

Pro-static Agents in Jet Fuels

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Of all the compounds and additives tested, water came closest to fulfilling the definition of an ideal pro-static agent, viz, a compound that greatly increases the charging tendency of a fuel without increasing its conductivity. After saturation with water, the charge density of clay-treated Jet A fuel increased by a factor of 23 and that of an untreated Jet A by a factor of 7. The conductivities of both fuels remained essentially the same. Since water did not increase the charging tendency or conductivity of silica gel-treated *n*-heptane it was concluded that it is not water per se, but rather its interaction with some constituent in the jet fuel that is responsible for its pro-static effect.

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PRO-STATIC AGENTS IN JET FUELS

INTRODUCTION

Over the past 15 years, there have been at least 116 reported fires or explosions attributed to static electricity generated by fuel while loading tank trucks and refuelers and 3 incidents while fueling commercial jet aircraft [1]. In most of these cases, the fueling operations were being carried out in the same fashion as they have been in the past when there was not an incident. In a number of instances, a second static-induced ignition occurred within a day or so following the first. In an attempt to account for these unusual occurrences, it has been postulated that, at the time of the explosion, the fuel was unusually electrostatically active, or "hot," as a result of contamination by trace amounts of pro-static agents. However, attempts to identify such agents in the fuel samples acquired from a number of these explosions were not successful. Therefore, the present study was initiated to determine if, by screening a wide variety of polar and ionic compounds and fuel additives, it would be possible to identify the types of compounds responsible for unusually high electrostatic activity in hydrocarbon fuels.

EXPERIMENTAL PROCEDURE

Screening Of Potential Pro-static Agents in *n*-Heptane

In the first phase of this study, 39 compounds and 24 fuel additives were screened for possible pro-static activity by measuring the effect of these materials on both the electrical conductivity and charging tendency of silica-gel-treated *n*-heptane. The compounds and additives selected for screening are identified in Appendix A. Most of the additives are approved for use in turbine fuels [2], although not all are listed in the current Qualified Products List [3]. Electrical conductivity was measured by the American Society for Testing and Materials (ASTM) method [4] and charging tendency by the Exxon Mini-Static Test procedure [5].

The apparatus used for the Mini-Static Test is shown in Fig. 1. In this test, the current is measured as a 50 cm³ sample of fuel is passed at a constant flow rate through an electrically isolated filter holder containing a 1.3-cm (1/2-in.) diameter filter. The filter current is multiplied by the flow velocity to express the charging tendency of the fuel in terms of charge density in microcoulombs per cubic meter. Both the ASTM conductivity method and the Mini-Static procedure were used to evaluate samples taken in a recent survey of jet fuels at 10 airports and 3 military bases in the United States [6]. Consequently, the results of the present study can be directly related to actual field experience. Prior to use, the *n*-heptane (Phillips Pure Grade, 99 mol %) was passed through a column containing Drierite and silica gel to remove moisture and polar contaminants that might interfere with the compound or additive being screened. This treatment

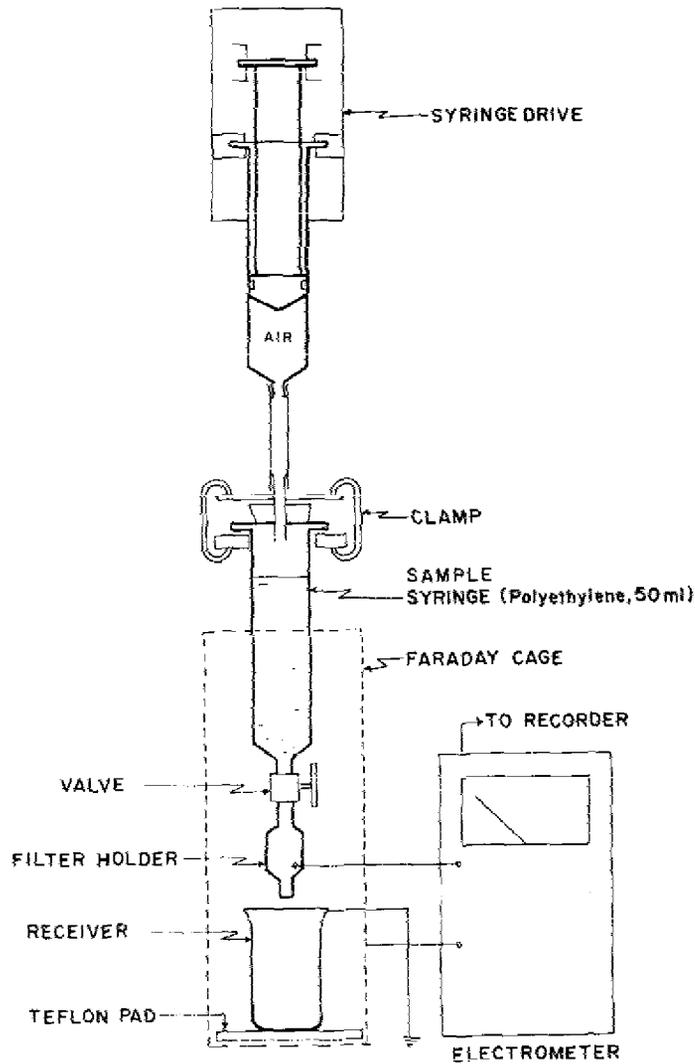


Fig. 1 - Exxon Mini-Static Tester

lowered the electrical conductivity from about 5 to 0.05 pS/m and the charging tendency from about 80 to 2 $\mu\text{C}/\text{m}^3$ depending on the batch of n-heptane.

The polar compounds were tested at concentrations of 100 and 1000 ppm (wt/vol), or at saturation, if the solubility was limited. The fuel additives were also tested at 1000 ppm, except for the static dissipator additives and the sodium sulfonates, which, because of their exceptional activity, had to be evaluated at 1 ppm.

Evaluation of Pro-static Agents in Clay-Treated and Untreated Jet A Fuels

In the second phase, the 20 most active compounds from the screening study were selected for further testing in clay-treated Jet A turbine fuel. The available inspection data on this fuel are given in Table 1.

Table 1 — Inspection Data On Jet A Fuels

Property	Type of Jet A Fuel	
	Clay-Treated Jet A	Untreated Jet A
Composition:		
Sulfur, mercaptan (ppm)	< 1	1
Sulfur, total (wt-%)	0.03	0.04
Volatility:		
Distillation:		
Initial boiling point (C (F))	169 (336)	166 (330)
10% reclamation (C (F))	169 (336)	185 (365)
50% reclamation (C (F))	208 (407)	212 (414)
90% reclamation (C (F))	249 (480)	238 (460)
Final boiling point (C (F))	289 (552)	282 (539)
Flash point (C (F))	54 (130)	49 (120)
Fluidity: freezing point (C (F))	-41.4 (-42.5)	(-40.8) -41.5
Corrosion: copper strip*	1A	1A
Conductivity:		
At refinery (pS/m)	0.38	0.32
At start of tests (pS/m)	0.10	0.16

*2 hr at 100°C (212°F).

In addition to the single paper filter used in the screening tests, charging tendency in this phase was evaluated on four other paper filters and on a Teflon® screen, all of which were cut from production model separator elements, and on a Fiberglas® and a paper filter from a coalescer element. The types of filter elements used, the manufacturers, and descriptions are as listed below.

<u>Type of Filter</u>	<u>Manufacturer</u>	<u>Description of Filter Medium</u>
CC-15-1	Fram*	Pleated Fiberglas® paper (2 layers)† Pleated paper† Bonded Fiberglas®† White polyester† White sock†
CS-58-10	Fram*	Pleated paper, high charging, obsolete
CS-61F		Pleated paper, ASA 3 rated
CS-64		Unpleated paper
A-3061	Keene ^A	Pleated paper plus Teflon® screen

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<u>Type of Filter</u>	<u>Manufacturer</u>	<u>Description of Filter Medium</u>
SO616 PLF	Velcon	Pleated paper plus unpleated paper

Type CC-15-1 is the coalescer element; the others are separator elements.

*Fram Corp., Industrial Divisions, Tulsa, Okla.

†Only the bonded Fiberglas[®] and the pleated paper were used in the present study of this coalescer element.

‡Keene Corp., La Grange, Ga.

||Velcon Filters Inc., San Jose, Calif.

The elements shown in Fig. 2, are representative of the types employed to filter jet fuels when loading tank trucks and refuelers and during aircraft servicing. In this type of filtration, which is illustrated in Fig. 3, the fuel passes through two sets of elements; in the first set, called the coalescer elements, particulate matter is removed and undissolved water droplets are coalesced; in the second set, the separator elements, coalesced droplets are separated from the fuel. Because the shorter relaxation volume downstream of the separator elements (4 vs 13 s for the coalescer), it is believed that the separator stage is the primary electrostatic charge generator in fuel handling.

Fuel samples were stored in epoxy-lined cans at least 2 days before testing. Charging tendency measurements were made immediately after the fuel conductivity tests.

In the third phase of this study, untreated Jet A Fuel was substituted for the clay-treated fuel in phase 2, and the entire test sequence was repeated. The inspection data on this fuel are given in Table 1. Because of the interest generated by the behavior of the sodium sulfonates, an additional five compounds were included in this phase of testing.

RESULTS AND DISCUSSION

Screening of Potential Pro-static Agents in *n*-Heptane

The effects of various polar compounds (acids, alcohols, aldehydes, amines, esters, and ketones) on the electrical conductivity and charging tendency of silica-gel-treated *n*-heptane are shown on Fig. 4 and 5. For each type of functional group represented in this series, a low and a high molecular weight compound and an aromatic analog are included. The results show that for the acid and the amine, increasing the length of the aliphatic chain from 2 to 10 carbon atoms definitely increases the effect that the molecule has on the electrical conductivity of *n*-heptane. However, the reverse is true for the alcohol, aldehyde, and ester derivatives. Also, the aromatic analogs of the acid, alcohol, aldehyde, amine, ester, and ketone have very little effect on electrical conductivity. The results demonstrate that, contrary to widespread opinion, trace amounts of many polar compounds have little effect on the electrical conductivity of hydrocarbon liquids. Even at a concentration of 1000 ppm, the most active compound tested (decylamine) did not

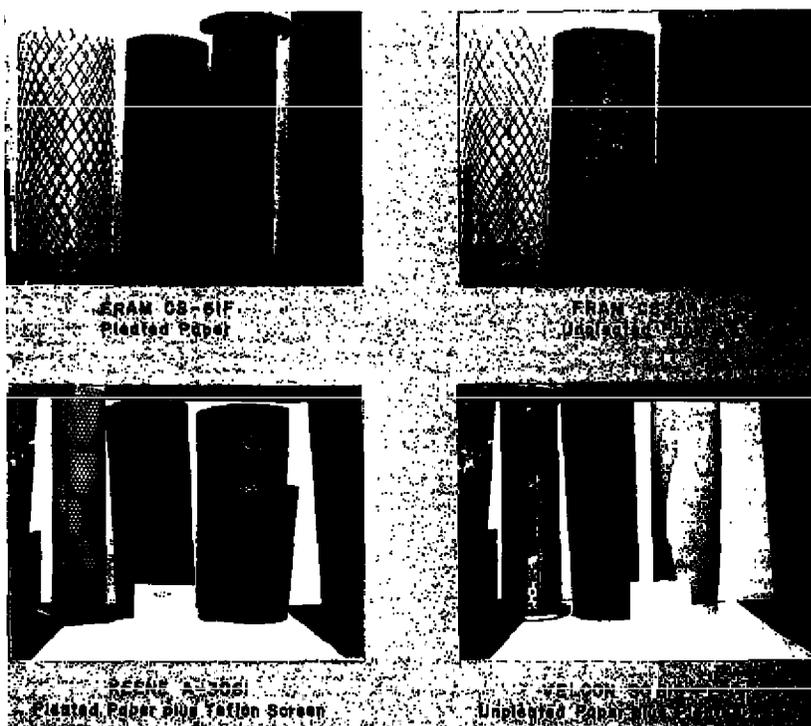


Fig. 2 — Separator elements disassembled

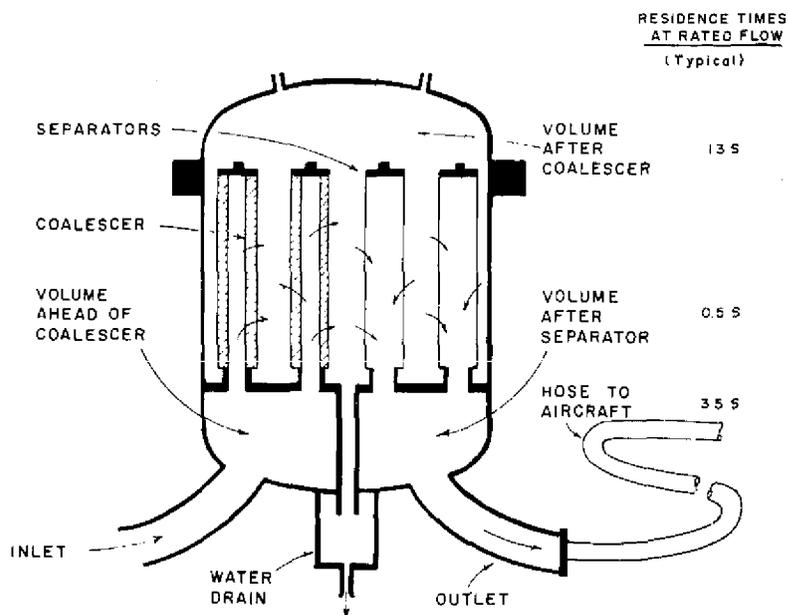


Fig. 3 — Flow of fuel through a filter/separator

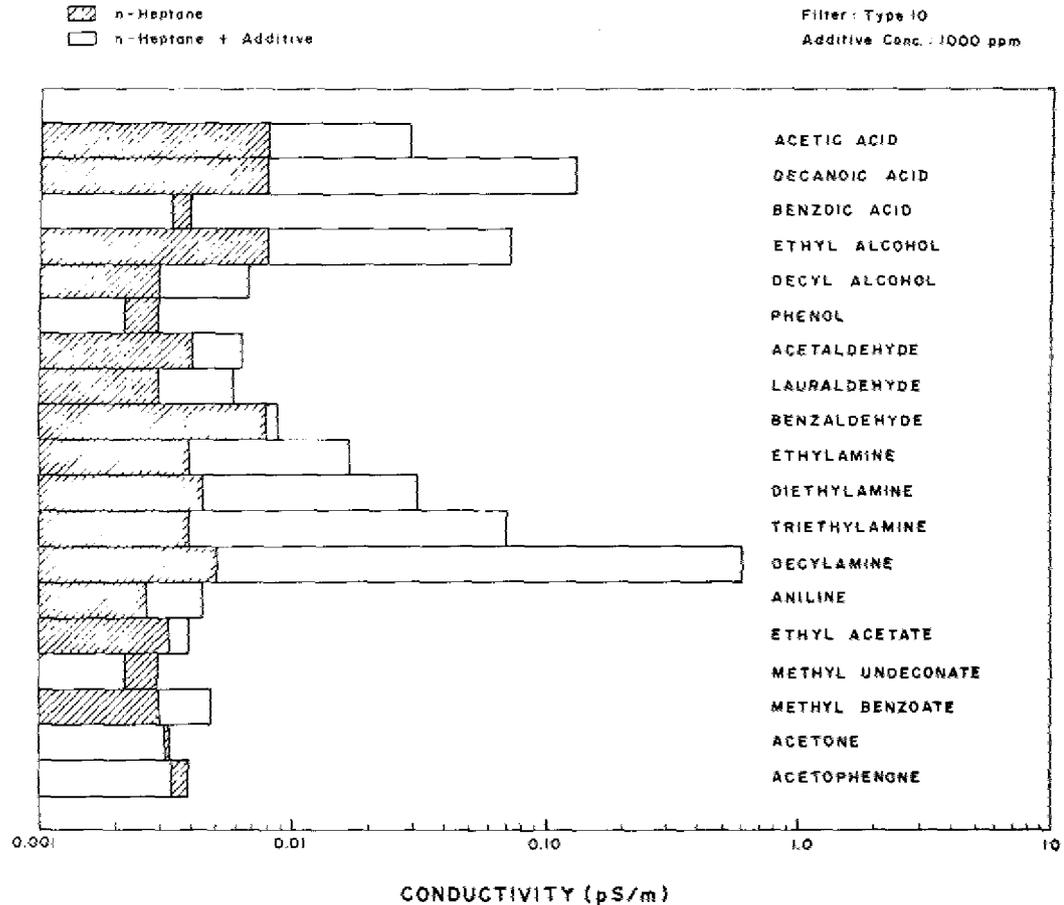


Fig. 4 — Effect of polar compounds on electrical conductivity of silica-gel-treated *n*-heptane

raise the conductivity of silica gel-treated *n*-heptane to the lowest level (0.09 pS/m) found in a recent survey of jet fuels [6].

The effect of the same polar compounds on the charging tendency of *n*-heptane is shown in Fig. 5. Just as with conductivity, most of these compounds had little effect on the charging tendency of *n*-heptane at a concentration of 1000 ppm. Some; e.g., acetic acid, decyl alcohol, and acetone, actually lowered it.

A number of higher molecular weight polyfunctional compounds were also tested (Fig. 6 and 7). Because of their limited solubility, these compounds were tested as saturated solutions. As indicated in the figures, none of these compounds has an appreciable effect on either electrical conductivity or charging tendency.

Ferrocene was tested because it is a fuel additive (though not for turbine fuels) and because iron compounds were identified in the fuel recovered from at least one electrostatic incident. However, ferrocene was found to be inactive.

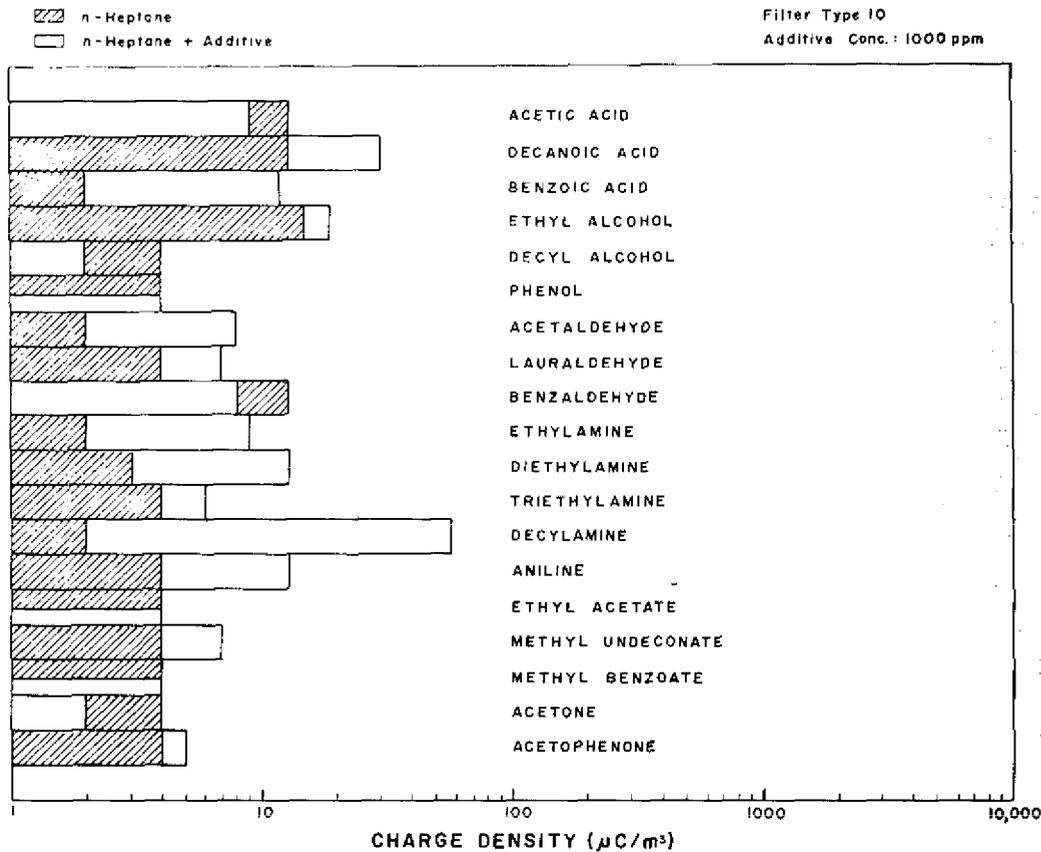


Fig. 5 — Effect of polar compounds on charging tendency of silica-gel-treated *n*-heptane

Naphthenic acid is neither a fuel additive nor a pure compound. It does increase both fuel conductivity and charging tendency, but it is not certain whether the increase results from the acid or from the impurities.

The effects of the antioxidants and the metal deactivator additives are shown in Fig. 8 and 9. Antioxidants Nos. 22 and 23 are higher molecular weight substituted amines and, in agreement with the data in Figs. 4 and 5, these compounds do increase conductivity and charging tendency. The other two antioxidants, Nos. 30 and 31, are substituted phenols, and, as does the parent compound shown in Fig. 4 and 5, these additives had little or no effect on conductivity or charging tendency. The metal deactivator, another substituted amine, only slightly increased conductivity and charging tendency.

All of the corrosion inhibitors and the thermal stability additive increased both the conductivity and charging tendency of *n*-heptane, as shown in Figs. 10 and 11. Three of the corrosion inhibitors increased the conductivity of the *n*-heptane above 10 pS/m: Gulf 178, 17.2 pS/m; Hitec E 515, 48.5 pS/m; and Na-Sul-LP, 393 pS/m. Gulf 178 also produced the highest charging tendency (8546 μC/m³) of any of the corrosion inhibitors.

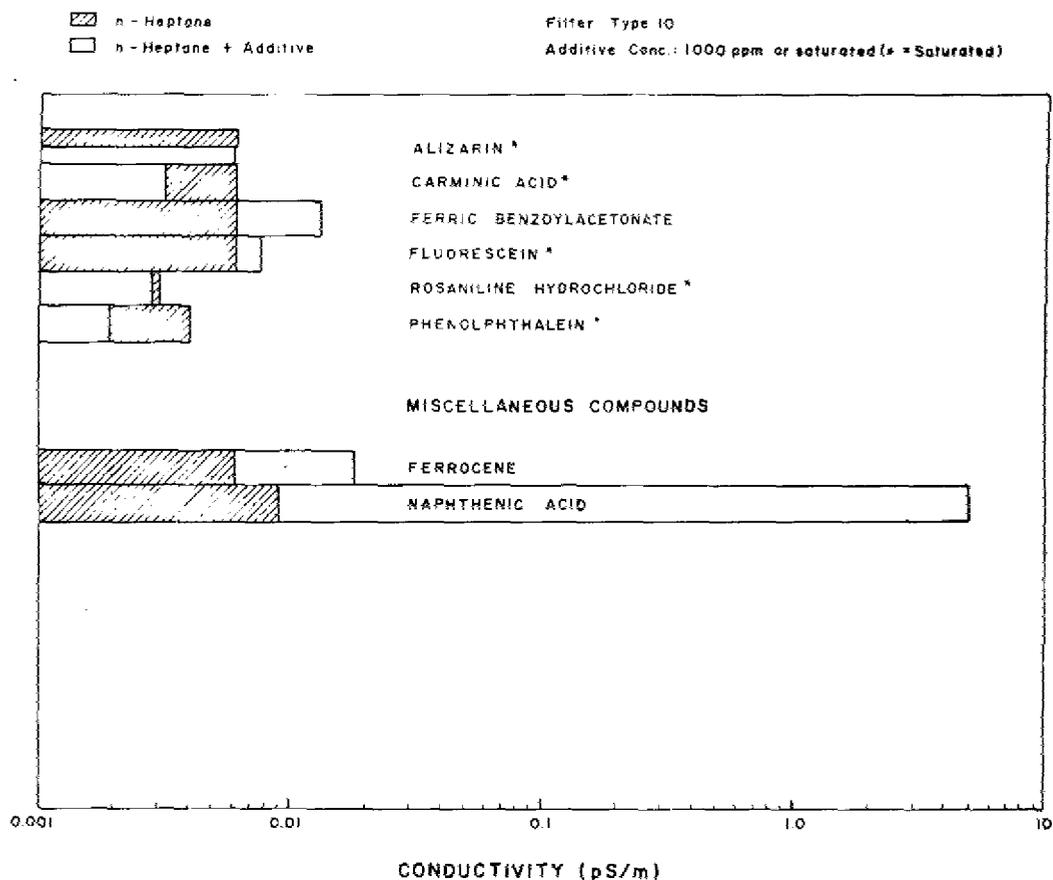


Fig. 6 — Effect of higher molecular weight polar and miscellaneous compounds on electrical conductivity of silica-gel-treated *n*-heptane

The response of the anti-icing additive was just the opposite of what was being sought in a pro-static agent—it increased conductivity but had very little effect on charging tendency.

The static dissipator additives were compared at a concentration that is considerably lower than the recommended dosage for two of the additives, Stadis 125 and Ethyl DCA 48, but close to the range for the other two additives, Stadis 450 and ASA-3. (See Appendix A). The effects that these additives had on the conductivity of *n*-heptane at a concentration of 1 ppm (Fig. 12) are in keeping with the recommended dosages; e.g., ASA-3, which has a recommended dosage of 0.6 ppm, had the greatest effect, whereas DCA 48, with a recommended dosage of 7 ppm, had the least effect. As with the anti-icing additive, DCA 48 and Stadis 125 had little or no effect on charging tendency. Contrarily, Stadis 450 and ASA-3 had a considerable effect.

Because some of the corrosion inhibitors and the static dissipator additive that had the greatest effect on the charging tendency of *n*-heptane (ASA-3) contain salts of various sulfonic acid derivatives, these types of compounds were examined further.

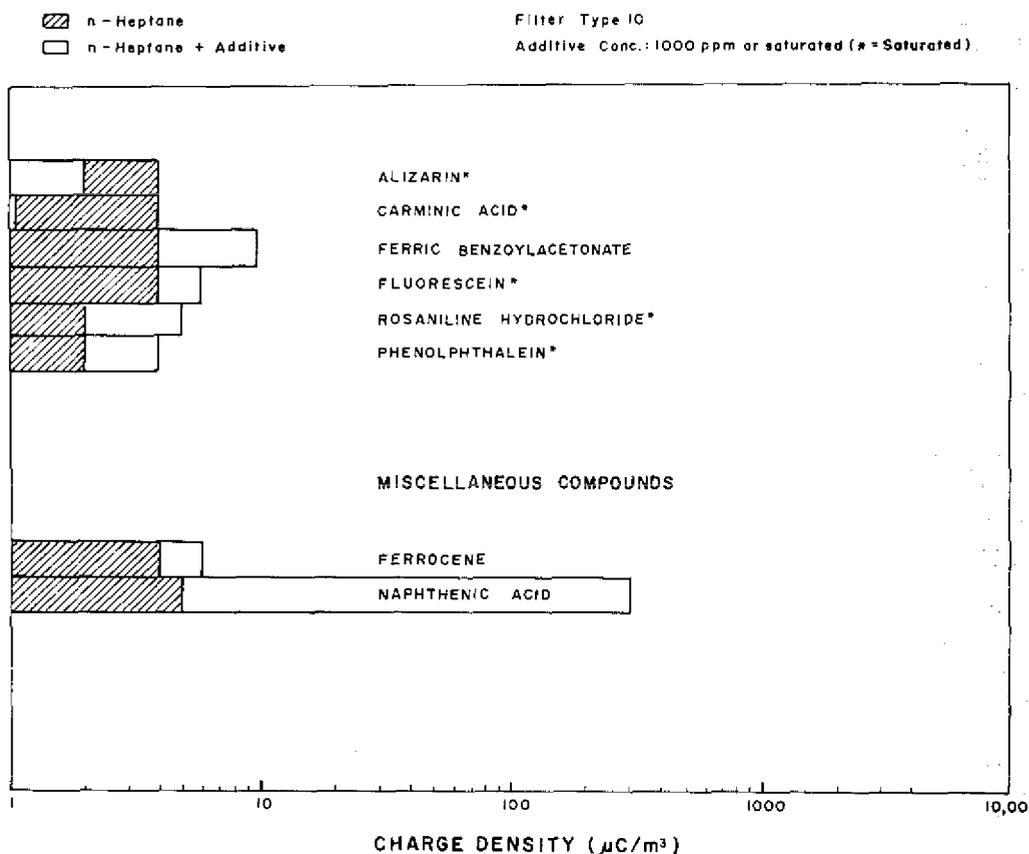


Fig. 7 — Effect of higher molecular weight polar and miscellaneous compounds on charging tendency of silica-gel-treated *n*-heptane

The results obtained with the sodium dialkyl sulfosuccinates are shown in Figs. 13 and 14. With the exception of the di-*n*-dodecyl compound, all of the higher molecular weight derivatives have about the same effect on the conductivity of *n*-heptane, but one compound, the diamyl derivative, was particularly effective in increasing the charging tendency of *n*-heptane. On the other hand, the inactivity of the lower molecular weight derivatives (diethyl and di-isopropyl) is difficult to explain, in view of the greater mobility of the lower molecular weight compounds.

Although the petroleum-derived sodium sulfonates have about the same molecular weight as the higher molecular weight dialkyl sulfosuccinates, they differ in structure in that the petroleum derivatives are basically aromatic rather than aliphatic compounds. Two of the petroleum derivatives, Petrosul 750 and Bryton 445, were particularly effective in increasing conductivity, but none of the three increased the charging tendency significantly.

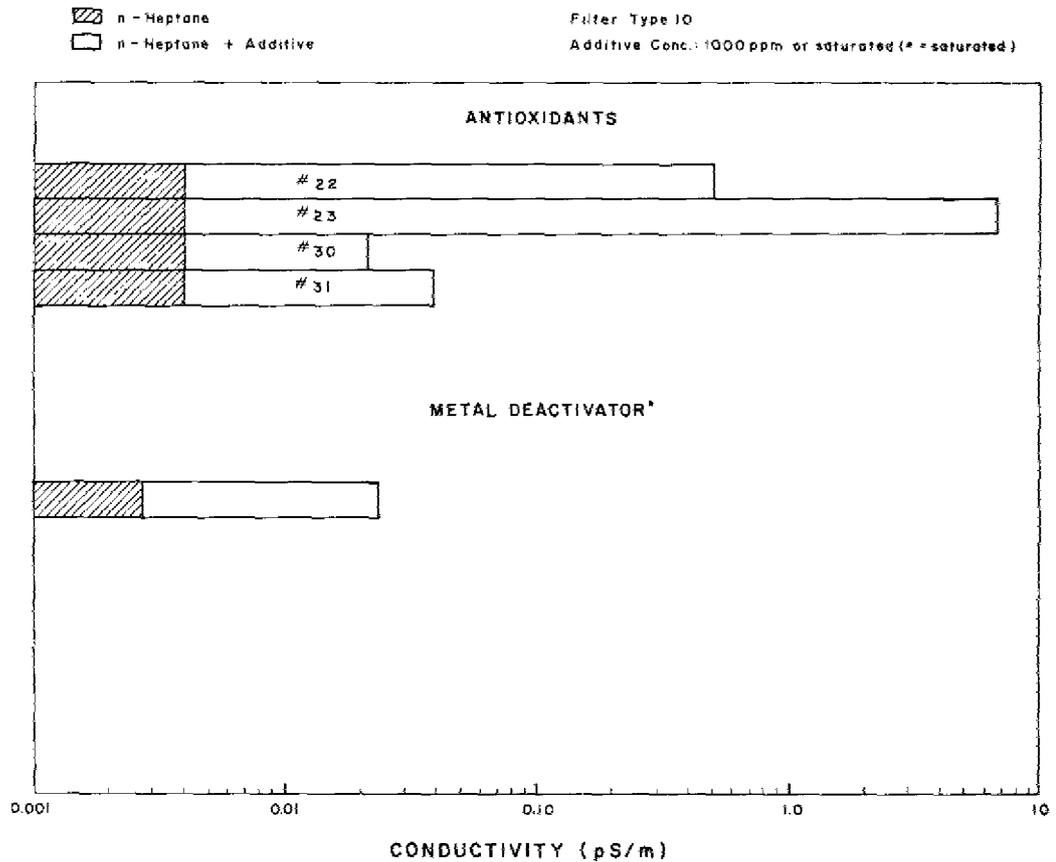


Fig. 8 -- Effect of antioxidants and metal deactivator on electrical conductivity of silica-gel-treated *n*-heptane

Selection of Potential Pro-static Agents

All of the compounds that, at a concentration of 1000 ppm, increased the charging tendency of silica-gel-treated *n*-heptane above $100 \mu\text{C}/\text{m}^3$ were selected for evaluation as potential pro-static agents in Jet A fuel. In addition, the static dissipator additives and the more active sodium sulfonates were also included, although some of these materials for example, (ASA-3 and Stadis 450) also produce rather dramatic increases in conductivity at a concentration of 1 ppm or less. It is recognized that if the conductivity of a hydrocarbon liquid exceeds 50 pS/m, the charge dissipates almost as quickly as it is generated. Consequently, compounds that increase conductivity above 50 pS/m are not pro-static agents in the sense implied here. Nevertheless, a number of compounds and additives that increased the conductivity of silica-gel-treated *n*-heptane above 50 pS/m were included in the tests with Jet A fuels because these compounds also have the greatest impact on the charging tendency.

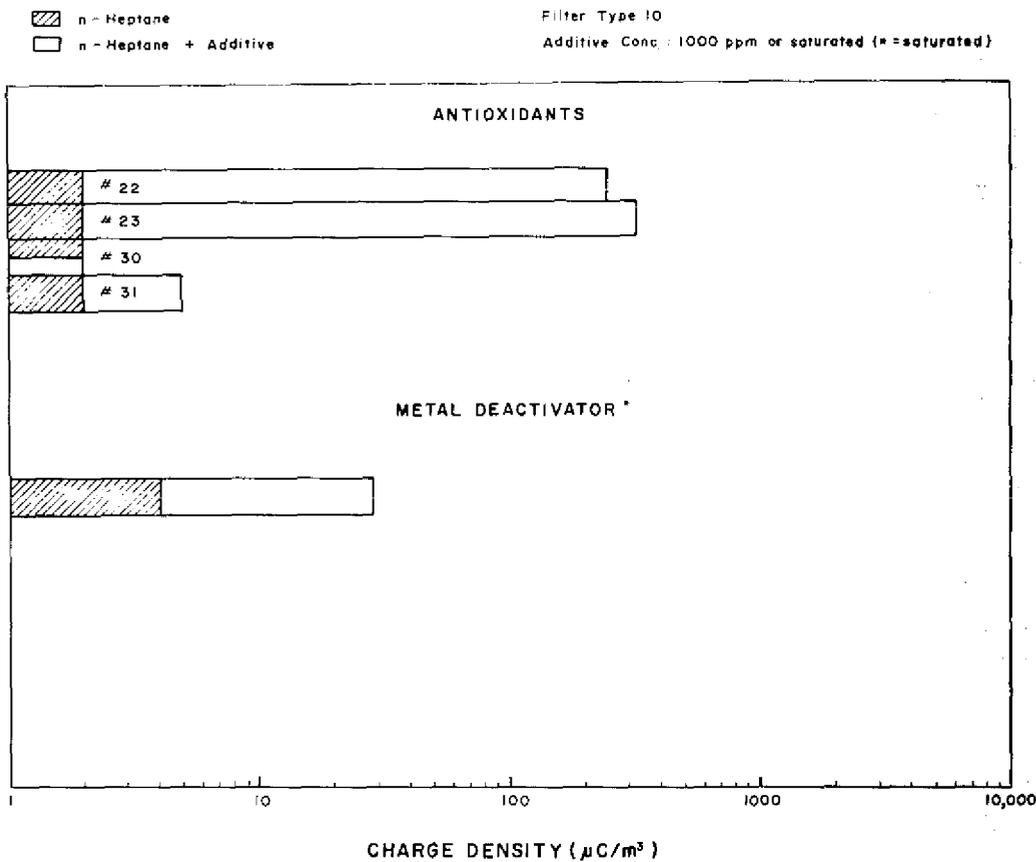


Fig. 9 — Effect of antioxidants and metal deactivator on charging tendency of silica-gel-treated *n*-heptane

Evaluation of Potential Pro-static Agents in Clay-Treated Jet A Fuels

The effects of the potential pro-static agents on the electrical conductivity and charging tendency of clay-treated Jet A fuels are given in Tables 2 to 4. To evaluate the data, requires some idea of what constitutes high charging. In a recent survey of Jet A fuels from 10 airports in the United States, it was found that only one sample in 338 had a charge density above $4000 \mu\text{C}/\text{m}^3$ when tested on Type 10 paper. It would seem then that $4000 \mu\text{C}/\text{m}^3$ is a reasonable value for a threshold of high charging. However, as indicated, if the conductivity of the fuel is greater than 50 pS/m, the charge dissipates almost as quickly as it is generated. As the conductivity decreases below 50 pS/m, the probability that charges will accumulate increases, reaching a maximum in the range of 1 to 10 pS/m, depending upon the system. In view of these considerations, the following criteria were used to evaluate pro-static effects in this work:

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

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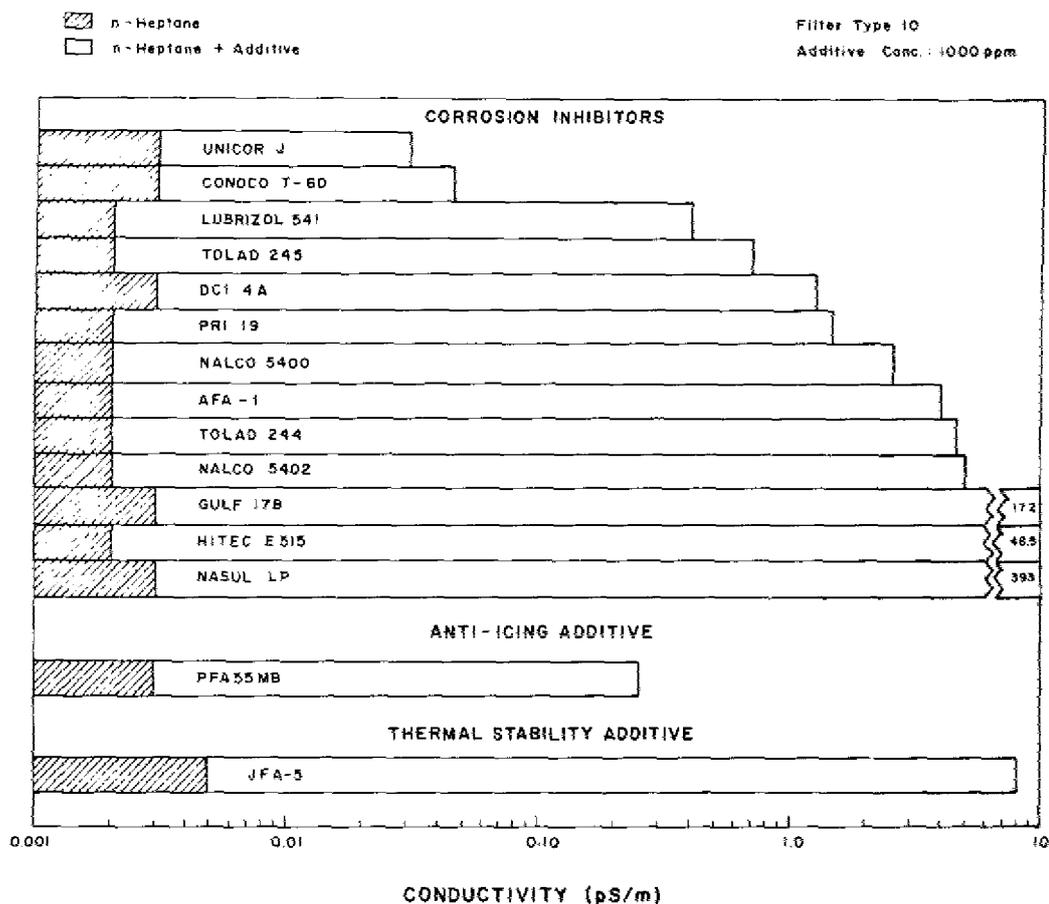


Fig. 10 — Effect of corrosion inhibitors, anti-icing, and thermal-stability additives on electrical conductivity of silica-gel-treated *n*-heptane

Applying these criteria to the data in Table 2 shows that pro-static effects were exhibited by three additives at a concentration of 100 ppm: Hitec E 515, Antioxidant No. 23, and Gulf 178. None of the other additives had a significant effect on either conductivity or charging tendency of clay-treated Jet A fuel at this concentration except Na-Sul-LP, which increased the conductivity to 52 pS/m without having a significant effect on the charging tendency. Nalco 5402 actually decreased the charge density while increasing the conductivity by a factor of 12. The charge densities measured with the other separator papers are all considerably lower than the values obtained with the Type 10 paper. The highest value, 4450 $\mu\text{C}/\text{m}^3$, was obtained with Gulf 178 on CS 61F paper. This was less than a third of the corresponding value obtained with the same additive on Type 10 paper. Gulf 178 also exhibited high charging on both the paper and Fiberglas[®] media of the coalescer element.

When the same additives were evaluated at a concentration of 1000 ppm (Table 3), pro-static effects were exhibited by an additional three additives: JFA-5, Nalco 5400, and AFA-1. Both Gulf 178 and Antioxidant No. 23 showed high charging on the Velcon

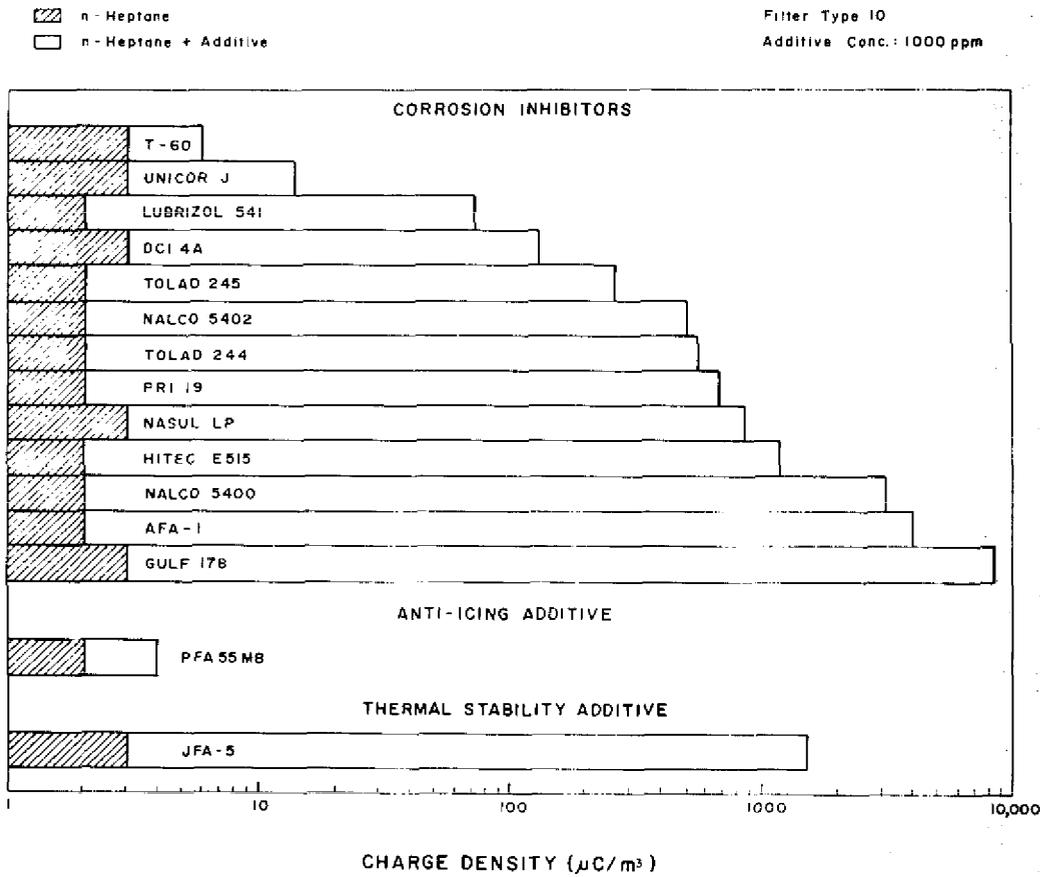


Fig. 11 — Effect of corrosion inhibitors, anti-icing, and thermal-stability additives on charging tendency of silica-gel-treated *n*-heptane

papers, as well as on the coalescer paper and Fiberglas[®] media. However, the conductivities achieved with both of the additives at this concentration (Gulf 178 conductivity is 54.8 pS/m and Antioxidant No. 23 conductivity is 103 pS/m) were above 50 pS/m, and hence, the high charging with either sample cannot be considered a true pro-static effect. High charging on filter media other than Type 10 was experienced with only one other additive (Na-Sul-LP on Fiberglas[®]), but again the conductivity was sufficiently high (414 pS/m) that this cannot be considered a prostatic effect either.

As shown by the data in Tables 2 and 3, charge densities obtained with the other filter media are considerably lower than the values obtained with the Type 10 paper. The data obtained with the two other types of Fram paper, CS-61F and CS-64, are generally quite similar and consistently higher than the values obtained with the other filter media (except Type 10). The Teflon[®] screen has the lowest available surface area of all of the filter media tested and, consequently, the lowest charge densities were obtained when this filter was used. Charging on Fiberglas[®] was less consistent: Usually if the conductivity was high (for example, with Na-Sul-LP and Gulf 178) the charge density

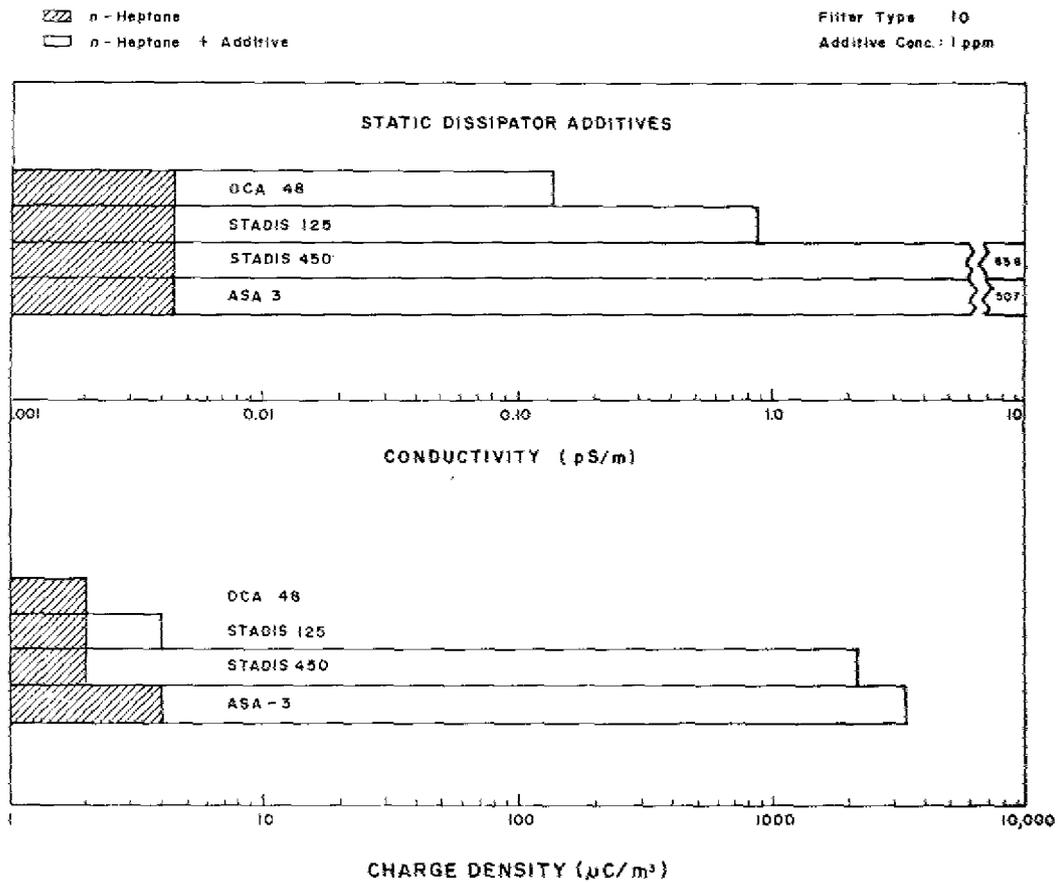


Fig. 12 — Effect of static-dissipator additives on electrical conductivity and charging tendency of silica-gel-treated *n*-heptane

was higher on Fiberglas[®] than on Type 10 paper. Otherwise the charging on Fiberglas[®] was generally lower on Fiberglas[®] than on Type 10 paper.

The maximum allowable concentrations for the additives listed in Tables 2 and 3 are less than 50 ppm (16.8 lb/1000 bbls). (See Appendix A). The data indicate that none of these additives would exhibit pro-static effects at this concentration. However, if a fuel were overdosed with certain of these additives, particularly Gulf 178 or Antioxidant No. 23, then pro-static effects would be expected.

The effects of the static dissipator additives are compared in Table 4. At 1 ppm, Stadis 125 slightly increases the charging tendency (on Type 10 paper), whereas DCA 48 actually decreases the charging tendency of clay-treated Jet A fuel by about 50%. None of the static dissipator additives exhibited high charging on any of the other filter media except for Stadis 125 and 450 on Fiberglas[®] and Stadis 125 on the coalescer paper. In the case of Stadis 125, this was definitely a pro-static effect on Fiberglas[®] at a concentration of 1 ppm. The values obtained for this additive at 5 ppm (4730 μC/m³ on Type CC-15 paper and 9300 μC/m³ on Fiberglas[®]) are the highest values obtained on any filter

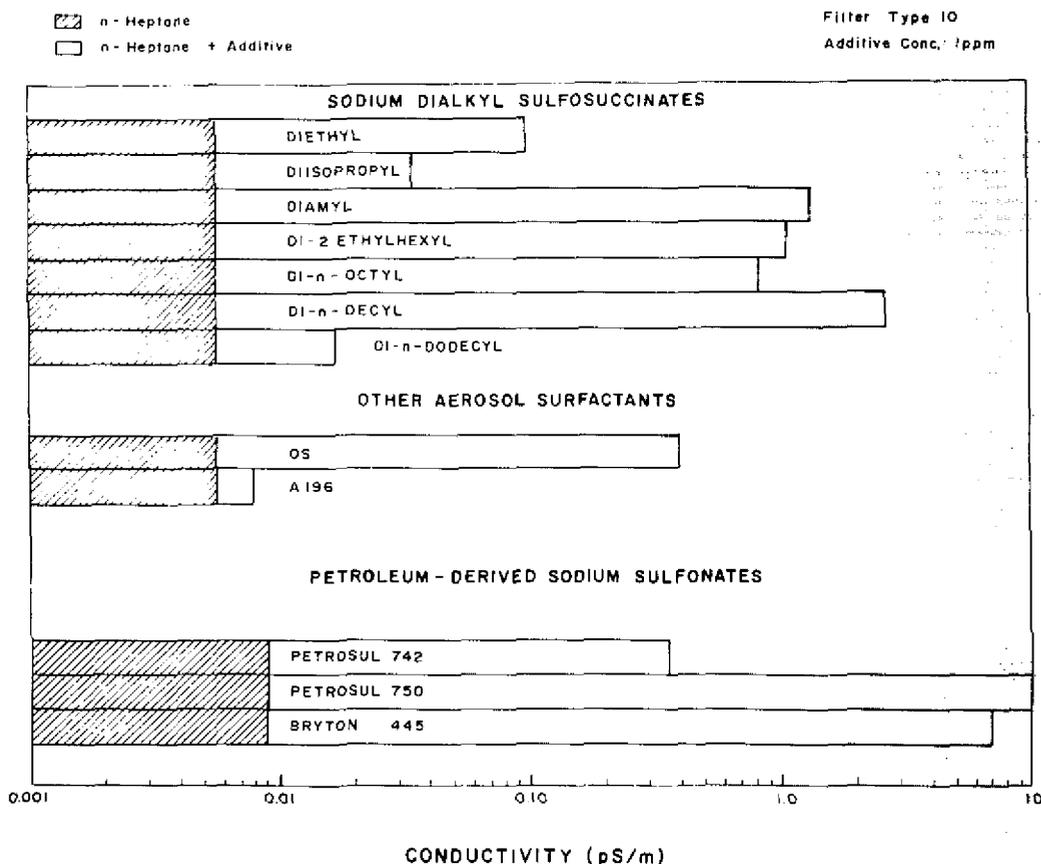


Fig. 13 — Effect of sodium sulfonates on electrical conductivity of silica-gel-treated *n*-heptane

media except Type 10 paper with a sample conductivity less than 50 pS/m. As shown in Tables 2 and 3, there were only four other cases in which Fiberglas® gave higher charging than Type 10 paper with clay-treated Jet A fuels, namely, Na-Sul-LP and Gulf 178 at 100 and 1000 ppm.

The data for the sodium sulfonates are also given in Table 4. As expected, the charge densities and conductivities obtained with these additives are somewhat higher than were obtained at 1 ppm in silica-gel-treated *n*-heptane (Figs. 13 and 14). The only pro-static effect attained in clay-treated Jet A fuel with the sodium sulfonates on any of the filter media was with Aerosol OT on Fiberglas®. High charging was also found at a concentration of 1.6 ppm for Bryton 430 and Petrosul 742 on Fiberglas®, but once again, the conductivity was too high for this to be a pro-static effect.

Evaluation of Pro-static Agents in Untreated Jet A Fuels

The results obtained when the same additives were tested in untreated Jet A fuel are given in Tables 5 and 6. Although the conductivity and charging tendency of the neat

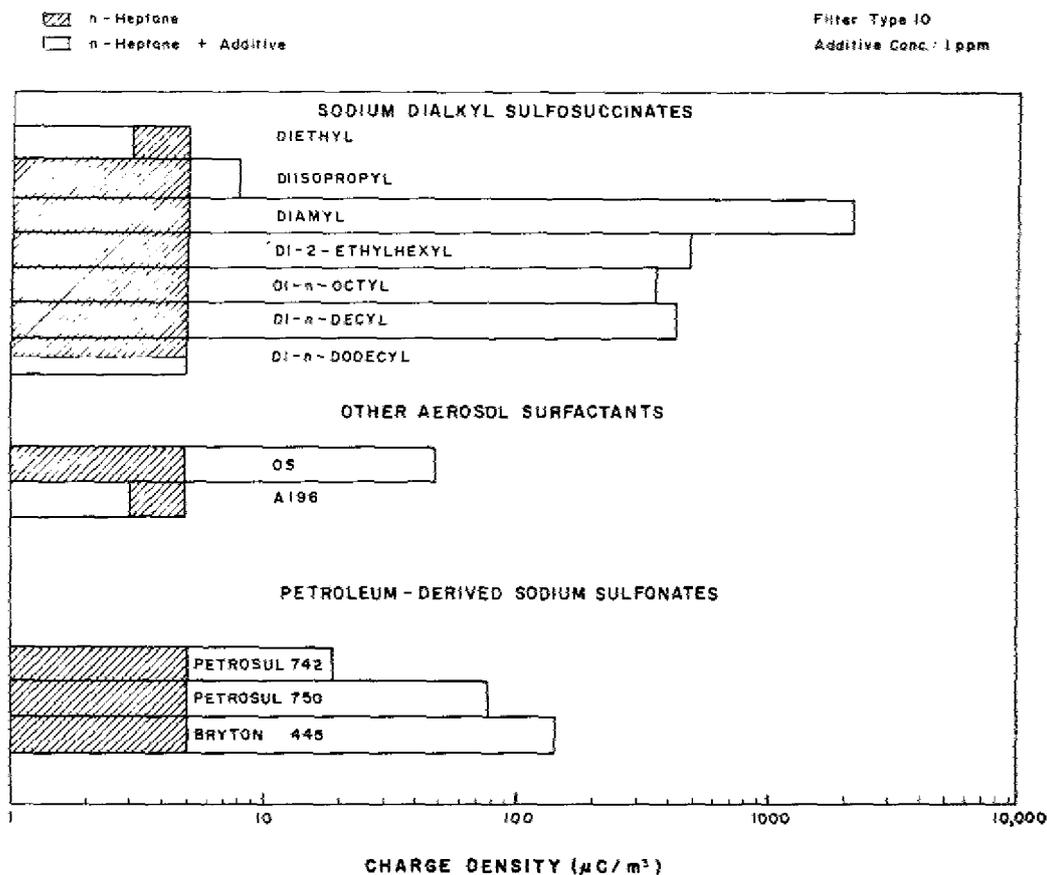


Fig. 14 — Effect of sodium sulfonates on charging tendency of silica-gel-treated *n*-heptane

untreated Jet A fuel was slightly higher than the neat clay-treated fuel (compare Tables 2 and 5), the untreated Jet A fuel was less responsive to most of the additives than was the clay-treated fuel; i.e., except for Nalco 5402 and JFA-5, both the conductivity and charging tendency in the untreated Jet A were lower than in clay-treated fuel (see Figs. 15 and 16). However, pro-static effects were obtained at 100 ppm for the same two additives (Gulf 178 and Antioxidant No. 23) in untreated Jet A fuel (Table 5) and with the clay-treated fuel (Table 2). Only one instance of high charging was found on any of the other filter media besides Type 10, namely, for Gulf 178 on Fiberglas®. In all other cases, the charge densities were remarkably low. As with the clay-treated fuel, the charge densities obtained with the CS-61F and CS-64 papers were consistently higher than with the other papers (except Type 10). Also, the Teflon® screen consistently gave the lowest charge densities of all the filter media.

The data obtained with the static dissipator additives and the sodium sulfonates in untreated Jet A fuel are given in Table 6. Stadis 125 decreased the charge density on Type 10 paper by about 50% at a concentration of 1 ppm, whereas DCA 48 only slightly decreased the charging tendency at the same concentration. Both Stadis 450 and ASA-3 increased the charging tendency of the untreated Jet A fuel to a greater extent than the

Table 2 — Effect of Fuel Additives on Electrical Conductivity and Charging Tendency of Clay-Treated Jet A Fuel at 100 ppm

Additive	Concentration (ppm)	Conductivity (pS/m)	Charge Density ($\mu\text{C}/\text{m}^3$)								
			Fram Separator			Keene Separator		Velcon Separator		Fram Coalescer	
			Type 10	CS-61F	CS-64	Paper	Teflon®	Pleated	Unpleated	Paper	Fiberglas®
None		0.102	909	5	6	1	7	2	2	5	48
Nalco	100	1.24	749	±3	3	-3	1	1	2	-57	(*)
Na-Sul-LP	100	52	1 200	-204	-233	-290	-181	-181	-193	-630	-1 895
Naphthenic acid	100	0.622	1 300	29	25	5	1	3	2	-8	28
Tolad 244	100	0.329	1 305	6	1	-2	1	3	-6	-3	-33
PRI-19	100	0.622	1 540	60	54	5	1	10	5	15	84
JFA-5	100	1.71	1 865	107	79	26	15	16	9	27	148
Nalco 5400	100	0.582	1 950	219	203	27	—	28	56	<621	1 040
AFA 1	100	0.276	2 530	376	370	46	18	42	86	439	1 390
Hitec E 515 Antioxidant	100	4.70	4 670	1590	<549	-6	1	122	290	29	<262
No. 23	100	1.41	5 660	2620	2070	290	35	842	439	92	387
Gulf 178	100	15.4	15 000	4450	4320	2013	168	1640	1440	6120	16 800

*Equilibrium not reached. Filter current changed continuously with each succeeding run.

Table 3 — Effect of Fuel Additives on Electrical Conductivity and Changing Tendency of Clay-Treated Jet A Fuel at 1000 ppm

Additive	Concentration (ppm)	Conductivity (pS/m)	Charge Density ($\mu\text{C}/\text{m}^3$)								
			Fram Separator			Keene Separator		Velcon Separator		Fram Coalescer	
			Type 10	CS-61F	CS-64	Paper	Teflon®	Pleated	Unpleated	Paper	Fiberglas®
None	—	0.102	909	5	6	1	7	2	2	5	48
Naphthenic acid	1000	3.01	1 430	67	51	12	6	13	8	36	(*)
Hitec E 515	1000	27.0	1 650	-961	-2290	-174	± 2	326	299	—	1 520
Tolad 244	1000	4.74	2 110	23	2	4	4	41	-5	(†)	-491
Na-Sul-LP	1000	414	2 870	-256	-305	-275	-107	-117	-266	—	-9 360
Nalco 5402	1000	8.80	3 110	68	42	29	28	26	34	-41	-791
PRI-19	1000	2.23	3 230	174	146	36	16	76	38	86	342
JFA-5	1000	6.19	8 360	1210	1110	284	27	130	53	99	1 010
Nalco 5400	1000	2.80	9 030	3600	2990	797	72	140	793	17	763
AFA 1	1000	2.06	9 750	3540	3320	201	43	939	958	683	473
Antioxidant No. 23	1000	103	10 800	8780	8540	2680	(*)	3721	732	(†)	-516
Gulf 178	1000	54.8	23 500	9460	9880	2600	312	6840	5520	19 800	25 600

*Equilibrium not reached. Filter current increased with each succeeding run.

†Equilibrium not reached. Filter current decreased with each succeeding run.

Table 4 — Effect of Static Dissipator Additives and Sodium Sulfonates on Electrical Conductivity and Changing Tendency of Clay-Treated Jet A

Additive	Concentration (ppm)	Conducting (pS/m)	Charge Density ($\mu\text{C}/\text{m}^3$)								
			Fram Separator			Keene Separator		Velcon Separator		Fram Coalescer	
			Type 10	CS-61F	CS-64	Paper	Teflon®	Pleated	Unpleated	Paper	Fiberglas®
None	—	0.102	909	5	6	1	7	2	2	5	48
Static dissipator additives:											
Ethyl DCA 48	1	9.86	461	-32	-38	-25	-5	-25	-27	-1100	-500
	5	62.3	1230	-25	-36	-47	-6	-26	-33	-189	-302
Stadis 125	1	7.48	1040	-134	-171	-183	-101	-153	-177	-952	-7 560
	5	46.5	2110	-78	-142	-720	-287	-455	-537	-4730	-9 300
Stadis 450	1	115	2950	34-4	76-18	-38	-20	-15	-16	(*)	-12 700
ASA-3	1	265	5860	153-3	153-7	34-21	3	-14	-10	—	718
Sodium sulfonates:											
Aerosol AY	1	5.85	-2680	750	628	541	133	470	626	1430	2 560
Aerosol OT	1	1.51	-1500	91	93	77	39	75	96	1070	7 110
Bryton 430	1	4.71	439	28	28	12	2	10	8	305	457
Petrosul 742	1	10.3	839	51	53	32	9	14	24	24	751
Petrosul 745	1	2.79	244	3	1	1	-3	-3	-1	146	323
Bryton 445	1.6	58.5	5190	106	98	51	46	55	76	3360	8 540
Petrosul 742	1.6	55.4	5490	174	147	101	38	71	87	(†)	15 300
Petrosul 750	1.6	17.0	1140	-6	-8	-10	1	-3	2	601	1 460

*Equilibrium not reached. Filter current changed with each succeeding run.
 †Equilibrium not reached. Filter current increased with each succeeding run.

Table 5 — Effect of Fuel Additives on Electrical Conductivity and Charging Tendency of Untreated Jet A Fuel

Additive	Concentration (ppm)	Conductivity (pS/m)	Charge Density ($\mu\text{C}/\text{m}^3$)								
			Fram Separator			Keene Separator		Velcon Separator		Fram Coalescer	
			Type 10	CS-61F	CS-64	Paper	Teflon®	Pleated	Unpleated	Paper	Fiberglas®
None	—	0.164	1160	109	74	10	2	10	7	15	17
Nalco 5402	100	1.34	833	170	98	33	8	24	14	29	-87
Na-Sul-LP	100	25.6	750	56	15	34	54	36	21	101	(*)
Naphthenic acid	100	0.804	543	108	74	17	3	11	0		49 [†]
Tolad 244	100	0.885	814	48	33	12	1	10	2	6	20
PRI-19	100	0.513	1370	146	87	29	5	28	11	19	122
JFA-5	100	1.87	2500	214	125	28	5	34	12	36	125
Nalco 5400	100	0.571	964	265	265	41	16	56	30	70	226
AFA-1	100	0.255	1650	451	384	30	9	49	19	28	854
Hitec E 515 Antioxidant	100	0.80	1120	96*	63*	11	4	29	10		67
No. 23	100	7.87	4210	1320	1130	207	28	590	217	67	(†)
Gulf 178	100	2.85	6340	1950	1710	537	54	975	440	1460	5490

*Equilibrium not reached. Filter current decreased with each succeeding run.

†Equilibrium not reached. Filter current increased with each succeeding run.

Table 6 — Effect of Static Dissipator Additives and Sodium Sulfonates on Electrical Conductivity and Changing Tendency of Untreated Jet A Fuel

Additive	Concentration (ppm)	Conductivity (pS/m)	Charge Density, ($\mu\text{C}/\text{m}^3$)								
			Fram Separator			Keene Separator		Velcon Separator		Fram Coalescer	
			Type 10	CS-61F	CS-64	Paper	Teflon®	Pleated	Unpleated	Paper	Fiberglas®
None		0.164	1 150	109	74	10	2	10	7	15	17
Static dissipator additives:											
Ethyl DCA 48	1	13.8	1 000	51	33	(*)	-5	-9	-17	-28	-198
Stadis 125	1	13.4	592	-256	-371	-424	-104	-262	-358	-1130	-3230
Stadis 450	1	55.9	4 790	393	230	125	-15	-10	-34	(†)	(*)
ASA-3	1	90.0	12 600	427	262	168	4	(‡)	16	101	(‡)
Sodium sulfonates:											
Aerosol AY	1	5.09	2 700	570	378	308	79	217	320	748	763
Aerosol OT	1	3.12	1 350	130	128	83	29	70	70	610	1400
Sul-fon-ate											
AA-10	1	55.7	7 230	5 920	5 940	6410	81	3920	8070	6580	9820
Acto 630	1	16.3	4 510	267	220	287	52	76	100	2560	3900
Bryton 430	1	65.0	10 200	12 300	11 900	8540	119	6160	8300	11 700	9900
Petrosul 742	1	49.8	7 850	77	7 470	5920	92	4760	6100	10 200	9460
Purified											
sulfonate	1	36.2	5 250	2 140	1 380	2560	76	354	481	5 220	4040
Petrosul 745	1	53.3	8 850	7 810	6 680	2290	43	1013	2220	nd	nd
Bryton 430	1.6	65.1	12 400	9 360	7 290	6860	134	2750	4480	12 900	15 900
Bryton 445	1.6	30.7	7 470	738	622	860	85	159	268	5 730	5 060
Petrosul 742	0.8	25.8	6 860	805	692	845	101	180	214	6 470	5 730
Petrosul 742	1.6	57.2	17 100	5 610	2 500	3970	159	323	1130	17 100	15 600
Petrosul 744 LC	1.6	131	13 900	1 690	1 030	1800	137	177	470	12 500	17 690
Petrosul 745	1.6	60.0	13 100	6 800	4 060	5370	119	833	2104	13 300	13 300
Petrosul 750	1.6	33.7	8 870	915	664	787	104	115	158	8 020	10 200

Note: nd = not discernible.

*Equilibrium not reached. Filter current decreased with each succeeding run.

†Equilibrium not reached. Filter current increased with each succeeding run.

‡Equilibrium not reached. Filter current changed continuously with each succeeding run.

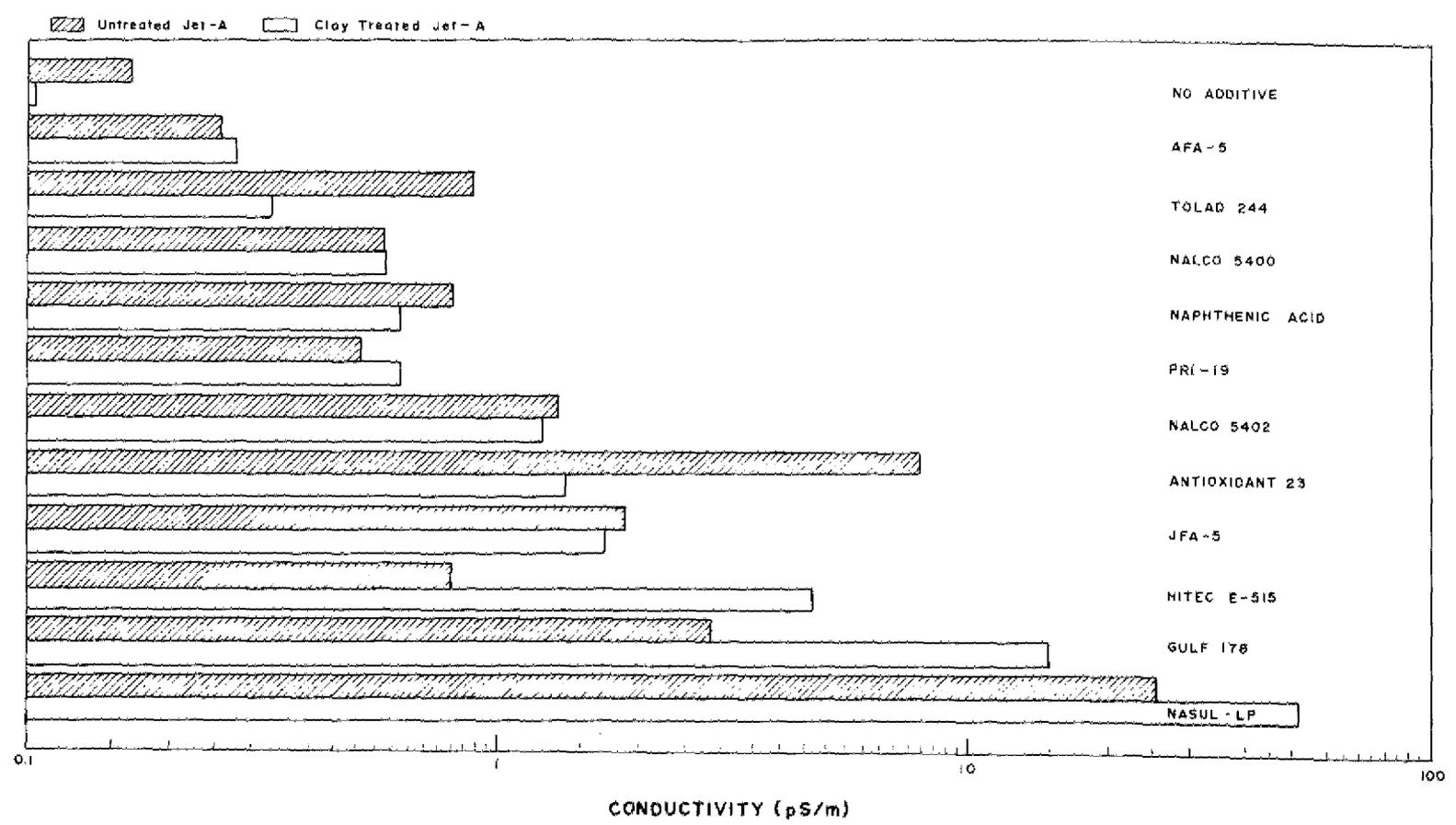


Fig. 15 -- Effect of selected fuel additives and polar compounds on electrical conductivity of untreated and clay-treated Jet A fuels

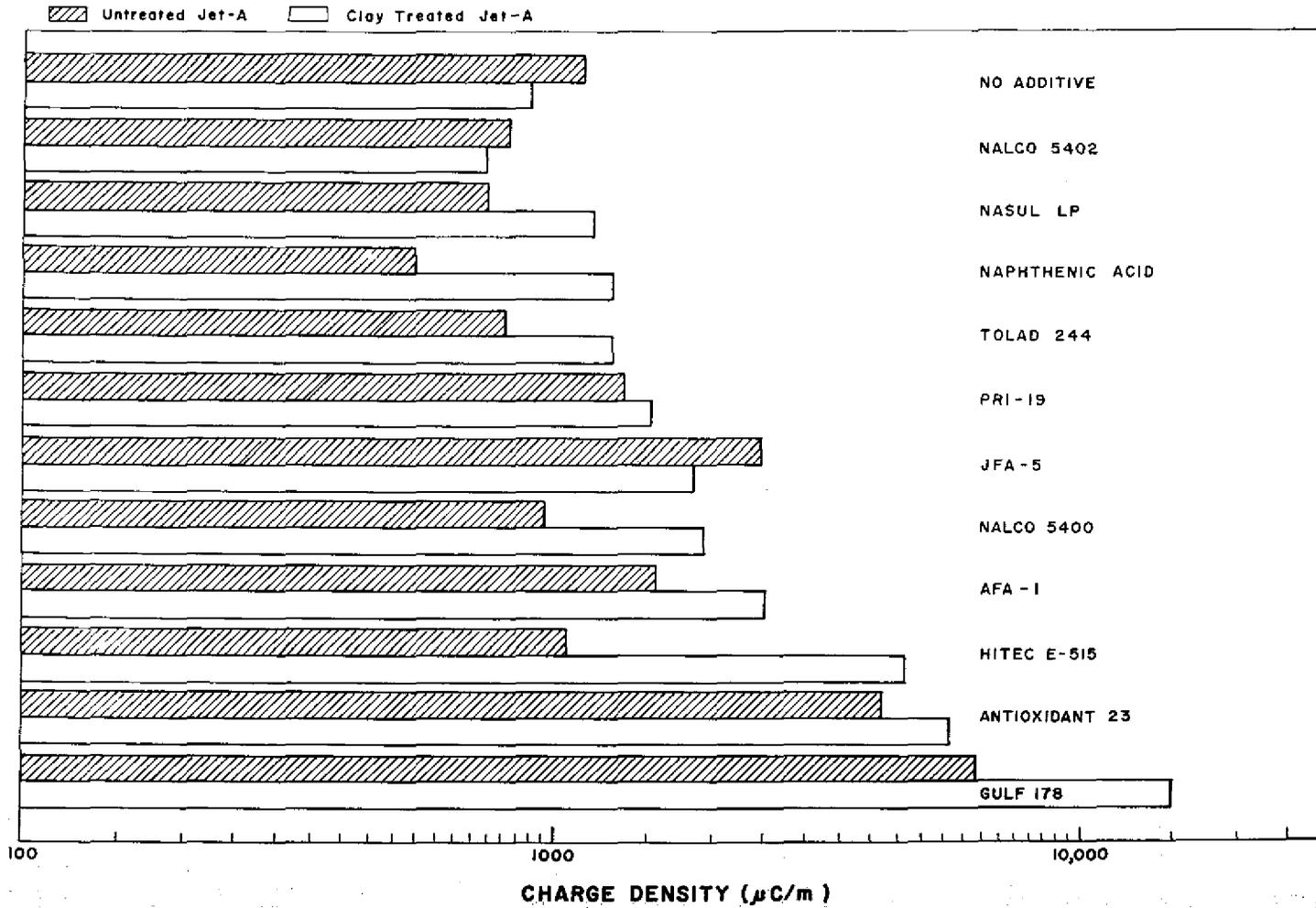


Fig. 16 — Effect on selected fuel additives and polar compounds on charging tendency of untreated and clay-treated Jet A fuels

clay-treated fuel, but both additives were less effective conductivity improvers in the untreated Jet A fuel. These variations in response to specific additives highlight the role of trace contaminants in jet fuels that react synergistically with certain additives and not at with others.

Aerosol AY and Aerosol OT had about the same effect on both the conductivity and charging tendency of the untreated Jet A fuel as on the clay-treated fuel, although the high charging with the Fiberglas® filter that was found with the clay-treated Jet A fuel (Table 4) was not found with the untreated fuel. What is perhaps more interesting about these two sulfonates is that the mere removal of six CH₂ groups (three from each octyl substituent of Aerosol OT) to produce the diamyl derivative (Aerosol AY) causes the charging tendency on Type 10 paper to double in jet fuel (Table 4 and 6) and quadruple in *n*-heptane (Fig. 14). Yet, removal of six more CH₂ groups to produce the diethyl derivative (Fig. 14) does not increase, but rather lowers, the charging tendency. The results underscore the sensitivity of the charging mechanism to the molecular structure of the charge-promoting species in the fuel. For example, introducing a substituted benzene ring, as in Sul-fon-ate AA 10 (sodium dodecylbenzenesulfonate) markedly increases the effect of the sulfonate on both the conductivity and charging tendency. (Note that Sul-fon-ate AA 10 and Aerosol AY have practically the same molecular weight. Sul-fon-ate AA 10 has a molecular weight of 348; Aerosol AY has a molecular weight of 360. However, Aerosol AY is strictly an aliphatic compound.)

Three of the petroleum-derived sulfonates, Acto 630, Petrosul 742, and Purified Sulfonate L, exhibited pro-static effects at a concentration of 1 ppm. Obviously, the other two, Bryton 430 and Petrosul 745 would show pro-static effects at a slightly lower concentration. Bryton 430, Petrosul 742, and Petrosul 745 also showed high charging on most of the other filter media. This is particularly evident in the data obtained at the higher concentration (1.6 ppm, see Table 6). It is also apparent from these data, as shown in Fig. 17, that charging tendency of the Petrosul compounds decreases with increasing molecular weight.

EFFECT OF MOISTURE

All of the fuel conductivity and charging tendency measurements were made under ambient conditions of 22.2°C (72°F) and 47% ± 11% relative humidity (RH). However, it is recognized that moisture can effect both properties. In a recent survey conducted by the Coordinating Research Council [6], fuel conductivity and charging tendency measurements were made on 93 samples of Jet A fuel under laboratory conditions (about 50% RH) and after conditioning at 100% RH. It was found that moisture had an unpredictable effect on fuel conductivity; with some samples it increased the conductivity; with others, it decreased the conductivity; and in some cases, moisture had no effect on the conductivity. However, for 85 of the samples, moisture increased the charging tendency by as much as 9.5 times depending on the fuel. The survey data for those samples for which the charge density exceeded 4000 μC/m³ after being conditioned at 100% RH are reproduced in Table 7. For all but three of these samples, the conductivity decreased after conditioning at 100% RH, and the charging tendency increased on the average by a factor of 6.4. More significantly from the stand-point of pro-static effects, the maximum conductivity after conditioning at 100% RH was only 5.4 pS/m, and for 10 samples the conductivity was less than 1.0 pS/m. None of the 63 compounds and

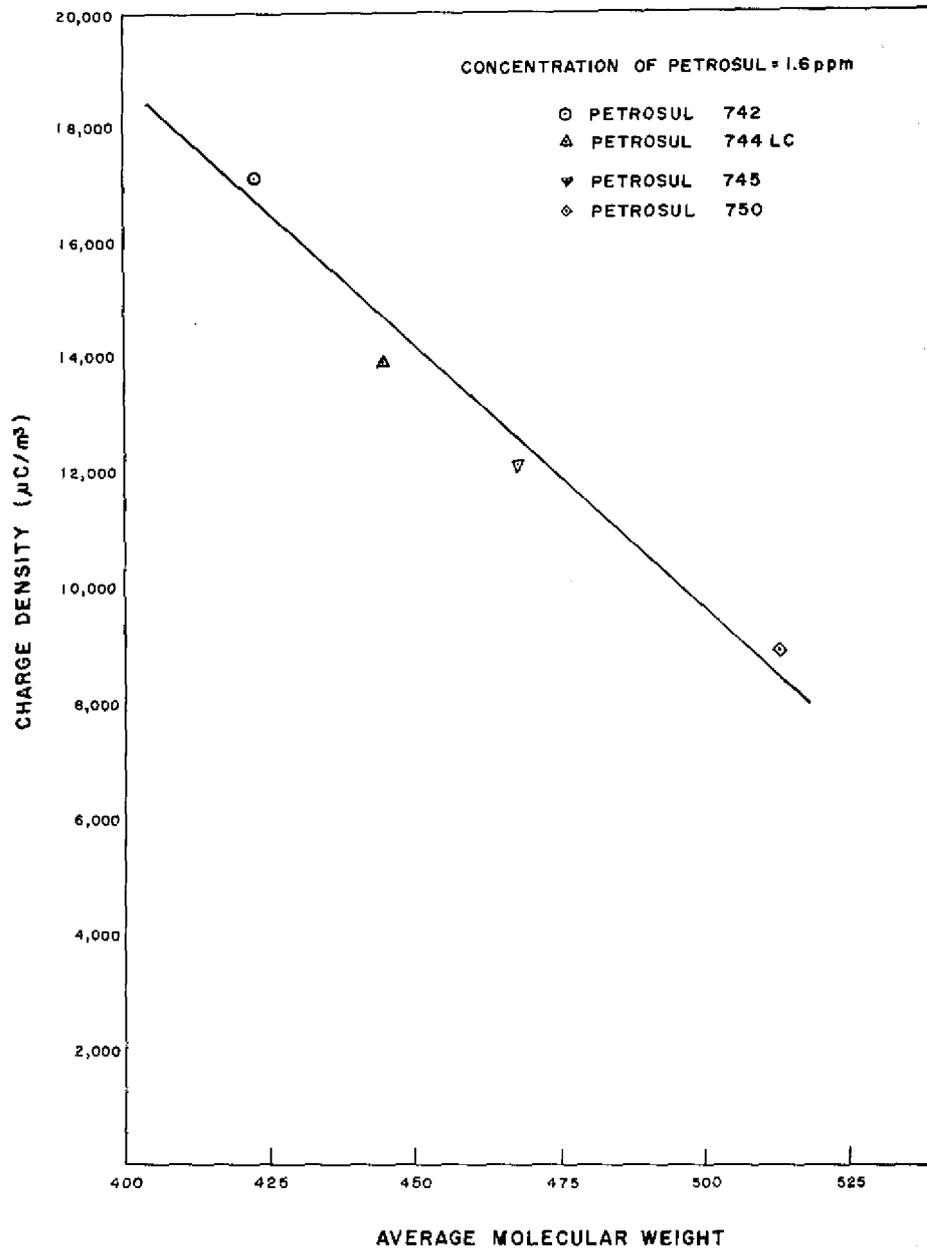


Fig. 17 — Effect of molecular weight of Petrosul compounds on charging tendency of untreated Jet A fuel

Table 7 — Effect of Humidity on Fuel Conductivity and Charging Tendency—Data on Jet A Fuel From CRC Survey*

Time of Year	Values at 50% RH			Values at 100% RH			K_2/K_1	CD_2/CD_1
	Water Concentration (ppm)	Conductivity (K_1) (pS/m)	Charge Density, (CD_1) ($\mu C/m^3$)	Water Concentration (ppm)	Conductivity (K_2) (pS/m)	Charge Density, (CD_2) ($\mu C/m^3$)		
PHASE ONE								
Winter	25	0.90	1140	77	0.42	8820	0.47	7.2
	30	2.73	960	93	1.03	4410	0.38	4.6
	41	1.94	720	75	1.17	5880	0.60	8.2
	48	0.44	770	81	0.22	5700	0.50	7.4
	36	0.84	570	83	0.52	4980	0.62	8.7
	40	0.50	885	88	0.48	5400	0.96	6.1
	17	0.50	550	98	0.38	4350	0.76	7.9
	19	4.39	790	97	1.50	8580	0.34	9.2
	20	3.54	1170	107	1.17	9090	0.33	7.8
17	6.85	780	65	5.40	4080	0.79	5.2	
PHASE TWO								
Summer	33	1.78	870	68	1.75	9150	0.98	9.5
	38	0.63	970	77	0.65	7070	1.03	7.3
	39	5.95	1050	72	5.20	7475	0.87	7.1
	37	0.71	2070	91	0.70	4870	0.99	4.3
	44	1.65	990	95	1.63	6000	0.99	6.1
	36	2.88	2055	88	2.68	7050	0.93	3.4
	38	0.21	1670	76	0.21	5870	1.0	3.7
	47	0.55	1040	67	0.72	5160	1.31	5.0
	65	0.57	1150	80	0.55	6015	0.96	5.2
	57	1.22	2650	90	1.11	5250	0.91	2.0
	52	1.55	1335	78	1.51	8850	0.97	6.6
38	2.07	1100	75	1.84	6180	0.89	5.6	
Fall	28	3.08	335	90	3.35	4350	1.09	8.2

*From Ref. 6.

Table 8 -- Effect of Moisture on Fuel Conductivity and Charging Tendency

Fuel	Conductivity (pS/m)		Charge Density ($\mu\text{C}/\text{m}^3$)	
	Before Shaking With Water*	After Shaking With Water	Before Shaking With Water*	After Shaking With Water
Clay-treated Jet A	0.060	0.070	140	3170
Untreated Jet A	0.313	0.126	390	2960
Silica Gel Treated <i>n</i> -Heptane	0.005	0.011	3	2

*These measurements were made approximately 6 months after the fuel conductivity and charging tendency measurements given in Tables 2 to 6. During this period, the conductivity of the clay-treated Jet A fuel decreased and the conductivity of the untreated fuel increased. The charging tendency of both samples decreased markedly over the same period.

additives tested in the present study produced this unique combination of effects; i.e., none of these compounds or additives were able to increase the charging tendency of the fuel without simultaneously increasing its conductivity. Thus, in *some* fuels, dissolved water is the most powerful pro-static agent identified to date.

In the present study both the untreated and the clay-treated Jet A fuels and silica-gel-treated *n*-heptane were shaken with distilled water (5 drops of distilled $\text{H}_2\text{O}/1000 \text{ cm}^3$ of fuel) and allowed to stand overnight. As indicated in Table 8, increasing the moisture content had little effect on the conductivity of either fuel or of the *n*-heptane. However, water did increase the charge density of both fuels, by a factor of 23 in the case of the clay-treated fuel, and by a factor of 7.6 for the untreated fuel. On the other hand, water had no effect on the charge density of the silica-gel-treated *n*-heptane, indicating that it is not water per se, but rather its interaction with some constituent of the fuel that is responsible for its pro-static effect in fuels.

SUMMARY AND CONCLUSIONS

At concentrations up to 1000 ppm, simple polar compounds (acids, alcohols, aldehydes, amines, esters, and ketones) do not significantly increase the electrical conductivity or charging tendency of silica-gel-treated *n*-heptane.

Certain fuel additives (corrosion inhibitors, an antioxidant, and a thermal-stability additive) at concentrations exceeding the maximum allowable values in fuels can have a pro-static effect on jet fuels when Type 10 paper is used.

Two of the static dissipator additives (DCA 48 and Stadis 125) have very little effect on the charging tendency on any of the separator media. However, Stadis 125 in clay-treated Jet A fuel does have a pro-static effect on both the paper and Fiberglas® media of the coalescer element. The other two static dissipator additives, Stadis 450 and ASA-3,

gave very low charging on all of the separator media except Type 10 paper. However, Stadis 450 gave high charging on the Fiberglas® coalescer medium.

The most electrostatically active compounds found in this study were the sodium sulfonates, particularly those derived from petroleum. Two of these compounds, Acto 630 and Purified Sulfonate L, gave charge densities in excess of $4000 \mu\text{C}/\text{m}^3$ at conductivities of less than $50 \text{ pS}/\text{m}^3$ and, hence, qualified as pro-static agents according to the definition adopted for this study. Other petroleum sulfonates and at least one synthetic sodium sulfonate (Sul-fon-ate AA 10) would probably be classified as pro-static agents at concentrations of less than 1 ppm.

Electrostatic activity is highly dependent on molecular structure. Within a given homologous series, such as the sodium diakyl sulfosuccinates, addition or subtraction of a few CH_2 groups can markedly change the effect that a given compound can have on the charging tendency of a hydrocarbon fuel. Also, a definite correlation between molecular weight and charging tendency was found for the Petrosul compounds with the maximum effect being shown by the material of the lowest molecular weight.

One type of filter media, the obsolete Type 10 paper, gave consistently higher charge levels than any of the other paper media tested regardless of the fuel sample. Of the separator elements in current use, two types of paper, Fram CS-61F and CS-64, gave higher values than the other three types. The lowest levels of charge were obtained with the Teflon® screen. With only the sample, 1000 ppm Gulf 178 in clay-treated Jet A fuel, was a charge density in excess of $300 \mu\text{C}/\text{m}^3$ obtained with Teflon®. Charging on Fiberglas® was irregular, sometimes exceeding that of Type 10 paper and at other times as low as that of low-charging papers.

A comparison of the results of the present study with available literature data indicates that water is an ideal pro-static agent. In one study it was found that increasing the moisture content of most fuels increased the charging tendency by as much as 9.5 times while decreasing fuel conductivity. In the present study it was found that saturation with water had little effect on the conductivity of either fuel or of silica-gel-treated *n*-heptane. However, water did increase the charge density of clay-treated Jet A by a factor of 23 and of untreated Jet A by a factor of 7.6. On the other hand, water had no effect on the charge density of the *n*-heptane, indicating that it is not water per se, but rather its interaction with some constituent of the fuel, that is responsible for its pro-static effect in fuels.

Finally, as demonstrated by the effect of moisture on conductivity and charging tendency, fuels vary in their response to additives. Similar charge-enhancing effects would be expected if the pro-static agents tested in this program were added to other jet fuels, but the magnitude of the charge would not necessarily be the same.

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Appendix A
COMPOUNDS AND ADDITIVES SELECTED FOR SCREENING

The polar organic compounds with their purity and suppliers are as follows:

<u>Polar Organic Compounds</u>	<u>Purity</u>	<u>Supplier</u>
Acetic acid	Reagent ACS	Fisher*
Decanoic acid	96% minimum	Eastman†
Benzoic acid	Reagent ACS	Eastman†
Ethyl alcohol	200 proof	U.S. Industrial Chemicals‡
Decyl alcohol	Melting point: -14.72° - -14.27° C (5.5°-6.5° F)	Eastman†
Phenol	Reagent ACS	Allied Chemical [¶]
Acetaldehyde	Boiling point: -6.67° - -5.56° C (20°-22° F)	Eastman†
Lauraldehyde	Boiling point: 85° C (185° F) at 13.3 kPa	Aldrich Chemical [¶]
Benzaldehyde	99% minimum	Eastman†
Ethylamine	Anhydrous	Eastman†
Diethylamine	Reagent grade	Fisher*
Triethylamine	98% minimum	Eastman†
Decylamine	Practical	Eastman†
Aniline	Certified ACS	Fisher*
Ethyl acetate	NF	Baker**
Methyl undecanoate	Spec grade	Baker**
Methyl Benzoate	Reagent grade	Fisher*
Acetone	Certified ACS	Fisher*
Acetophenone	Certified ACS	Fisher*

Other miscellaneous organic compounds are as follows:

<u>Compound</u>	<u>Purity</u>	<u>Supplier</u>
Alizarin	Not available	Fisher*
Carminic acid	Not available	Fisher*
Ferric benzoylacetate	Not available	Fisher*
Ferrocene	Practical	Eastman†
Fluoroscein	Practical	Eastman†
Indigo	Not available	Eastman†
Naphthenic acids	Practical	Eastman†

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<u>Compound</u>	<u>Purity</u>	<u>Supplier</u>
Pararosaniline hydrochloride	Not available	Eastman†
Phenolphthalein	Not available	Fisher*

*Fisher Scientific Co., Fairlawn, N.J.

†Eastman Organic Chemicals, Rochester, N.Y.

‡U.S. Industrial Chemicals, New York, N.Y.

|| Allied Chemical Corp., New York, N.Y.

¶ Aldrich Chemical Co., Milwaukee, Wis.

**J.T. Baker, Phillipsburg, N.J.

Table A1 gives the suppliers, composition, and allowable concentrations of the fuel additives selected for this study. It also gives the supplier of each additive.

The Composition and Suppliers of the sodium sulfonates selected for this study follow:

<u>Name</u>	<u>Composition</u>	<u>Molecular Weight</u>	<u>Supplier</u>
	Sodium diethyl sulfosuccinate	276	American Cyanamid*
	Sodium di-isopropyl sulfosuccinate	304	American Cyanamid*
Aerosol AY	Sodium diamyl sulfosuccinate	360	American Cyanamid*
Aerosol OT	Sodium di-2-ethylhexyl sulfosuccinate	444	American Cyanamid*
	Sodium di- <i>n</i> -octyl sulfosuccinate	444	American Cyanamid*
	Sodium di- <i>n</i> -decyl sulfosuccinate	500	American Cyanamid*
	Sodium di- <i>n</i> -dodecyl sulfosuccinate	556	American Cyanamid*
Aerosol A 196	Sodium dicyclohexyl sulfosuccinate	386	American Cyanamid*
Aerosol OS	Sodium isopropyl naphthalene sulfonate	272	American Cyanamid*
Sul-fon-ate AA 10	Sodium dodecyl benzene sulfonate	348	Tennessee Corp.†

*American Cyanamid, Stamford, Conn.

†Tennessee Corp., Atlanta, Ga.

Table A1 — Fuel Additives, Their Compositions, Allowable Concentrations, and Their Suppliers

Additive	Composition	Recommended Concentration	Minimum Effective Concentration*	Maximum Allowable Concentration*	Listing on Qualified Products List†	Supplier
		lb/1000 bbl	lb/1000 bbl	lb/1000 bbl		
Antioxidant No. 22	<i>N,N'</i> -Disecodary butyl- <i>p</i> -phenylenediamine	—	—	8.4	—	1
Antioxidant No. 23	<i>N,N'</i> -Di-isopropyl- <i>p</i> -phenylenediamine in methanol and isopropanol	—	—	16.8	—	1
Antioxidant No. 30	2,4-Dimethyl-6-tertiary butyl phenol	—	—	8.4	—	1
Antioxidant No. 31	2,4-Dimethyl-6-tertiary butyl phenol and other alkylated phenols	—	—	8.4	—	1
Dupont Metal Deactivator	<i>N,N'</i> -Disalicylidene-1,2-propane diamine	—	—	2.5	—	1
Anti-icing additive	98% Ethylene glycol monomethyl ether and 2% glycerol	—	—	—	—	2
Corrosion inhibitors: Apollo PRI 19	—	—	3	8	Yes	3
Conoco T 60	—	—	6	16	Yes	4
Du Pont AFA-1	—	—	4.5	12	Yes	1
Du Pont DCI-4A	—	—	3	8	Yes	1
Gulf 178	—	—	—	—	No	5
Hitec E 515	—	—	7.5	16	Yes	6

Table A1 -- Fuel Additives, Their Compositions, Allowable Concentrations, and Their Suppliers -- (Continued)

Additive	Composition	Recommended Concentration	Minimum Effective Concentration*	Maximum Allowable Concentration*	Listing on Qualified Products List†	Supplier
Lubrizol 541	—	—	3	6	Yes	7
Nalco 5400A	—	—	—	—	No	8
Nalco 5402	—	—	3	8	Yes	8
Na-Sul-LP	—	—	—	—	No	9
Tolad 244	—	—	4.5	6	No	10
Tolad 245	—	—	7.5	12	Yes	10
Unicor J	—	—	3	8	Yes	11
Thermal stability additive: Du Pont JFA-5	—	3-4	—	—	—	1
Static dissipator additives: Ethyl DCA 48	Polymeric amine salt in xylene	2	—	—	—	12
Shell ASA-3	Equal parts of chromium salt of an alkylated salicylic acid‡, calcium dioctyl sulfosuccinate, and vinyl/methacrylate polymer	0.2	—	—	—	13
Stadis 125	—	0.5-5.0	—	—	—	1
Stadis 450	—	0.1-1.0	—	—	—	1

*Ref. 7.

†Ref. 3.

‡I = E. I. du Pont de Nemours and Co., Deepwater, N.J., 2 = Phillips Petroleum Co., Bartlesville, Okla., 3 = Apollo Chemical Corp., Clifton, N.J., 4 = McNutt Industries, Oklahoma City, Okla., 5 = Gulf Oil Corp., Pittsburgh, Pa., 6 = Edwin Cooper Inc., Sauget, Ill., 7 = Lubrizol Corp., Painesville, Ohio., 8 = Nalco Chemical Corp., Sugarland, Tex., 9 = King Organic Chemicals, South Norwalk, Conn., 10 = Tretolite Division, St. Louis, Mo., 11 = UOP Process Division, McCook, Ill., 12 = Ethyl Corp., Houston, Tex., 13 = Shell Oil Co., Houston, Tex.

¶Including weight of solvent.

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The name, molecular weight, and suppliers of the petroleum sulfonates follow:

<u>Name</u>	<u>Molecular Weight</u>	<u>Supplier</u>
Acto	425	Humble*
Bryton 430	435	Bryton Chemical†
Bryton 445	450	Bryton Chemical†
Petrosul 742	423	Pennsylvania Refining‡
Petrosul 744 LC	445	Pennsylvania Refining‡
Petrosul 745	468	Pennsylvania Refining‡
Petrosul 750	513	Pennsylvania Refining‡
Purified Sulfonate	420	Chevron§

The composition of the petroleum sulfonates is—62% sulfonates (typical formula— $C_{24}H_{38}SO_3Na$), 33% mineral oil, 4.5% water, 0.5% inorganic salt.

*Humble Oil and Refining Co., Linden, N.J.
 †Bryton Chemical Corp., Saddle Brook, N.J.
 ‡Pennsylvania Refining Corp., Butler, Pa.
 §Chevron Research Co., San Francisco, Calif.