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Effect of a Static Dissipator Additive on the Charging Tendency of Jet Fuels

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ABSTRACT

The effect of a static dissipator additive on the charging tendency of both JP-4 and JP-5 type jet fuels was examined at various flow velocities on a laboratory scale. For our use, the term charging tendency refers to the current generated by a given quantity of fuel when passing through a filter or an insulated section of piping rather than to the ability of a fuel to produce dangerously high potentials when loaded into a tank. It was found that when the conductivity of the fuel is increased by the addition of the static dissipator additive, the charging tendency also increases, passes through a maximum, and then decreases. Also, at higher flow velocities, there is an overall increase in the charging tendency of the fuel, and the position of the maximum in the charging tendency vs conductivity curve shifts to a higher conductivity range. However, since the rate at which the charge on the fuel dissipates also increases with increasing conductivity, no increase in electrostatic hazard due to the use of the static dissipator additive is foreseen during fuel handling operations as long as the ability of additive-treated fuels to generate charge is recognized and sufficient time is permitted for the charge to relax before the fuel enters a receiving tank.

PROBLEM STATUS

This is an interim report on a continuing problem.

AUTHORIZATION

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EFFECT OF A STATIC DISSIPATOR ADDITIVE ON THE CHARGING TENDENCY OF JET FUELS

INTRODUCTION

Hydrocarbon liquids such as jet fuels and motor and aviation gasolines can generate sufficient electrostatic charge when flowing through the pipes and filters of a modern fuel handling system to produce electrical discharges when the liquids are loaded into receiving tanks (1-5). Fortunately these discharges seldom lead to ignitions, but there have been occasions in which fires and explosions, attributable to static electricity generated by the fuel, have occurred during the loading of tank trucks (6) and aircraft (7).

One way of reducing the danger of electrostatic discharges during fuel handling is by the use of a static dissipator additive to raise the conductivity of the fuel and thereby promote the rapid dissipation of the charge (7). Indeed one such additive, Shell ASA-3 (Shell Oil Company), is currently available and has already gained acceptance outside of the United States (8). Some 87 airlines have agreed to accept jet fuel containing the static dissipator additive, which is now available throughout Canada and at some 30 international airports scattered around the world. The additive is not being used in this country mainly: (a) because of the low incidence of electrostatic ignitions during fuel handling operations in the United States, and (b) because of the adverse effect that some consider the additive to have on the water separation characteristics of the fuel. However, American authorities are keenly aware of the electrostatic problem and appear to have taken the position that the additive is available for use if the need should arise.

Because of the possibility that a requirement for the use of the static dissipator additive could develop on short notice, it is advisable that the individuals making decisions about the additive's use have an understanding of the additive itself and how it affects the properties of the fuel and the operation of the aircraft. Considerable information on this subject has already been published (7). However, one of the problems which has not yet been thoroughly investigated is the effect of the additive on the charging tendency of jet fuel. Shafer, et al. (9), have examined the effect of a commercial static dissipator additive on the charging tendency of naptha in a system which employed stacked paper filter elements. In the present report, the charging tendency of both JP-4 and JP-5 fuels, which had been treated with Shell ASA-3, was studied in an apparatus containing the same type of fiber glass filter used in many military and commercial filter/separator units.

EXPERIMENTAL PROCEDURE

The fuels used in this study (Table 1) were specification grade JP-4 and JP-5 fuels. The conductivities of these samples, as measured by Shell charged-ball method (10), are about average for jet fuels delivered to aircraft (11).

The static dissipator additive, Shell ASA-3, is a mixture consisting of equal parts of (a) the chromium salts of mono and dialkylsalicylic acids, (b) calcium aerosol OT (dodecyl sulfosuccinate), and (c) a 50-percent concentrate, in hydrocarbon solvent, of the copolymer of laurylmethacrylate and methylvinylpyridine (8).

Table 1
Fuels Used in Study

Fuel Type	Sample Designation	Water Separometer Index Modified (WSIM)	Conductivity (C.U., 10^{-14} mho/cm)
JP-4	J-334	96	2.5
JP-5	J-436	96	1.9

Samples were prepared by adding the appropriate amount of ASA-3 to the fuel and shaking for 1/2 hour on an Eberbach shaker. The additive-treated fuel was stored in metal containers for 2 days before any measurements were made.

The charging tendency was determined by two separate methods: gravity and separometer.

Gravity Method

A 1-liter sample of fuel was allowed to flow from a reservoir through a metal tube and filter and into a tank. The total charge transferred, or the streaming current developed during the passage of the fuel through the apparatus, was used as a measure of the charging tendency. Details of this procedure and a description of the apparatus are given in Ref. 12.

Separometer Method

Since the water separometer (13) provides a convenient means of handling small quantities of fuel under a variety of flow conditions which approximate those encountered in practice, this device was modified, as shown in Fig. 1, to permit the measurement of charging tendency of fuels at various flow velocities. The modifications include the use of Teflon tubing to electrically isolate the coalescer cell (filter), removal of the water fall-out chamber, and the addition of an electrometer to measure the current generated by pumping fuel through the cell. As in similar experiments (12), a single coarse-bonded fiber glass filter was used in the coalescer cell. The procedure consisted of recording the filter current at 30-second intervals as a one-liter sample was pumped through the apparatus.

RESULTS AND DISCUSSION

Conductivity

The effect of the static dissipator additive on the conductivity of the two jet fuels is shown in Fig. 2. Fuel conductivity is expressed in conductivity units (C.U.), where 1 C.U. = 10^{-14} mho/cm. Although the sample of the JP-4 used in this study was much more responsive to the static dissipator additive than the JP-5 sample, there is no reason to assume that all JP-4 fuels behave in this manner. A comparison of the NRL data with data replotted from the RCAF study (7), as shown in Fig. 2, reveals that the conductivity of the Canadian JP-4 sample is almost midway between the NRL data for JP-4 and JP-5. Such differences in response to the additive are probably due to variations in the nature of the impurities in the particular fuels rather than to any inherent differences in the nature of JP-4 and JP-5 fuels.

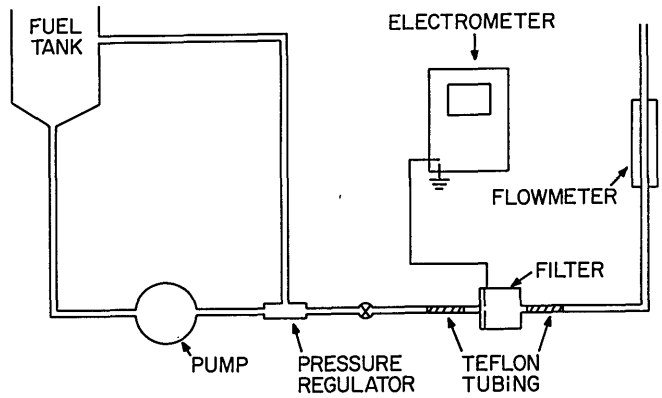

Fig. 1 - Schematic of the water separometer showing modifications for filter current measurements

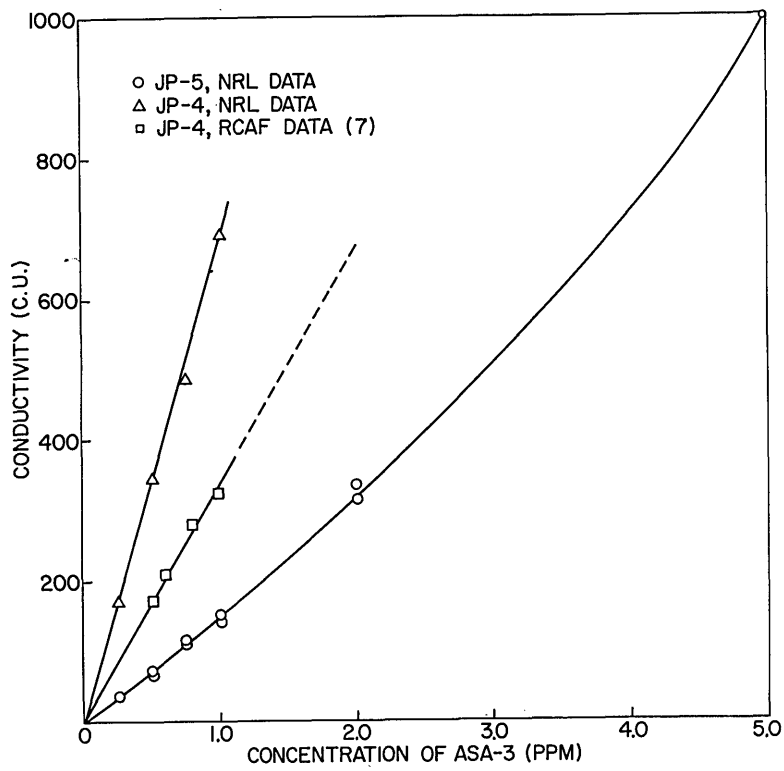

Fig. 2 - Effect of the static dissipator additive on the conductivity of JP-4 and JP-5 jet fuels

A comparison of the effectiveness of ASA-3 and Navy Special Fuel Oil in increasing the conductivity of JP-5 fuel is given in Fig. 3. The data on the Navy Special are replotted from Ref. 12. As expected, ASA-3 is far more efficient at raising the conductivity of jet fuel than Navy Special Fuel Oil. However, one sample of JP-5 (J-437) which had an unusually high original conductivity (K = 34 C.U.), was found to be far more responsive to the addition of Navy Special Fuel Oil than any of the other fuels tested (12). Since this fuel also had an unusually low water separation index modified (WSIM = 14), it was felt that the enhanced activity of this sample was probably due to a synergistic effect involving a surfactant in the fuel and some polar or ionic compounds in the Navy Special.

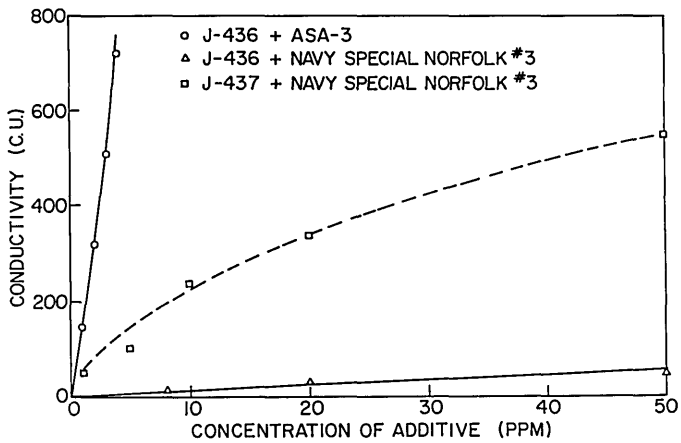

Fig. 3 - Comparison of the effectiveness of static dissipator additive and Navy Special Fuel Oil in increasing the conductivity of jet fuel

The conductivity of fuels containing ASA-3 was found to decrease when the samples were stored in metal containers. As shown in Tables 2 and 3, a decrease of 18 to 40 percent took place during the first month for fuels containing ASA-3. The decrease in conductivity for the samples that were stored 6 months was comparable. These results are in general agreement with the findings of Davies (14), who reported decreases in conductivity of approximately 30 percent for large (181,000 Imperial gallons) samples stored for 20 months. According to Davies, the depletion of the additive took place during the first 2 months of storage, after which no further loss of conductivity occurred.

In a separate study in which JP-5 samples containing ASA-3 were stored in soft glass containers, the conductivity was observed to increase rather than decrease during storage. As indicated in Table 4, the greatest increase occurred during the first 3 weeks of storage, after which the conductivity remained relatively stable. This overall increase, which totaled 33 to 81 percent after 2 months of storage, is probably due to an ion-exchange process involving the chromium and/or calcium ions in the static dissipator additive with the sodium ions on the surface of the glass. Since, by this mechanism, two sodium ions would enter the hydrocarbon solvent for each calcium ion which departed, the total number of ions in solution would be increased, and hence the conductivity of the hydrocarbon as well. These results also are in agreement with the observations made by Davies (14), who reported increases in conductivity of up to 50 percent for fuels containing ASA-3 when stored in glass containers.

Table 2
Effect of Storage in Metal Containers on Conductivity of JP-4 Containing ASA-3

Shell ASA-3 (ppm)	Conductivity After Different Storage Times (C.U., 10^{-14} mho/cm)			Decrease in Conductivity on Storage (%)
	2 Days	1 Month	6 Months	
None	2.5	2.5	2.5	0
0.01	11.2	8.0	—	26.8
0.02	20.7	12.5	—	39.6
0.03	29.1	18.9	—	35.1
0.05	50.8	30.5	—	40.0
0.10	82.4	57.6	—	30.0
0.15	127	82.6	—	35.0
0.20	181	126	—	30.4
0.25	222	181	—	18.4
0.50	346	—	222	35.8
0.75	487	—	300	38.4
1.00	694	—	473	30.9

Table 3
Effect of Storage in Metal Containers on Conductivity of JP-5 Containing ASA-3

Shell ASA-3 (ppm)	Conductivity After Different Storage Times (C.U., 10^{-14} mho/cm)			Decrease in Conductivity After 6 Months (%)
	4 Days	2 Weeks	6 Months	
None	1.9	1.8	1.8	5.3
0.25	36.0	32.4	24.1	33.1
0.50	66.2	65.5	51.6	22.0
0.75	116	111	82.5	28.9
1.00	141	143	101	28.4
2.00	249	233	153	38.6
5.00	816	808	657	19.5

Table 4
Effect of Storage in Glass Containers on Conductivity of JP-5 Samples Containing ASA-3

Shell ASA-3 (ppm)	Conductivity After Different Storage Times (C.U., 10^{-14} mho/cm)			Increase in Conductivity After 2 Months (%)
	2 Days	3 Weeks	2 Months	
0.25	30.5	46.2	42.2	38.4
0.50	70.2	119	127	81.4
0.75	109	168	145	33.0
1.00	150	226	206	37.3
2.00	314	444	462	47.2
5.00	899	1100	1280	33.6

Charging Tendency

The results of the charging tendency measurements using the gravity method are given in Fig. 4 for JP-4 samples and in Fig. 5 for JP-5. Also, shown in Fig. 5 are the results obtained in a previous study on the effect of Navy Special Fuel Oil on the charging tendency of JP-5 (12). No really significant difference in charging tendency is noted when the contaminant is Navy Special as compared with ASA-3. In each case, the charging tendency is seen to increase with increasing conductivity, pass through a maximum, and then decrease. However, the position of the maximum in the JP-4 curve (Fig. 4) occurs at a higher conductivity range than in the JP-5 curve (Fig. 5). Also, the JP-4 samples exhibit a higher degree of charging than was found for the JP-5 samples. The reason for the enhanced charging behavior on the part of the JP-4 samples is due to the lower viscosity of JP-4, approximately 0.77 centipoise for JP-4 at 80°F vs 1.2 centipose for JP-5. In a gravity-type apparatus, such as used in these experiments, the fluid with the lower viscosity has a greater flow velocity and hence a greater charging tendency. Consequently, flow velocity must be taken into account in evaluating charging tendency data obtained with a gravity-type apparatus.

The values for the streaming current, as given in Figs. 4 and 5, are a measure of the total current generated by the fuel in passing through both the delivery tube and filter of the charging tendency apparatus. In order to demonstrate that most of the charge is generated when the fuel passes through the filter, experiments were conducted in which the filter was isolated electrically by means of a short length of Teflon tubing and the current measured at the filter as the fuel flowed through the apparatus. The resulting filter currents, which are shown in Fig. 6 for the JP-4 samples, were found to be equal in magnitude but opposite in sign to the streaming current measured at the receiving tank (Fig. 4). The difference in sign is due to the fact that in order to compensate for the charge given up by the fuel as it passes through the filter, which then flows to the ground as the filter current, an equal amount of charge must flow from ground to the receiving tank (streaming current). Since the filter current is equal in magnitude to the streaming current, the amount of charge generated elsewhere in the apparatus, i.e., in the delivery tube, is negligible.

In a separate series of experiments, direct measurements were made of the amount of charge generated by the fuel flowing through the delivery tube alone, that is, with the

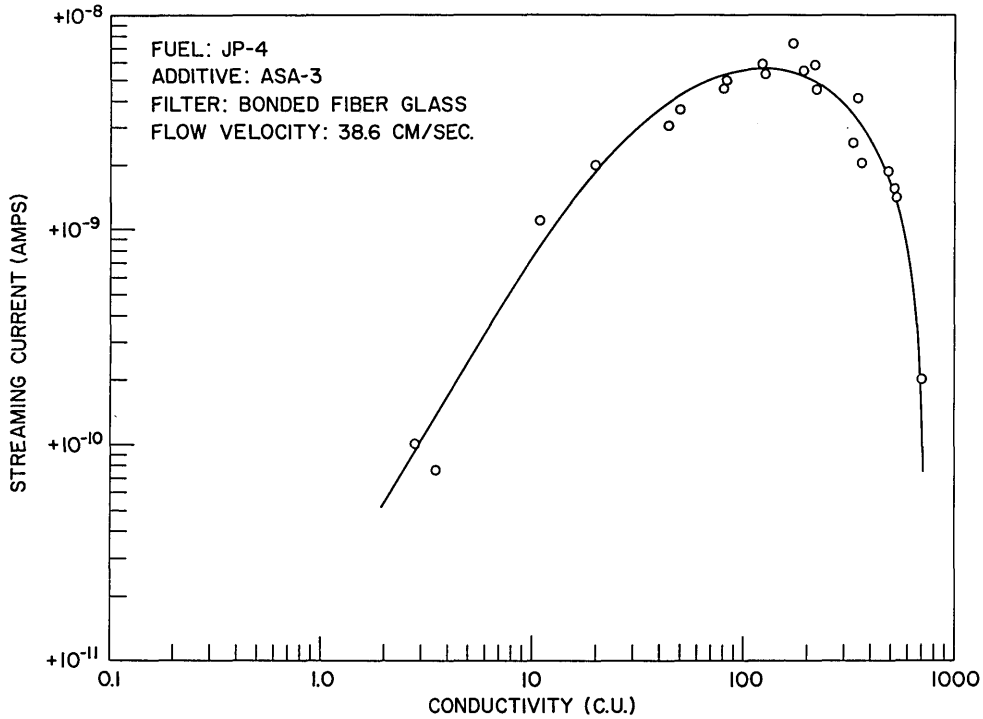

Fig. 4 - Effect of conductivity of the charging tendency of JP-4 fuel containing the static dissipator additive, gravity method

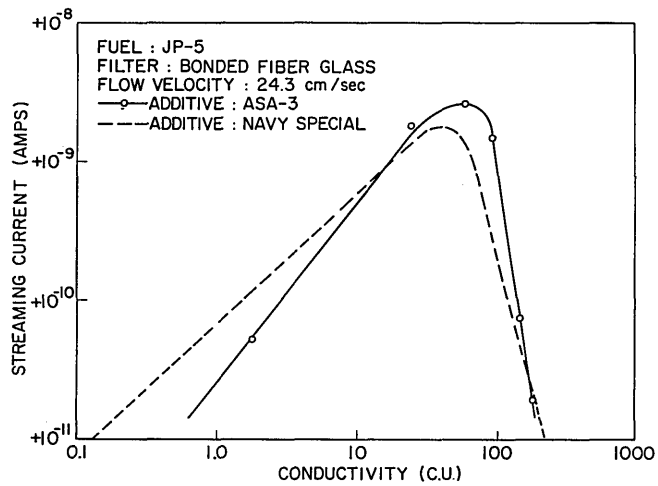

Fig. 5. Effect of conductivity on the charging tendency of JP-5 fuel containing the static dissipator additive, gravity method

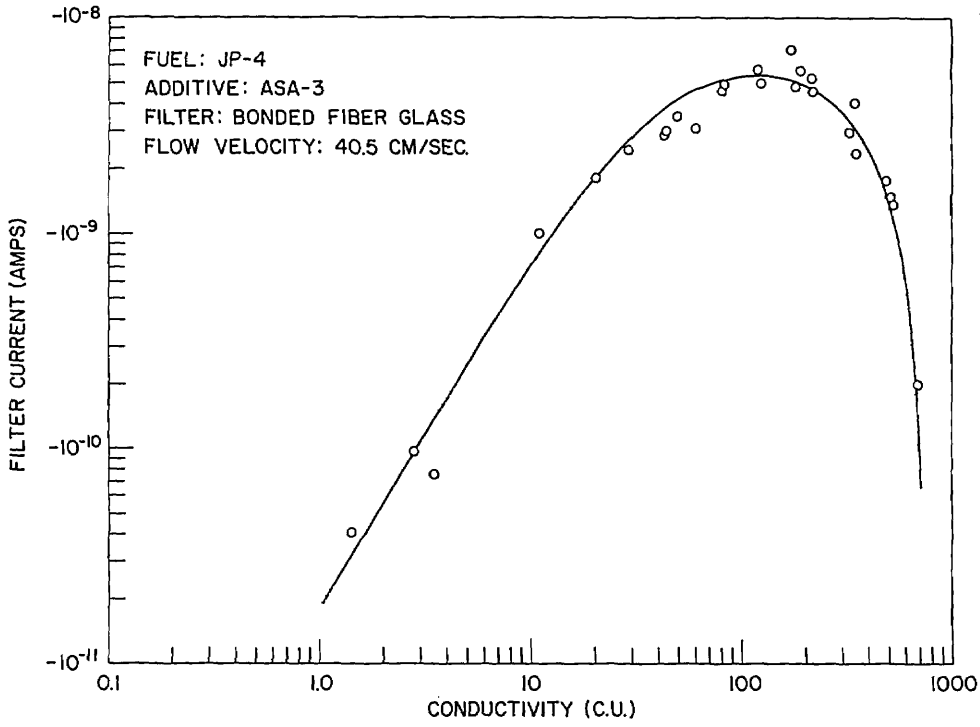

Fig. 6 - Effect of conductivity of JP-4 fuel containing the static dissipator additive on filter current, gravity apparatus

coalescer cell out of the system. With the filter removed, the flow velocity increased by a factor of 3.5, which reduced the duration of the run from 420 to 120 seconds. To compensate for the shorter flow times, readings of the streaming current were taken at 10-second rather than 30-second intervals as in the previous experiments.

A plot of streaming current vs time for the unfiltered samples, as given in Fig. 7, reveals that the streaming current achieves an equilibrium value after about 40 to 60 seconds of flow, but drops off toward the end of the run due to a loss of hydrostatic head.

The results of the streaming current measurements for the unfiltered systems are given in Fig. 8 for the JP-4 sample and Fig. 9 for the JP-5. Due to the difference in flow velocities, direct comparisons of the charging tendencies for the filtered vs unfiltered configurations cannot be made. But if one keeps in mind that the values for the streaming currents in Figs. 8 and 9 are higher than they would be if they were obtained at the same flow velocities employed for the corresponding curves for the filtered systems (Figs. 4 and 5), one can estimate that charging tendencies for filtered systems are at least 100 times greater than for unfiltered systems. Also, as in the case of the filtered system, the charging tendency for the unfiltered systems increases with increasing conductivity, passes through a maximum, and then decreases. In addition, the position of the maximum in the charging tendency-conductivity curve shifts to a higher conductivity range and to a higher streaming current value for the fuel (JP-4) with the greater flow velocity.

An attempt was made to use an equation, derived by Gavis and Koszman (15), to calculate the theoretical streaming currents for JP-4 and JP-5 when flowing through the delivery tube of our apparatus.

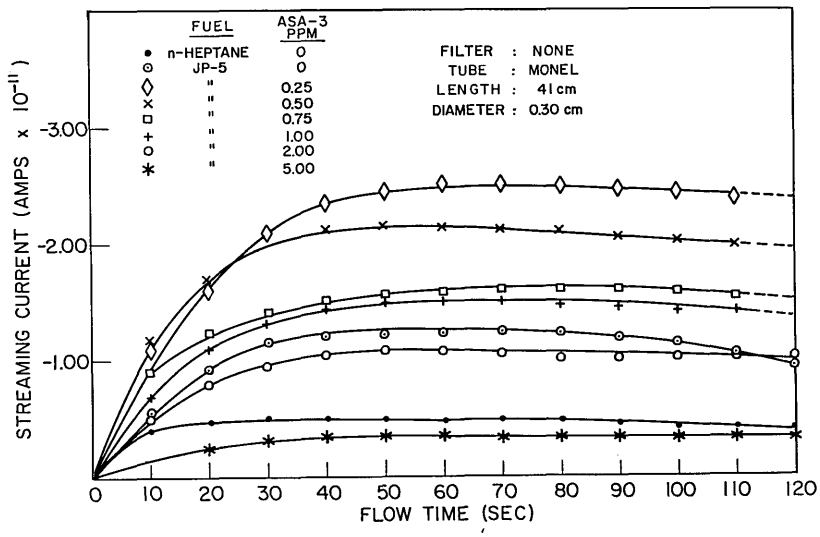

Fig. 7 - Effect of flow time on the streaming current in the delivery tube-gravity apparatus

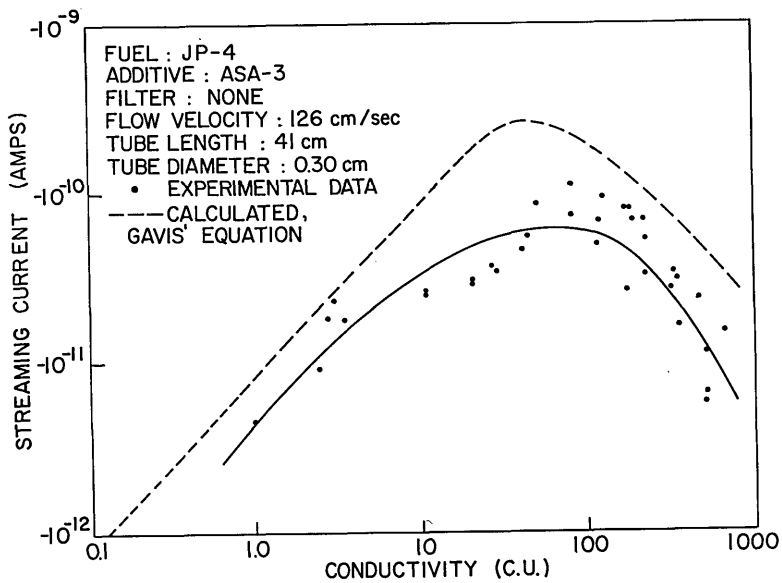

Fig. 8 - Effect of conductivity of JP-4 fuel containing the static dissipator additive on streaming current in the delivery tube, gravity apparatus

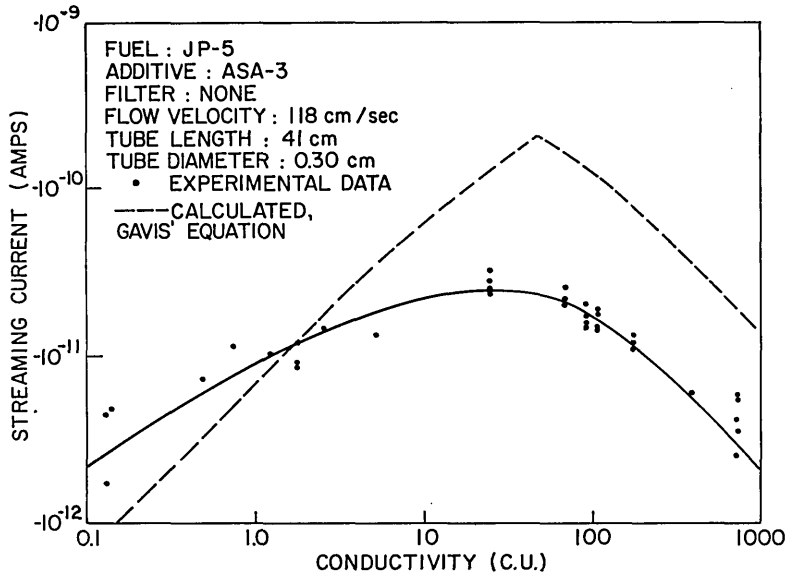

Fig. 9 - Effect of conductivity of JP-5 fuel containing the static dissipator additive of streaming current in the delivery tube, gravity apparatus

According to Gavis and Koszman, if the system is at room temperature and if the kinematic viscosity of the fuel is essentially equal to that of heptane, the streaming current can be calculated by:

$$\frac{I}{\varepsilon\varepsilon_0 \bar{v}^{1-7/8} d^{7/8} (1-e^{-L/\bar{v}\tau})} = 0.769 , \tag{1}$$

where

I = streaming current, amp;

ε = relative dielectric constant;

ε_0 = permittivity of free space = 8.85×10^{-14} sec/Ω-cm;

$\bar{v}$ = average velocity, cm/sec;

d = tube diameter, cm;

L = tube length, cm;

τ = relaxation time, sec, $\tau = \varepsilon\varepsilon_0/K$;

K = conductivity of liquid, mho/cm.

Conditions for application of this equation:

1. The Reynolds number $Re > 2100$ (turbulent flow),

2. The group, $d^2/Re^{7/4}\tau\nu < 10^{-5}$,

where

ν = kinematic viscosity, cm^2/sec.

Equation (1) was used to calculate theoretical streaming current curves for JP-4 and JP-5 in our apparatus, and the results of these calculations are shown by the dashed lines on Fig. 8 and 9. In either case, the experimental data fell somewhat short of the theoretical curve, with the JP-5 data showing the greater differences. Better agreement between theory and experiment was not achieved in this study because the experiments were conducted under flow conditions which approached the limits of applicability of Gavis and Koszman's equation. For example, in this study the Reynolds number for the JP-5 sample was 2300, which barely satisfies condition 1 of Eq. (1), and secondly, at higher conductivities, condition 2 was not met by either JP-4 or JP-5. This necessitated the estimation of another value for the constant in the above equation, and the accuracy of this estimation from the available curves was not very great. Consequently, the data from the present experiment do not permit a fair test for the validity of Gavis and Koszman's equation.

In order to demonstrate the effect of flow velocity on charging tendency and to compare charging tendencies under conditions resembling those encountered in practice, measurements were made of the filter currents developed as the fuel was pumped through the coalescer cell of the water separometer. This instrument was selected for this purpose since it was designed to simulate the flow conditions which exist in an actual filter/separator unit. Flow rates were adjusted in these experiments so that the flow velocities through the filter (0.625 to 2.50 cm/sec) covered the flow velocity range in an operational filter/separator unit (0.5 to 1.0 cm/sec). The results of these charging tendency experiments are given in Fig. 10 for JP-4 and Fig. 11 for JP-5. As shown by these figures, not only does the charging tendency increase with increasing flow velocity, but also the position of the maximum in the filter current vs conductivity curves shifts to a higher conductivity range.

These results confirm the conclusions from the charging tendency experiments in the gravity-flow apparatus and are in agreement with the findings of Gavis and Koszman (15) regarding the effect of flow velocity on charging tendency. Although Gavis and Koszman were primarily concerned with the development of charge by n-heptane, with and without an antistatic additive, when flowing through tubes, it appears that their conclusions regarding the effect of flow velocity on charging tendency also apply to systems containing fiber glass filters.

It may also be seen from Fig. 10 and 11, that changes in flow velocity may have profound effects on charging tendency at certain conductivity levels. For example, a JP-4 fuel with a conductivity of 200 C.U. moving at a flow velocity of 1.25 cm/sec would have a filter current of 7×10^{-11} amp, which is about the same as for untreated fuel with a conductivity of 2 C.U. If, however, the flow velocity were doubled, the filter current would increase to 7.8×10^{-10} amp, which is greater than the maximum value (6.1×10^{-10} amp) obtained at the lower flow velocity. Thus a fuel which might be considered capable of generating only a low charge at one flow velocity could become highly charged if the flow velocity were increased.

Relaxation

As in Ref. 12, the term charging tendency is used to refer to the amount of charge generated at the principal source of electrification, that is, at the point where most of the charge separation takes place. If there is a filter in the system, the charging tendency refers to the filter current, or the amount of charge generated by the passage of

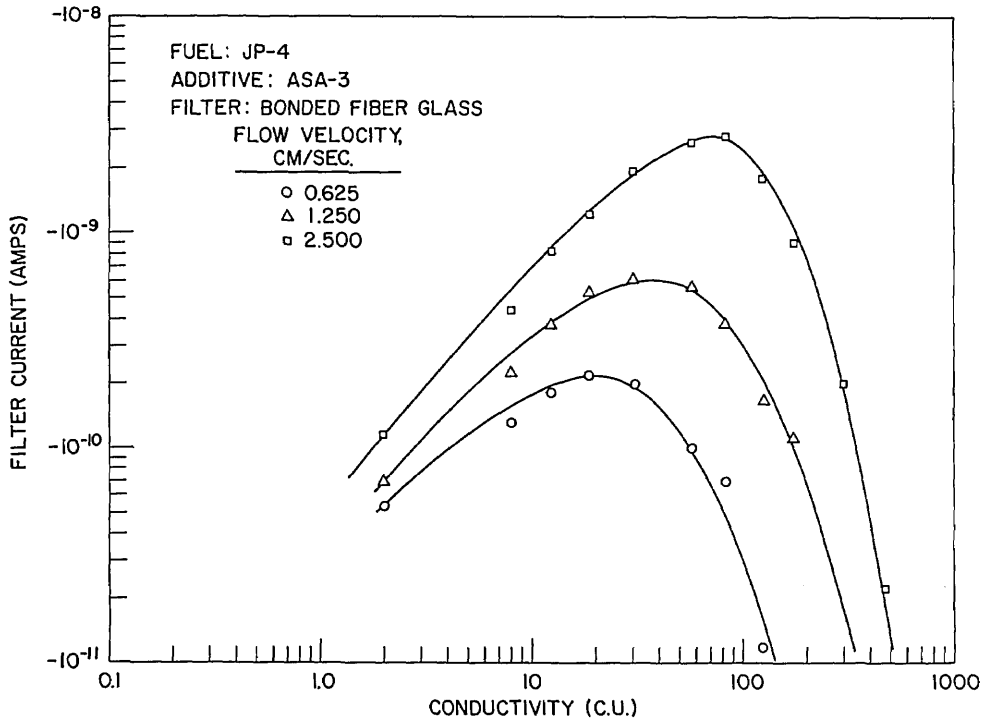

Fig. 10 - Effect of conductivity and flow velocity of charging tendency of JP-4 fuel containing the static dissipator, additive-separometer method

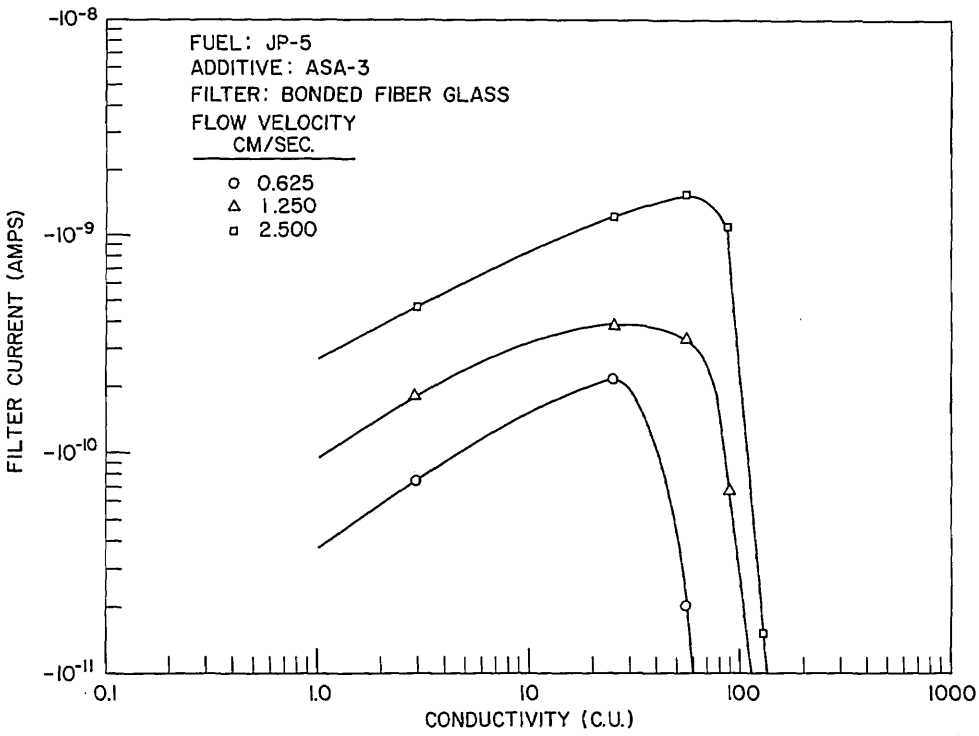

Fig. 11 - Effect of conductivity and flow velocity on charging tendency of JP-5 fuel containing the static dissipator, additive-separometer method

the fuel through the filter. In the absence of a filter, the charging tendency refers to the current developed by the fuel flowing through the piping of the system, or streaming current, as it is sometimes called. Within the limits of these definitions, the results of the present study demonstrate that the charging tendency of both JP-4 and JP-5 fuels may be increased by the addition of a static dissipator additive if the conductivity of the treated fuel falls within a particular range for the flow conditions involved. Whether or not a hazardous situation from the standpoint of electrostatic discharges will result depends upon the amount of charge remaining on the fuel surface when the fuel arrives at the receiving tank. This quantity then depends upon the conductivity of the fuel and the time required for a particle of fuel to travel from the filter/separator unit to the receiving tank.

The rate at which the charge on a fuel dissipates (12) can be calculated from

$$q = q_0 \, e^{-tK/\varepsilon\varepsilon_0} , \tag{2}$$

where

q_0 = initial charge, coulombs;

q = charge at time t, coulombs;

t = the elapsed time, sec;

K = conductivity, mho/cm;

ε = liquid dielectric constant;

ε_0 = 8.85×10^{-14} farad/cm.

This equation holds, provided that the fuel is not too highly charged, and the conductivity of the fuel is greater than 1 C.U. For lower conductivity fuels and for more highly charged fuels it has been shown (16,17) that the charge relaxes faster than predicted by this expression.

Using the above equation, the percent of the original charge on a fuel remaining after a given period of time was calculated for fuels in the range of 1 to 100 C.U. The results of these calculations, as shown in Fig. 12, indicate that if the conductivity of the fuel is greater than 25 C.U., most of the charge is dissipated in 1 second or less. The length of piping downstream of a filter required to achieve a 1-second relaxation time at various flow rates is shown in Fig. 13. As can be seen from this figure, if the flow rate is increased by a factor of two, then the length of piping must also be doubled in order to achieve the same relaxation time. For example, if the flow rate in a 4-inch line is increased from 400 to 800 gal/min, the length of pipe required to produce a 1-second relaxation time must be increased from 10 to 20 feet. If this were not done, the fuel would receive only a 0.5 second relaxation time, which in the case of a fuel with a conductivity of 25 C.U. would mean that 49.7 percent of the charge on the fuel would still be present when the fuel reached the receiving tank. Considering the high charging tendency at certain flow velocities for fuels with a conductivity of 25 C.U., this could result in a hazardous situation if flammable vapors were present in the receiving tank.

Although it appears that a 1-second relaxation time may be adequate for fuels with conductivities greater than 25 C.U., considerably more time is required for lower conductivity fuels as indicated by Fig. 12. In order to allow for the wide variety of flow conditions met in practice, the American Petroleum Institute (6) recommends that if a fuel

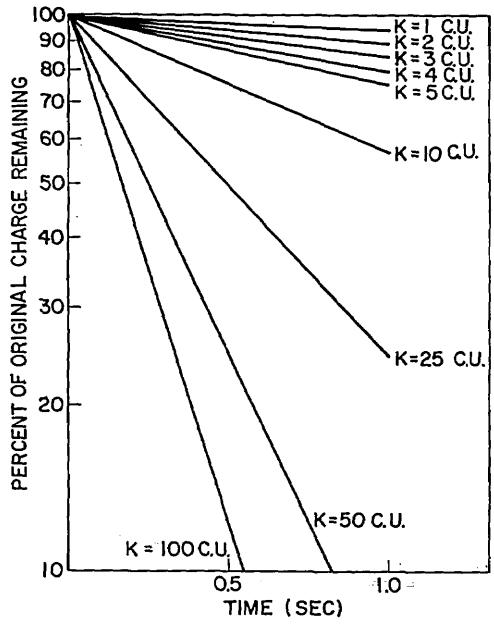

Fig. 12 - Calculated charge decay curves for fuels of various conductivities

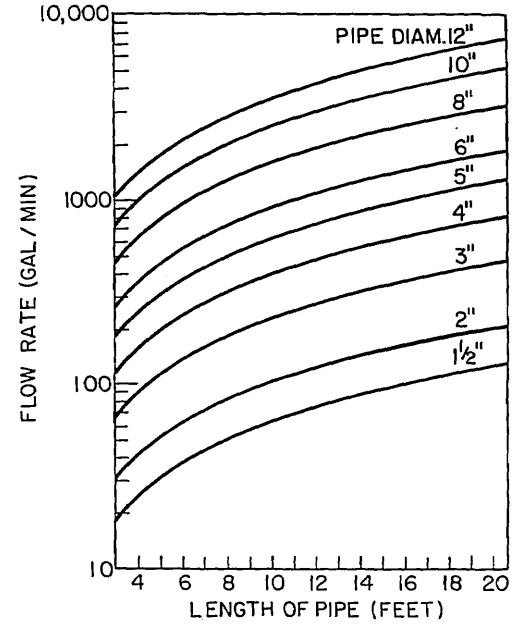

Fig. 13 - Length of pipe required to achieve a 1-second relaxation time at various flow rates

is to be loaded into a compartment where flammable vapors might be present, at least 30-seconds relaxation time should be provided in the piping system between the filter and the receiving tank. Bustin, et al. (16), have shown that even very low conductivity fuels (K = 0.01 C.U.) lose most of their charge after 30 seconds of relaxation.

SUMMARY AND CONCLUSIONS

As the conductivity of JP-4 or JP-5 type jet fuel is increased by the addition of ASA-3, the charging tendency (i.e., the filter current or streaming current) was found

to increase, pass through a maximum, and then decrease. At higher flow velocities, the charging tendency increases and the position of the maximum in the charging tendency vs conductivity curve shifts to a higher conductivity range. However, since the rate at which the charge on the fuel dissipates also increases with increasing conductivity, no increase in electrostatic hazard due to the use of the static dissipator additive is foreseen during fuel handling operations as long as sufficient time is allowed for the charge on the fuel to relax downstream of the filter/separator unit. On the other hand, failure to recognize the charge generating capabilities of the so-called "higher conductivity" fuels ($K > 25$ C.U.) could lead to the creation of a hazardous situation, particularly in high-speed refueling operations, if drastic reductions were to be made in the length of piping downstream of the filter/separator under the mistaken belief that such fuels could not generate sufficient electrostatic charge to produce an electrical discharge in the receiving tank.

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13. ABSTRACT

The effect of a static dissipator additive on the charging tendency of both JP-4 and JP-5 type jet fuels was examined at various flow velocities on a laboratory scale. For our use, the term charging tendency refers to the current generated by a given quantity of fuel when passing through a filter or an insulated section of piping rather than to the ability of a fuel to produce dangerously high potentials when loaded into a tank. It was found that when the conductivity of the fuel is increased by the addition of the static dissipator additive, the charging tendency also increases, passes through a maximum, and then decreases. Also, at higher flow velocities, there is an overall increase in the charging tendency of the fuel, and the position of the maximum in the charging tendency vs conductivity curve shifts to a higher conductivity range. However, since the rate at which the charge on the fuel dissipates also increases with increasing conductivity, no increase in electrostatic hazard due to the use of the static dissipator additive is foreseen during fuel handling operations as long as the ability of additive-treated fuels to generate charge is recognized and sufficient time is permitted for the charge to relax before the fuel enters a receiving tank.

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