that silica gel treatment removes virtually all of the charge-promoting species from the hydrocarbon liquid. Hence, charges produced by SGT n-heptane on foams were found to be negligible.

The electrical conductivities of the JP-4 fuels and their charging tendencies on Type 10 paper are given in Table 2. Also shown in the table for comparison are the ranges in both fuel conductivity and charge density as obtained in a recent survey of JP-4 samples taken from Loring AFB, Me., and Homestead AFB, Fla. [3]. Three samples, Nos. 19, 20, and 32, were found to fall beyond the survey range in charge density for JP-4 fuels. All three samples would be considered electrostatically active or 'hot' based on criteria employed in a recent study [5]. The criteria are as follows:

1. The charge density must exceed 4000 $\mu C/m^3$ when measured on Type 10 paper.
2. The conductivity must be less than 50 pS/m.

Since the conductivities of samples 19, 20, and 32 are far below 50 pS/m (samples 19 and 20 are below 1 pS/m), all three samples would be considered exceptionally 'hot.' Hence, they were judged particularly suitable for the present study in which it was desired to evaluate charging of a wide variety of fuels, and particularly fuels producing a high charge, on the foams.

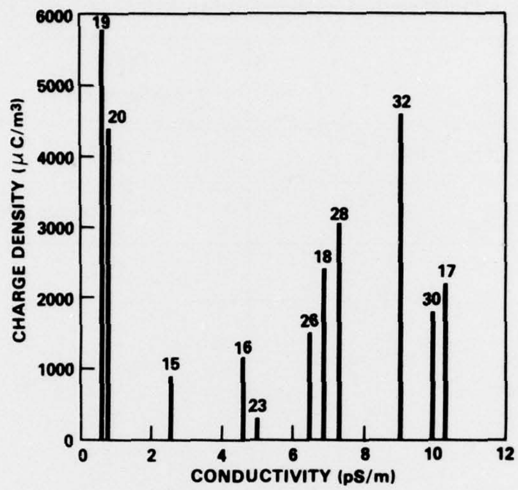

Fig. 2 — Charging tendency of JP-4 fuels on Type 10 paper vs fuel conductivity (fuel sample number shown)

The effect of fuel conductivity on charging tendency on Type 10 paper is shown in Fig. 2. As concluded from earlier studies [3,5], charge densities of different fuels were independent of fuel conductivity.

The results of the charging tendency measurements for JP-4 fuels on the polyurethane forms are listed in order of increasing fuel conductivity in Table 4 and are shown graphically in Figs. 3—8. The data show that, just as with the Type 10 paper (Fig. 2), charge density is independent of fuel conductivity. Furthermore, no significant differences between the used and new foams were found (Figs. 3 and 4). The sign of the charge was positive for most fuels on the orange, yellow, and red foams (Figs. 3, 4, and 5). Sample 32, one of the 'hot' fuels on Type 10 paper, charged negatively on all three types of polyester foam, however. In addition, Sample 32 produced the highest levels of charge of all the fuels on the polyester foams. In contrast, the other two 'hot' fuels, samples 19 and 20, exhibited very low charging on the same foams, demonstrating that charging on Type 10 paper is no indication of performance on polyurethane foams.

Charging on the new blue and charcoal polyether foams (Figs. 6—8) was found to be dramatically different from charging on the orange, yellow, and red polyester foams. On the average, the magnitude of the charge densities was about six times greater on the polyether foams: one sample (32) actually produced 8.5 times more charge on the blue and charcoal foams than on the polyester foams. Also, with only two exceptions, the sign of the charge was negative on the polyether foams as opposed to the unpredictable nature of the charging on the polyester foams. The highest charge density obtained on the polyether foams (213 $\mu C/m^3$ for Sample 32 on the blue, fine, foam) is fairly close to the charge density of a poorly charging fuel (Sample 23) on Type 10 paper (Table 2). These results suggest that with a suitably high charging fuel, fairly substantial levels of charge can be generated on polyether foams.

Table 4 — Electrical Conductivity and Charging Tendency of JP-4 Fuels on Polyurethane Foams

JP-4 No.	19	20	15	16	23	26	18	28	32	30	17
Conductivity, pS/m	0.651	0.759	2.60	4.65	5.00	6.54	6.85	7.30	9.13	9.98	10.27
Filter	Charge Density, $\mu C/m^3$										
Type 10 paper	5800	4440	939	1170	266	1480	2370	3040	4580	1780	2190
Polyester Foams											
No. 2 Orange, used	-3	12	2	12	-8	0	12	-8	-39	-3	16
No. 3 Orange, new	0	15	26	16	-4	8	16	-1	-26	3	20
No. 4 Yellow, used	-3	9	26	21	-8	1	15	-2	-20	3	23
No. 5 Yellow, new	-5	8	15	24	-5	1	11	-3	-8	2	17
No. 6 Red	0	12	31	29	-11	12	3	-7	-23	4	11
Polyether Foams											
No. 7 Blue, coarse	-5	-4	-45	-24	-133	-60	-117	-91	-170	-91	-138
No. 8 Blue, fine	-16	-6	-34	-36	-133	-70	-106	-98	-213	-69	-156
No. 9 Charcoal, fine	-11	-1	4	0	-125	-34	-77	-74	-204	-47	-75
Blank, i.e. no foam	8	8	10	10	3	8	2	6	10	5	3

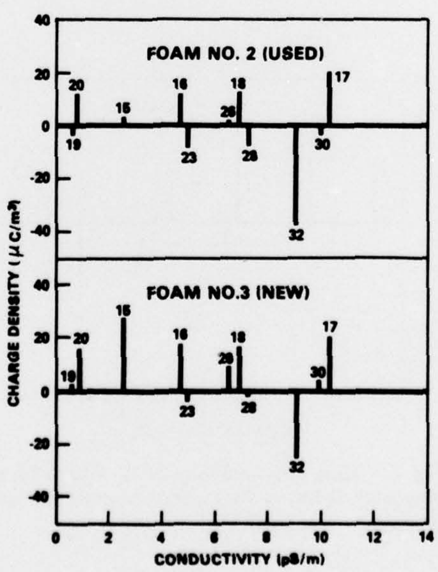

Fig. 3 — Charging tendency of JP-4 fuels on orange polyester foams vs fuel conductivity (fuel sample numbers shown)

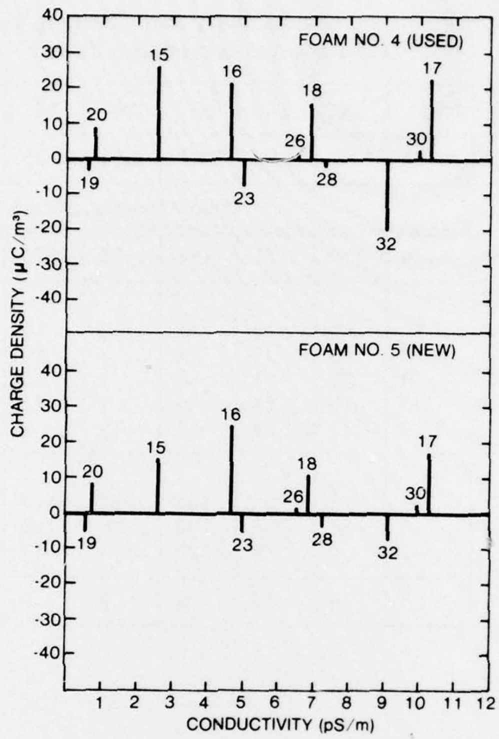

Fig. 4 — Charging tendency of JP-4 fuels on yellow polyester foams vs fuel conductivity (fuel sample numbers shown)

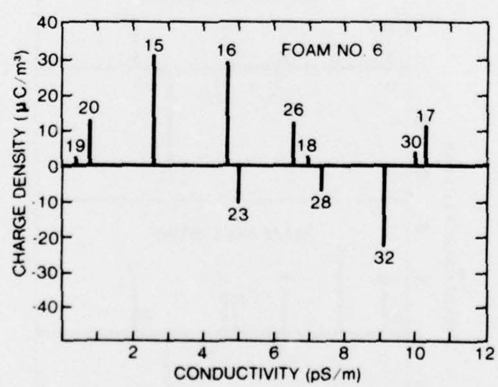

Fig. 5 — Charging tendency of JP-4 fuels on red polyester foam vs fuel conductivity (fuel sample numbers shown)

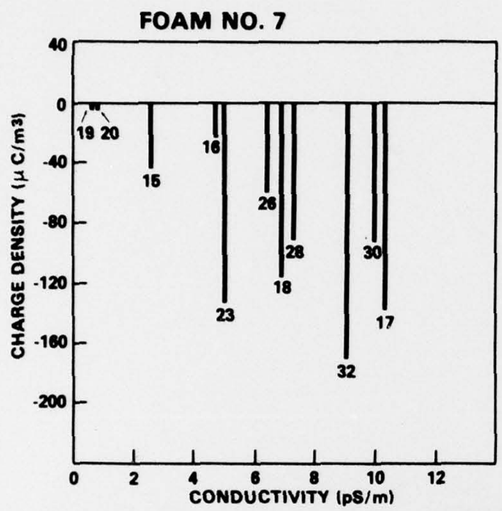

Fig. 6 — Charging tendency of JP-4 fuels on blue (coarse) polyether foam vs fuel conductivity (fuel sample numbers shown)

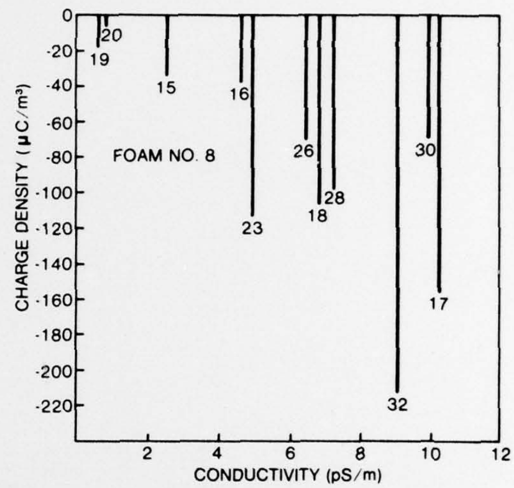

Fig. 7 — Charging tendency of JP-4 fuels on blue (fine) polyether foam vs fuel conductivity (fuel sample numbers shown)

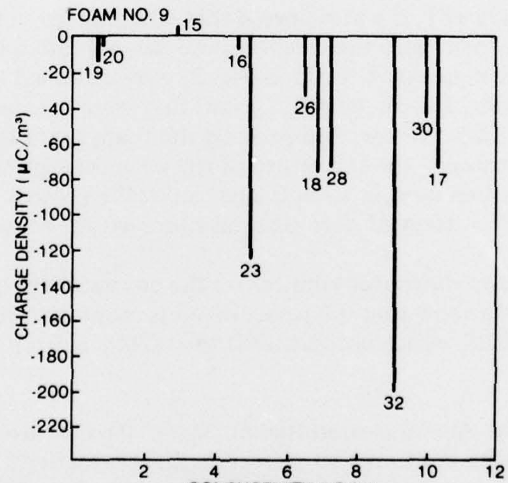

Fig. 8 — Charging tendency of JP-4 fuels on charcoal (fine) polyether foam vs fuel conductivity (fuel sample number shown)

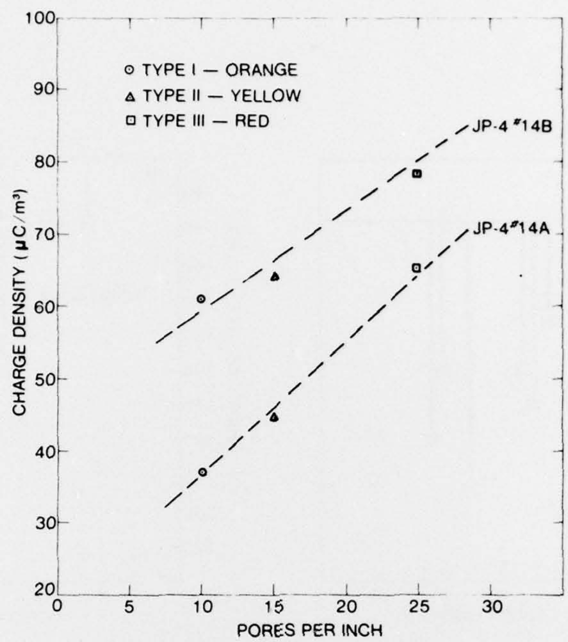

Fig. 9 — Effect of porosity of compressed polyurethane foams on charging tendency of JP-4 fuels. Type I, orange; Type II, yellow; Type III, red.

In a preliminary study [6], it was reported that charging was a function of the porosity of the foam and that the foam with the smallest pore size exhibited the highest charging. However, these data, which are reproduced in Fig. 9, were obtained on small, cylindrical sections of the foam (diameter, 1.3 cm; length, 1.3 cm) that were compressed in the standard filter holder of the Mini-Static Tester. Compressing the foam tends to magnify the effect of the small pore size by increasing the tortuosity of the path through the filter. Since the foam is not compressed when used in aircraft fuel tanks, the present study was conducted on uncompressed foam. No effect of pore size was observed for the uncompressed foams.

The effect of the static dissipator additive on the conductivity of JP-4 fuel No. 32 is shown in Fig. 10. The data show that 0.3 ppm ASA-3 is more than sufficient to increase the conductivity above 50 pS/m, which is considered the safe level from the standpoint of electrostatic hazards.

Charging levels of the ASA-3 treated fuel on Type 10 paper are shown in Fig. 11. Although the charge density continues to increase with conductivity (generally for a given treated fuel, charge density peaks in the range of 100—200 pS/m before falling off [7]), high charge levels at conductivities greater than 50 pS/m are not considered hazardous. This is because conductivities above this value afford relaxation in the pipeline downstream of the filter, and the charge relaxes almost as quickly as it is generated. The only reason high charge levels are recorded above 50 pS/m with the Mini-Static Tester is because there is virtually no opportunity for the charge to relax downstream of the standard filter in this apparatus.

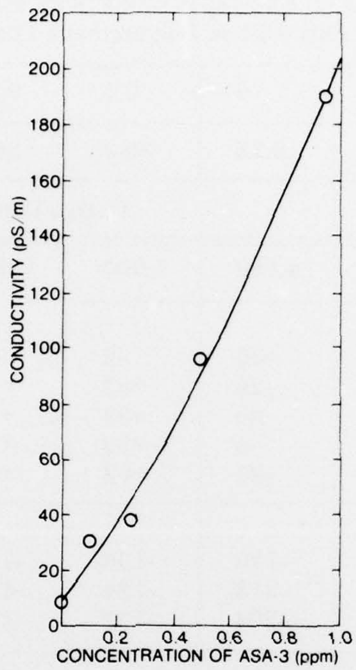

Fig. 10 — Effect of Static Dissipator Additive (ASA-3) on conductivity of JP-4 Fuel 32

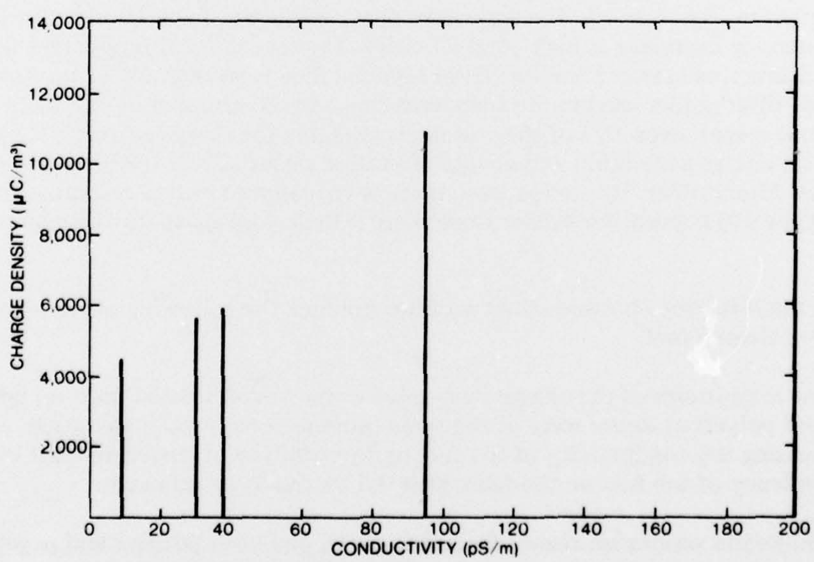

Fig. 11 — Charging tendency of ASA-3 treated JP-4 Fuel 32 on Type 10 paper vs fuel conductivity

Table 5 — Effect of ASA-3 on Electrical Conductivity and Charging Tendency of JP-4 Fuel #32 on Polyurethane Foams

Concentration, ASA-3, ppm	0	0.1	0.25	0.5	1.0
Conductivity, pS/m	9.13	30.4	38.2	95.5	200
Filter	Charge Density, $\mu C/m^3$				
Type 10 Paper	4,580	5,690	5,900	10,920	12,440
Polyester Foams					
No. 2 Orange, used	-39	-2	+8	+3	-3
No. 3 Orange, new	-26	+33	+16	+32	+13
No. 4 Yellow, used	-20	+38	+19	+15	+12
No. 5 Yellow, new	-8	+30	+27	+22	+1
No. 6 Red	-23	+42	+50	+37	+19
Polyether Foams					
No. 7 Blue, coarse	-170	-136	-136	-101	-79
No. 8 Blue, fine	-213	-184	-171	-109	-79
No. 9 Charcoal, fine	-204	-132	-165	-109	-44
Blank, i.e. no foam	+ 10	-23	-7	+ 29	+ 33

Charging levels of the ASA-3 treated fuels on the various foams are given in Table 5 and are plotted in Figs. 12—17. The data show that, unlike the Type 10 paper in Fig. 11, the charge density decreases at high conductivities. The reason for this apparent discrepancy lies in the differences between the two filter holders. Since less than 5% of the volume of the modified filter holder used in the foam charging tests is occupied by the foam (the foam is mostly void space), over 95% of the volume is available for charge relaxation. Consequently, both charge generation and charge relaxation occur as fuel traverses the volume of the modified filter holder. By comparison, there is virtually no charge relaxation in the standard (Type 10) paper filter holder since there is little void space downstream of the filter.

Given the difference between the two filter holders, the following observations apply to the ASA-3 treated fuel:

1. The magnitudes of the charge densities for the ASA-3 treated fuels on both the polyester and polyether foams were of the same order as for the untreated fuels. In other words, increasing the conductivity of the fuel by the addition of ASA-3 did not increase the charging tendency of the fuel on the foam as it did on the Type 10 paper.

2. Unlike the various untreated fuels that developed both positive and negative charges on the orange, yellow and red foams, the ASA-3 treated fuel (with two minor exceptions) always charged positively on these foams.

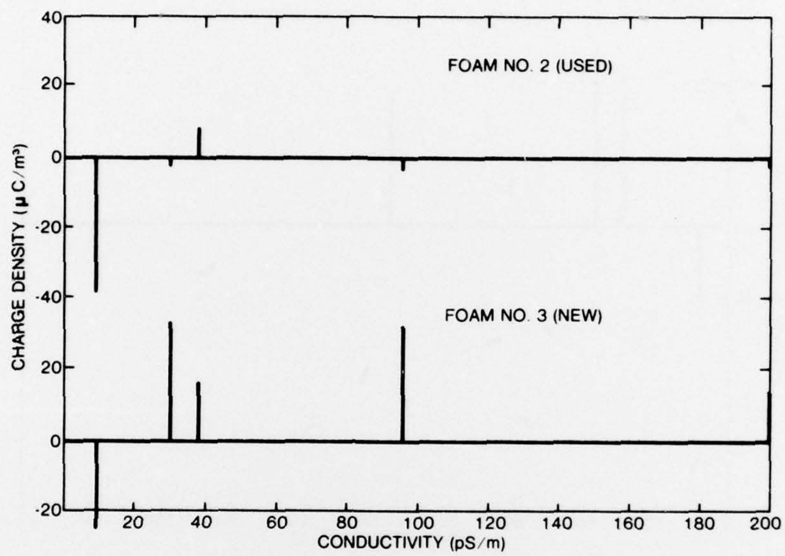

Fig. 12 — Charging tendency of ASA-3 treated JP-4 Fuel 32 on orange polyester foams vs fuel conductivity

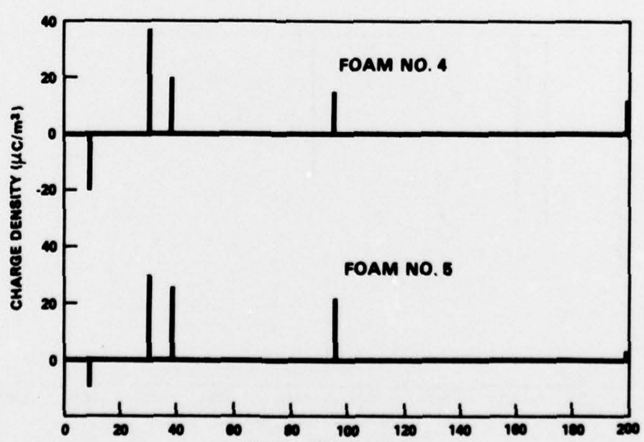

Fig. 13 — Charging tendency of ASA-3 treated JP-4 Fuel 32 on yellow polyester foams vs fuel conductivity

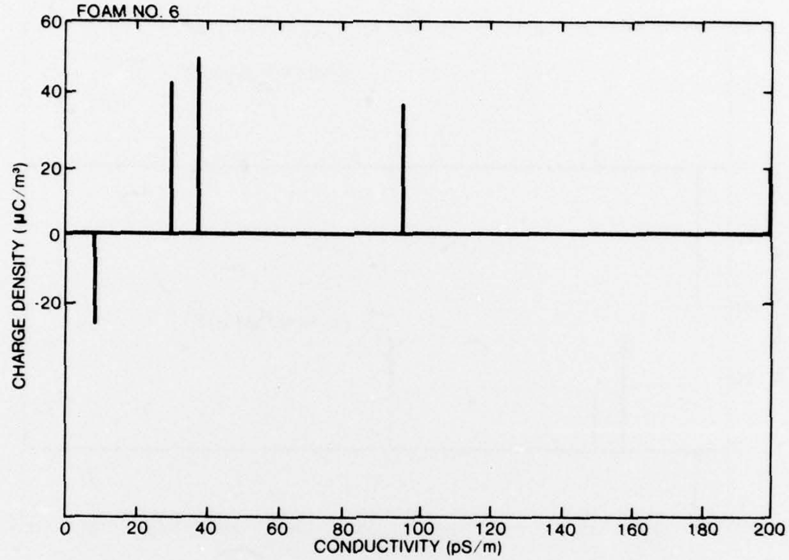

Fig. 14 — Charging tendency of ASA-3 treated JP-4 Fuel 32 on red polyester foam vs fuel conductivity

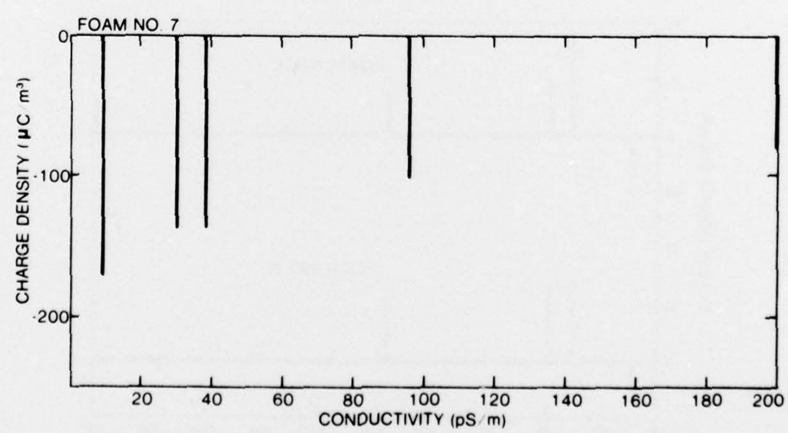

Fig. 15 — Charging tendency of ASA-3 treated JP-4 Fuel 32 on blue (coarse) polyether foam

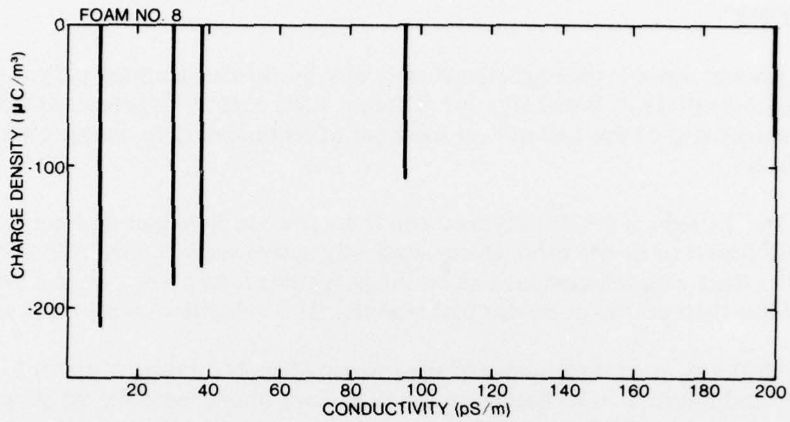

Fig. 16 — Charging tendency of ASA-3 treated JP-4 Fuel 32 on blue (fine) polyether foam

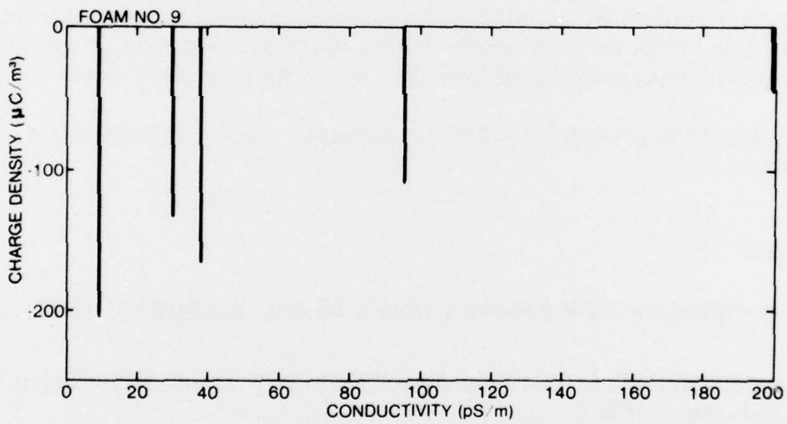

Fig. 17 — Charging tendency of ASA-3 treated JP-4 Fuel 32 on charcoal (fine) polyether foam

3. As with the untreated fuels, charging of the ASA-3 treated fuels was about six times greater on the polyether foams than on the polyester foams. The sign of the charge of the treated fuels on polyether foams was always negative.

4. With the ASA-3 treated fuels, the magnitude of the charge density decreased gradually with increasing conductivity on both types of foam. However, since the charge levels were still relatively high at a fuel conductivity of 100 pS/m, it appears that the conductivity should be increased above this level to protect fuel systems employing foam-filled tanks.

CONCLUSIONS

JP-4 fuels can become charged electrostatically by flowing through polyurethane foam. However, the magnitude of the charge for different fuels cannot be predicted from the electrical conductivity of the fuel nor on the basis of its tendency to charge on a paper (Type 10) filter.

Of the two generic types of polyurethane foam tested (polyester and polyether), the polyether was found to be the more electrostatically active surface. For both untreated and ASA-3 treated fuels, the charge densities on the polyether foams were, on the average, about six times greater than on the polyester foams at the flow velocities used in this study.

Although the signs of the charges of the untreated fuels on the polyester foams were both positive and negative, the charges on the polyether foams were almost always negative. In the case of the ASA-3 treated fuels, the charges on the polyester foams were almost always positive, but the charges on the polyether foams were always negative.

The maximum charge density for a given ASA-3 treated fuel was found to occur when the fuel conductivity was less than about 100 pS/m. Therefore, if a static dissipator additive were to be used to protect an aircraft fuel system with foam-filled tanks, it is recommended that the fuel conductivity be maintained well above 100 pS/m instead of the 50 pS/m value, which is the generally accepted lower level for fuels containing static dissipator additive.

Finally, the charging tendency of SGT *n*-heptane on both types of foams was found to be negligible.

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