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# EFFECT OF NAVY SPECIAL FUEL OIL ON THE CHARGING TENDENCY OF JET FUEL

Joseph T. Leonard, et al

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# Effect of Navy Special Fuel Oil on the Charging Tendency of Jet Fuel

Joseph T. Leonard and Homer W. Carhart

*Fuels Branch*
*Chemistry Division*

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## ABSTRACT

As part of a long-range study on the generation and dissipation of static electricity in hydrocarbon liquids, the effect of Navy Special Fuel Oil contamination on the conductivity and charging tendency of JP-5 fuels was examined on a laboratory scale. It was found that while the conductivity of jet fuel increases with the addition of Navy Special Fuel Oil, the magnitude of this effect depends upon the nature of the impurities in both the JP-5 and the Navy Special Fuel Oil.

As the conductivity of the contaminated fuel increases, the charging tendency was found to increase, passing through a maximum when the conductivity was in the range of 30 to 40 conductivity units (C.U.), where 1 C.U. = $10^{-14}$ mho/cm, and then decrease. However, the position of the maximum in the charging tendency curve depends on flow rate and may occur at a higher or lower conductivity range depending upon flow conditions.

The results of the present study indicated that if a load of jet fuel were to become contaminated with Navy Special Fuel Oil so that the conductivity of the resulting product were in the proper range, this fuel would emerge from a filter/separator unit in a much more highly charged condition than if it had not been contaminated. However, as long as sufficient time is permitted for the charge to relax before the fuel enters the receiving tank, no increase in electrostatic hazard should occur.

## PROBLEM STATUS

This is an interim report on a continuing problem.

## AUTHORIZATION

NRL Problem C01-05
Project RR 010-01-44-5851

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# EFFECT OF NAVY SPECIAL FUEL OIL ON THE CHARGING TENDENCY OF JET FUEL

## INTRODUCTION

Whenever hydrocarbon liquids such as motor and aviation gasolines and jet fuels flow with respect to a solid surface, an electrostatic charge develops in the liquid. It is generally held that this charging phenomenon is due to the presence of certain ionic impurities which are present in the liquid in parts per million or parts per billion quantities. When the liquid is at rest, ionic impurities are adsorbed at the interface between the hydrocarbon and the solid surface, with either the negative or positive ions showing a rather strong attachment for the solid phase, while the ions of the opposite sign remain in the liquid. When the liquid moves, this portion of the ionic material is carried along by the hydrocarbon, giving rise to a charge in the liquid. The opposite charge then leaks to ground from the solid phase.

If the conductivity of the hydrocarbon is sufficiently low, charge may accumulate, giving rise to high potentials when the liquid is loaded into a tank. If conditions are favorable, local potentials may exceed the breakdown value of the vapor space in the tank and electrical discharges will follow. Whether or not the vapor will be ignited then depends on the composition of the vapor and the nature and energy of the discharge.

The existence of such discharges during fuel handling operations is recognized as a potential hazard (1-5), but, although several explosions which were attributable to static electricity generated by fuel have occurred during the loading of tank trucks (6) and aircraft (7), the number of such incidents is exceedingly small in comparison with the number of refueling operations that are carried out safely on a world-wide basis. However, the insistence on cleaner fuels and the necessity of pumping these fuels at faster rates could mean that we are headed in the direction of greater hazard from this source.

Since the ability of a fuel to generate and dissipate electrostatic charge is due to the presence of ionic impurities, the accidental contamination of a clean fuel by such materials could have an effect on the electrostatic hazard involved in handling these fuels. A potential contaminant in naval operations is Navy Special Fuel Oil, which, on at least one occasion, has found its way into jet fuel storage tanks (8). Since this product contains ionic impurities which are known to influence the electrostatic properties of hydrocarbon fuels, the effect of contamination of JP-5 type jet fuels by Navy Special was examined.

## EXPERIMENTAL PROCEDURE

### Samples

The fuels used in this study are listed in Table 1; included are three JP-5 type jet fuels which pass the Navy Specification for jet fuel (J-431, J-435 and J-436), and two fuels which fail because of their poor water separation properties (J-417 and J-437). All of the fuels given in Table 1 were used in the conductivity studies. For the fuel charging tendency experiments, only the fuels which passed the water separometer test were used with Navy Special Norfolk #3 as the contaminant. In order to obtain data at very low conductivities, a sample of pure grade n-heptane was also used.

Table 1
Fuels Used in This Study

| Fuels | Water Separometer Index Modified (Ref. 9) | Conductivity (C.U.) |
|---|---|---|
| JP-5 Fuels | | |
| J-431 | 98 | 0.17 |
| J-435 | 87 | 0.60 |
| J-436 | 96 | 1.86 |
| J-417 | 33 | 15.2 |
| J-437 | 14 | 34.0 |
| n-Heptane | — | 0.14 |
| Navy Specials | Source | |
| H | Middle East | |
| I | Middle East | |
| Norfolk #3 | Trinidad | |

A stock solution was prepared containing 1 cc of Navy Special Fuel Oil in 1000 cc of a given fuel. Aliquots of the stock solution were dissolved in 3500 cc of said fuel to produce samples containing from 1 to 50 ppm of Navy Special. The sample solutions were shaken on an Eberbach shaker for 1/2 hour and allowed to stand for 2 days in glass containers before the conductivity determinations were made.

### Water Separometer

The effect of Navy Special Fuel Oil on the filter/separator performance was evaluated by using the modified procedure of the water separometer specification test (9).

### Conductivity Measurements

Fuel conductivity determinations were made according to the procedure described by Klinkenberg (10a).

### Fuel Charging Tendency Experiments

It is known that most of the charging of fuels takes place when the fuel passes through the filter/separator unit. In order to observe the effect of filtration on the charging tendency of fuels contaminated by Navy Special Fuel Oil, the fuel charging apparatus described by Klinkenberg (10b) was modified by the addition of a coalescer cell (filter) to the end of the delivery tube (Fig. 1). The coalescer cell, which is shown in detail in Fig. 2, is the same type as is used in the Water Separometer (9). For the fuel charging tendency experiments, a single, coarse, bonded fiber glass filter disk was placed in the coalescer cell.

Klinkenberg's procedure calls for passing the same sample of fuel through the apparatus three times and determining the average charge built up on the receiving tank for the three passes. In the present study it was found that the use of a filter on the fuel

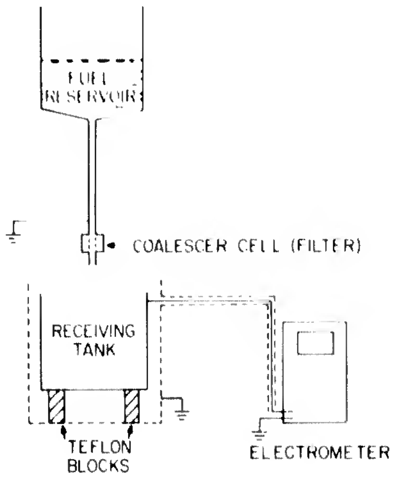


Fig. 1 - Modified Shell fuel charging apparatus

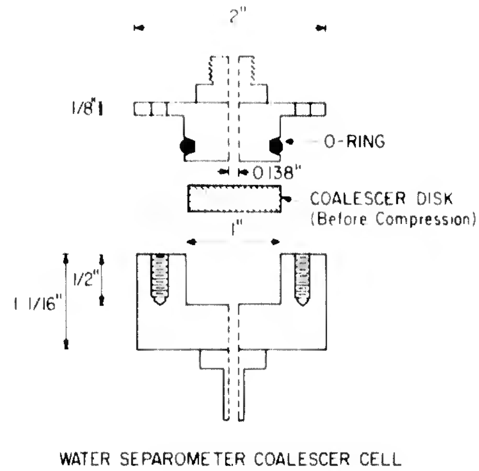


Fig. 2 - Water separometer coalescer cell

charging apparatus produced an abnormally high charge level the first time that fuel passed through the filter. On the second and third passes, the amount of charge decreased, reaching an equilibrium value at the fourth pass. Hence, in these experiments, the total charge transferred during the fourth pass is reported as the equilibrium charging tendency.

### Streaming Current

In order to demonstrate the high degree of charging that occurs when the fuel first encounters the filter, the streaming current was measured as a function of time. For this purpose, the electrometer was switched to the ammeter scale and the current recorded at 30-second intervals while the fuel was flowing into the receiving tank.

## RESULTS AND DISCUSSION

### Water Separometer

In a previous study (8) it was shown that the water separometer index modified (WSIM) of specification JP-5 fuels can be drastically reduced by contamination with various Navy Special Fuel Oils. The results of the present study (Fig. 3) confirm this observation and demonstrate that as little as 5 to 15 ppm of Navy Special Norfolk #3 is sufficient to lower the WSIM of a good fuel to below 85, which is the minimum value allowed for JP-5 fuels under Navy Specification (11).

Gardner and Moon (12) report a similar decrease in WSIM with both antistatic and corrosion inhibitor additives. Of the two, the antistatic additive was found to have a much greater effect in reducing the WSIM. But as Gardner points out, this effect is not critical as long as the antistatic additive is not used in excess of the recommended level. On the other hand, the WSIM value for JP-4 fuels had to be reduced to 55 to accommodate the use of pipeline corrosion inhibitors. The results of the present study indicate that it would take less than 40 ppm of Navy Special Norfolk #3 to reduce the WSIM below this value.

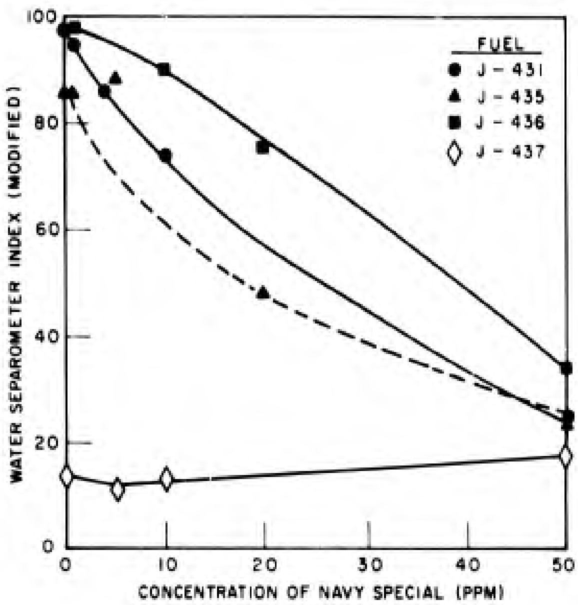


Fig. 3 - Effect of Navy Special Norfolk #3 on the water separometer index modified of jet fuels

## Conductivity

The effect of Navy Special Fuel Oil on the conductivity of jet fuels is shown in Figs. 4 and 5. Fuel conductivity is expressed in terms of conductivity units (C.U.), where 1 C.U. = $10^{-14}$ mho/cm.

It is interesting to note in Figs. 4 and 5 that the two fuels which failed the water separometer test, J-417 and J-437, showed the greatest increase in conductivity upon the addition of Navy Special Fuel Oil. Such behavior suggests the possibility of an interaction

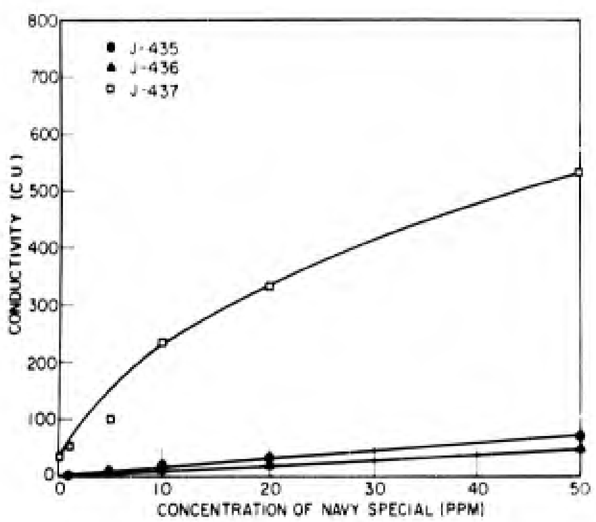


Fig. 4 - Effect of Navy Special Norfolk #3 on the conductivity of jet fuels

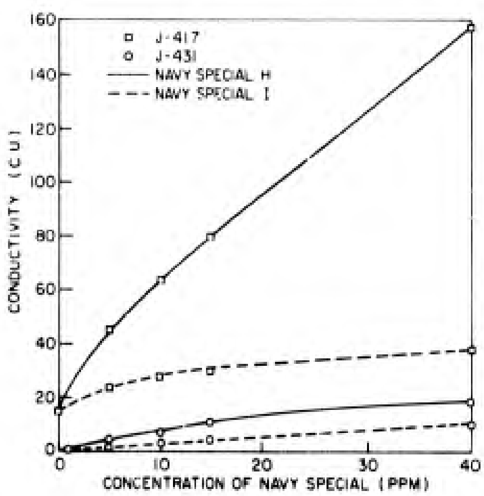


Fig. 5 - Effect of Navy Special Fuel Oils H and I on the conductivity of jet fuels

between the impurities in the original fuels (probably surface active compounds) which were responsible for their low WSIM ratings and the impurities in Navy Special H and Norfolk #3 (polar and/or ionic compounds). The fuels that passed the water separometer test (J-431, J-435 and J-436) apparently lack this particular type of impurity and hence do not show as great a response to the Navy Special Fuel Oils. It should also be noted here that the effectiveness of Shell Oil's anti-static additive at extremely low concentrations (<1 ppm) is due to a similar synergistic effect resulting from the interaction of a surfactant with the chromium salt of an organic acid (13).

The variation in effectiveness of different Navy Special Fuel Oils in increasing the conductivity of a given fuel can be seen in Fig. 5 by comparing the response of J-417 and J-431 to Navy Specials H and I. Navy Special I apparently contains less, or perhaps less active, polar compounds and hence does not produce as great an effect on the conductivity as Navy Special H. The most effective Navy Special Fuel Oil tested was Norfolk #3. As indicated in Fig. 4, only 5 ppm of Norfolk #3 was required to raise the conductivity of J-437 to 100 C.U., which is still within the "safe range" recommended for fuels containing an antistatic additive. Fuels which have conductivities in the range of 50 to 300 C.U. are considered to be safe from the standpoint of electrostatic discharges during fuel handling operations (14).

## Charging Tendency

The results of the charging tendency experiments are summarized in Table 2 and are plotted in Fig. 6. The data indicate that the charging tendency of the contaminated fuel goes through a maximum when the conductivity is in the range of 30 to 40 C.U. and then decreases upon the addition of more Navy Special Fuel Oil. This is because the effect which is being observed, i.e., the net charge on the fuel, is really the result of two competing processes — charge generation and charge dissipation. Thus, the addition of Navy Special Fuel Oil to a fuel provides more ionic material for the charge separation process, thereby increasing the charge generation capability of the fuel. However, the additional ionic material simultaneously increases the conductivity of the fuel and, consequently, the rate at which the charge will dissipate. The charging tendency of the fuel then is the net result of these competing reactions. At the flow rate used in this study (145 cc/min), charge generation is the predominant reaction up to a conductivity of 30 C.U. Above 40 C.U., charge dissipation takes over.

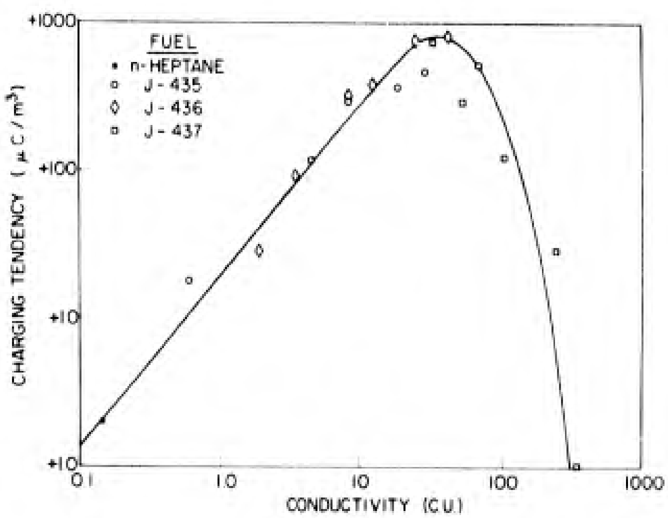


Fig. 6 - Effect of conductivity on the charging tendency of jet fuels contaminated with Navy Special Norfolk #3

Table 2
Summary of Results of Fuel Charging Tendency
and Streaming Current Measurements

| Sample | Navy Special (ppm) | Conductivity (C.U.) | Charging Tendency ($\mu$ Coulombs/$m^3$) | Streaming Current ($10^{-10}$ amps) | |
|---|---|---|---|---|---|
| | | | | Equilibrium | Estimated |
| n-Heptane | 0 | 0.14 | +2 | – | +0.1 |
| J-435 | 0 | 0.6 | +18 | +0.4 | +0.4 |
| | 1 | 4.6 | +119 | +2.4 | +3.0 |
| | 5 | 8.7 | +298 | +5.6 | +7.1 |
| | 10 | 18.8 | +373 | +6.6 | +7.9 |
| | 20 | 28.9 | +473 | +10.8 | +12.3 |
| | 50 | 68.6 | +524 | +9.0 | +12.5 |
| J-436 | 0 | 1.9 | +29 | +0.7 | +0.7 |
| | 1 | 3.5 | +93 | +1.9 | +2.2 |
| | 5 | 8.6 | +320 | +6.4 | +7.3 |
| | 10 | 12.5 | +387 | +7.6 | +8.7 |
| | 20 | 25.0 | +776 | +14.5 | +18.5 |
| | 50 | 42.7 | +824 | +17.8 | +19.6 |
| J-437 | 0 | 32.4 | +756 | +17.0 | +18.0 |
| | 1 | 53.3 | +293 | +6.8 | +3.2 |
| | 5 | 101 | +121 | +0.8 | +2.7 |
| | 10 | 235 | +29 | +0.24 | +0.7 |
| | 20 | 328 | +1.0 | – | +0.02 |
| | 50 | 542 | – | – | – |

These results are in general agreement with the data of Klinkenberg (Fig. 7) showing the effect of Kuwait crude oil on the charging tendency of gasoline (10c). However, due to the use of a filter in the present study, the magnitude and the sign of the charge are different from Klinkenberg's data.

## Streaming Current

The results of a typical streaming current-time plot are shown in Fig. 8. As indicated by the figure, after the initial high charging period, the streaming current-time curve decreases and tends to reach an equilibrium value (equilibrium streaming current) which is characteristic of the sample.

Plotting the equilibrium streaming current as a function of conductivity, one obtains a curve (Fig. 9) which is similar in shape to the charging tendency vs conductivity plot (Fig. 6). Thus streaming current may also be regarded as a measure of the charging tendency of fuel. Alternatively, one may estimate the streaming current from the charging tendency data by dividing the charge at time $t$, by $t$. When this is done, one obtains a curve for the estimated equilibrium streaming current (Fig. 10) which is nearly superimposable on Fig. 9, thereby demonstrating the interconvertibility of the two sets of data.

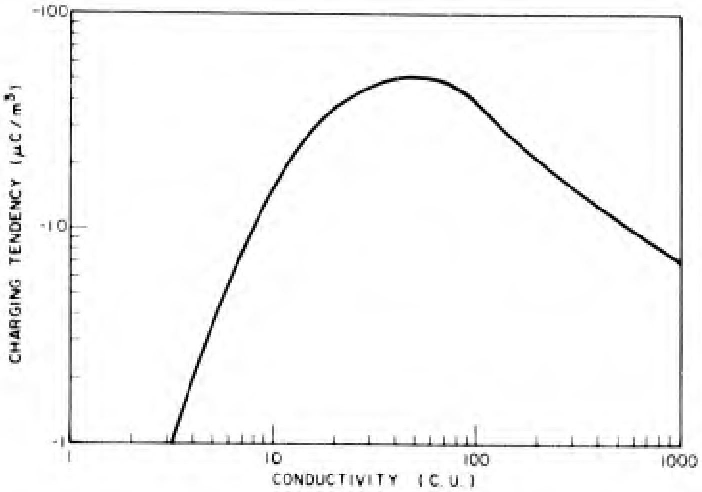


Fig. 7 - Effect of conductivity on charging tendency of gasoline contaminated with Kuwait crude oil (after Klinkenberg (10c))

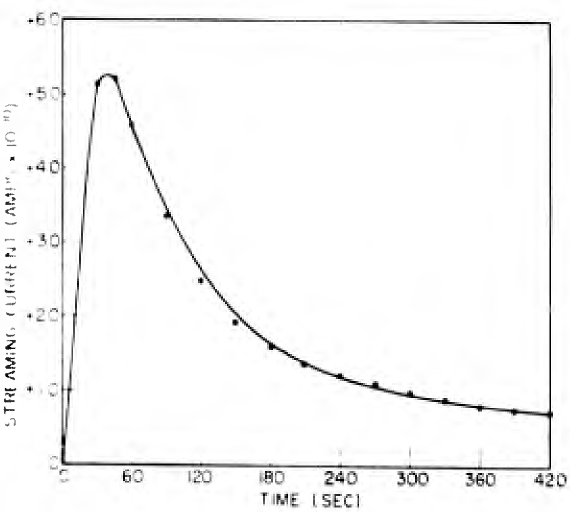


Fig. 8 - Streaming current as a function of flow time

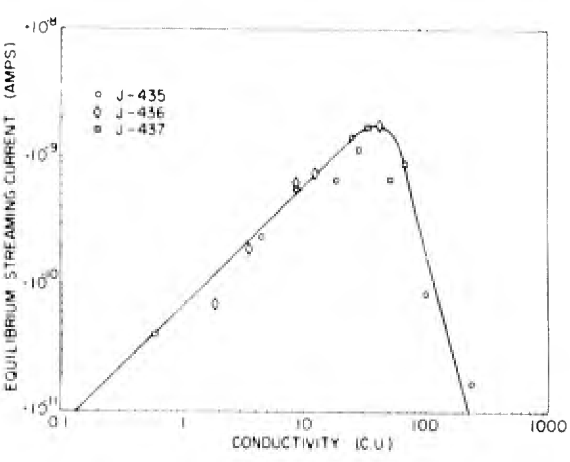


Fig. 9 - Effect of conductivity on the equilibrium streaming current of jet fuels contaminated with Norfolk #3

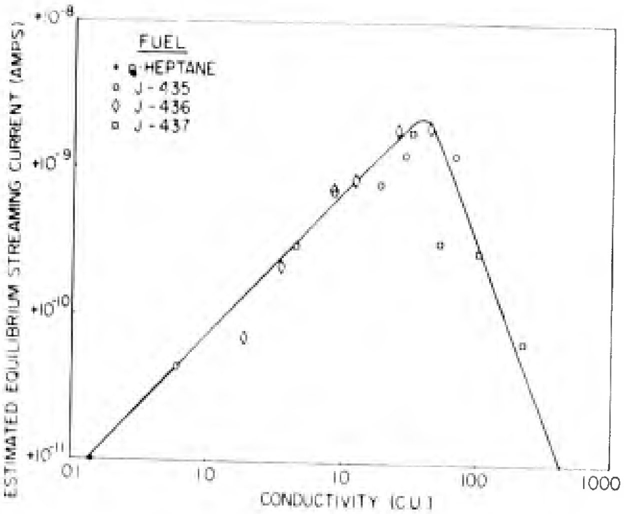


Fig. 10 - Effect of conductivity on estimated equilibrium streaming currents for jet fuels contaminated with Navy Special Norfolk #3

Relaxation

As mentioned earlier, the charging tendency of jet fuels containing Navy Special Fuel Oil was found to increase with increasing conductivity of contaminated product, pass through a maximum when the conductivity was in the range of 30 to 40 C.U., and then decrease. However, the position of the maximum in the charging tendency curve depends on the flow rate and may occur at a higher or lower conductivity range depending on flow conditions (15).

The term "charging tendency" as used in this report refers to the total charge generated by a sample of fuel as it flows from a storage tank, through a delivery tube and filter, and into an insulated receiving tank. Since the amount of charge generated in the delivery tube is negligible in comparison to that which is generated in the filter, and since there is virtually no opportunity for the charge to relax downstream of the filter, the charging tendency is, in effect, a measure of the quantity of charge generated by the passage of the fuel through the filter. Under these conditions, it was found that the charging tendency of jet fuel contaminated with Navy Special Fuel Oil was as much as 29 times greater than that of the original fuel.

In a practical refueling system, however, the entire fuel handling system, including the receiving tank, is supposed to be grounded. Under these circumstances, the charge on the fuel begins to relax immediately downstream of the filter, even before the fuel reaches the receiving tank. In such a system, the amount of charge on the fuel when it arrives at the receiving tank will depend upon the initial charge on the fuel (its charging tendency), the rate at which the charge relaxes, and the residence time of the fuel in the piping downstream of the filter.

In most cases, the rate at which the charge on a fuel dissipates is given by*

*The conductivity of most clean jet fuels today is in the range of 0.5 to 5.0 C.U. (16) with about 43 percent of the samples showing conductivities below 1 C.U. Bustin, et al. (17), have shown that if the conductivity of the fuel is less than 1 C.U., the charge will relax faster than predicted by this exponential law.

$$q = q_0 e^{-tK/\varepsilon\varepsilon_0} \qquad (1)$$

where

$q_0$ = initial charge on fuel, coulombs;

$q$ = charge at time $t$, coulombs;

$t$ = the elapsed time, sec;

$\varepsilon_0$ = absolute dielectric constant of vacuum, $8.85 \times 10^{-14}$ farad/cm;

$\varepsilon$ = dielectric constant of the fuel, approximately 2 for hydrocarbon fuels;

$K$ = conductivity, mho/cm.

Since the decay of charge is an exponential function of conductivity, it is customary to speak of the half-time value, or the time required for the charge on the fuel to decrease to 1/2 of its original value. The half-time value decreases from 12 seconds for a fuel with a conductivity of 1 C.U. to 0.12 second for a fuel with a conductivity of 100 C.U. In the present experiment, the maximum charging tendency was found when the conductivity of the fuel was in the range of 30 to 40 C.U. According to the above equation, the half-time value for a fuel in this range is 0.35 second. Therefore, in this particular case, as long as the residence time of the fuel in the piping downstream of the filter exceeds 0.35 second by a comfortable margin, say a total of 1 to 2 seconds, there should be no increase in hazard from electrostatic ignition. However, in order to allow for the wide variety of flow conditions met in practice, the American Petroleum Institute recommends that if a fuel 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 point of entry into the tank (6). Tests have shown that after 30 seconds most of the charge on a fuel, regardless of its conductivity, will have dissipated. Consequently, in any installation where considerably less than 30 seconds relaxation time is allowed, a compromise is being made with safety, particularly if the charging tendency of the fuel is increased by contamination with a polar compound-containing material such as Navy Special Fuel Oil.

## SUMMARY AND CONCLUSIONS

Contamination of jet fuel by Navy Special Fuel Oil results in an increase in electrical conductivity of the contaminated product. However, the magnitude of this effect depends upon the nature of the impurities in both the JP-5 and the Navy Special Fuel Oil.

As the conductivity of the contaminated fuel increases, the charging tendency increases, passes through a maximum when the conductivity is in the range of 30 to 40 C.U. and then decreases. However, the position of the maximum in the charging tendency curve depends on flow rate and may occur at a higher or lower conductivity range depending upon flow conditions.

The results of the present study indicate that if a load of jet fuel were to become contaminated with Navy Special Fuel Oil so that the conductivity of the resulting product were in the proper range, this fuel would emerge from a filter/separator unit in a much more highly charged condition than if it had not been contaminated. However, as long as sufficient time is permitted for the charge to relax before the fuel enters the receiving tank, no increase in electrostatic hazard should occur.

Finally, this investigation points up the usefulness of conductivity measurements in indicating the presence of very small amounts of certain impurities which may be found in jet fuel, such as Navy Special Fuel Oil. Ordinarily these impurities would not be detected by the conventional testing procedures until much larger concentrations were present. However, a word of caution is necessary here, since low conductivity of itself cannot be regarded as an indication that a fuel is free of all types of impurities. Certain other contaminants, such as suspended rust, have been shown to have no effect on the conductivity of jet fuels (18).

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13. ABSTRACT

As part of a long-range study on the generation and dissipation of static electricity in hydrocarbon liquids, the effect of Navy Special Fuel Oil contamination on the conductivity and charging tendency of JP-5 fuels was examined on a laboratory scale. It was found that while the conductivity of jet fuel increases with the addition of Navy Special Fuel Oil, the magnitude of this effect depends upon the nature of the impurities in both the JP-5 and the Navy Special Fuel Oil.

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| Charging tendency | | | | | | |
| Electrostatic charge | | | | | | |
| Fuel contamination | | | | | | |
| Jet fuels | | | | | | |
| Navy Special Fuel Oil | | | | | | |
| Charge relaxation | | | | | | |