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FACTORS AFFECTING ELECTROSTATIC HAZARDS

P. W. KIRKLIN
MOBIL RESEARCH AND DEVELOPMENT CORPORATION
PAULSBORO, NEW JERSEY 08066

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DECEMBER 1978

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Final Report Period Covering April 1977 to July 1978

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Conductivity additives ASA-3 and Stadis 450 have been found to significantly reduce static electricity in JP-4 containing approved additives when fuel conductivity is at least 100 CU at use temperatures. In the absence of conductivity additives, some additives caused increased charge accumulation which may have contributed to previous static ignited aircraft fires. Tests were performed in a Mobil Research small-scale electrification unit modified to simulate USAF fueling velocities and aircraft fuel tank configurations.

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PREFACE

This project on the influence of additives on electrostatic charging was sponsored by the USAF Aero Propulsion Laboratory at Wright-Patterson Air Force Base under contract F33615-77-C-2047. Mr. C. R. Martel of the Aero Propulsion Laboratory was the USAF Project Engineer responsible for monitoring this work. His guidance and suggestions are gratefully acknowledged.

Mr. D. L. Rhynard, was the principal investigator of record for the first half of the contract work period and is credited with the design of the experimental program. Further, Mr. Rhynard served as consultant to his successor and his contribution to the successful conclusion of the project is gratefully acknowledged.

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SECTION I

INTRODUCTION

This report summarizes the investigation, "Factors Affecting Electrostatic Hazards," Contract No. F33615-77-C-2047, conducted by Mobil Research and Development Corporation (MRDC) in Paulsboro, N. J. The test program was conducted April 15, 1977 through July 15, 1978, D. L. Rhynard was the initial principal investigator and on December 1, 1978, P. W. Kirklin succeeded him as principal investigator.

Background

Since the fall of 1974, the USAF has experienced several fuel system fires believed to have been initiated by electrostatic spark discharges. The reported incidents all involved aircraft equipped with fuel tanks containing bladder cells packed with reticulated polyurethene foam. It was suspected that high fuel flow velocities, splashing and/or spraying of fuel into receiver tanks, or passage of fuel through porous media, e.g. filter-separator elements or reticulated foam could result in electrostatic charge separation in aviation turbine fuels during USAF aircraft fueling operations.

Currently, MIL-T-5624K allows for the optional use of the conductivity additive ASA-3 to minimize static charge buildup. Conductivity additives have been used for many years for static electricity protection in ground distillate fuels and commercial jet fuels, but it was not known if the AF fueling systems were conducive to the use of conductivity additive treated fuel. In the

AF system, fuel is often delivered at high velocities through restrictive nozzles into fuel tanks that may be lined with low conductivity bladder material and filled with reticulated plastic foam. If static charges are generated as fuel is delivered to the tank, the insulating properties of the foam and bladder may inhibit the ability of the anti-static additive to relax the induced electrical charge. Thus, it was considered necessary to evaluate the electrostatic hazards and additive effect in an Air Force type fueling system.

Objective

The primary objective of the MRDC contract was to provide specific information for guidance to the USAF on the use of conductivity (i.e. anti-static) additives in JP-4 fuel (MIL-T-5624K) as a means of reducing static electricity hazards throughout the ground refueling and aircraft fuel system.

The necessary research and testing were to be performed in order to determine the following:

(a) Are there additives or combinations of additives that aggravate the static spark discharge hazard?

(b) Does temperature or water content significantly change the effects of various additives or combinations so as to increase or decrease the static discharge hazard?

(c) Are there interactions among the fuels, additives, reticulated plastic foams, and fuel bladder cells that affect the static discharge hazard?

(d) Do various fuel additive combinations significantly affect fuel charging by filter-separator elements, in high velocity fuel flow streams, and at fuel discharge conditions (i.e., fuel tank inlet ports)?

(e) Can the use of conductivity additives at too low a concentration increase the electrostatic hazards?

To meet the objectives, the contract investigated the effect of conductivity additives, ASA-3 (Shell) and Stadis 450 (DuPont) on electrostatic charge generation and accumulation in JP-4 fuel with various other additives currently permitted including fuel system icing inhibitor, (FSII) (ethylene glycol monomethyl ether, MIL-I-27686), corrosion inhibitors (QPL-25017-12) and antioxidants and metal deactivators listed in MIL-T-5624K.

Test Apparatus

The primary test apparatus was the Small Scale Electrification Test (SSET) rig developed by Mobil. This device is shown schematically in Figure 1. The SSET consists primarily of a fuel supply drum, pump, separate vessels containing coalescer and separator elements and a fuel receiving vessel, each electrically isolated via Teflon blocks. In AF refueling systems, dirt and water are removed from the fuel by similar filter-separator (F/S) elements; however, these porous media can also cause significant electrostatic charging of the fuel. In the SSET studies with clean dry fuels, the F/S elements are used primarily as charging devices and are not intended to simulate DOD water and dirt removal F/S elements or USAF

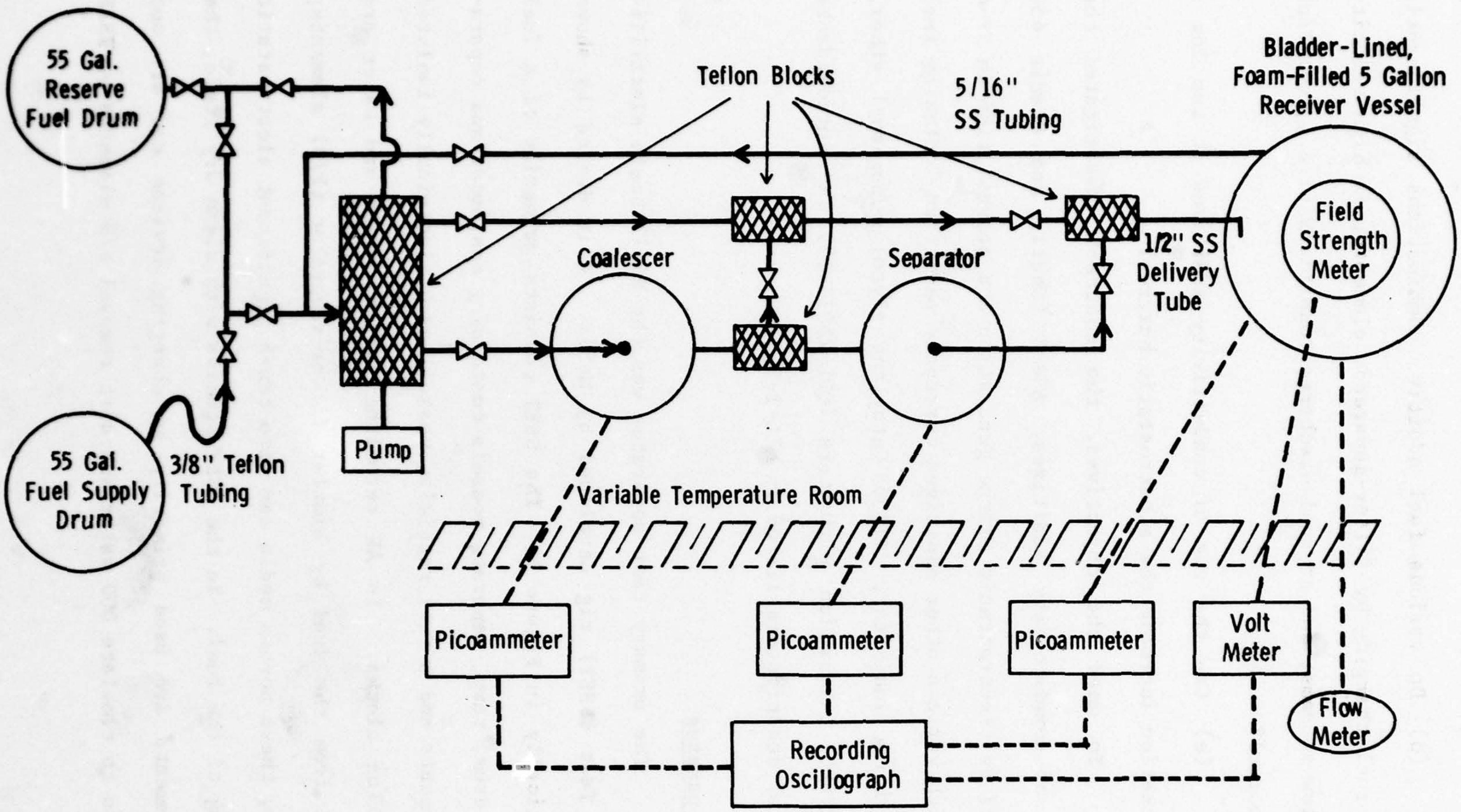


Figure 1. Block Diagram of Small Scale Electrification Test Rig

F/S practice. The SSET fuel supply, coalescer and separator vessels are interconnected by 5/16-inch (O.D.) stainless steel tubing through Teflon blocks for electrical isolation. However, the receiver fuel delivery tube is 1/2-inch (O.D.) from the Teflon block to the receiver as shown in Figure 1. Square-end orifices of either 0.10 or 0.12-inch (I.D.) can be attached to the drop tube to provide further variation of fuel linear flow velocity into the receiver. The drop tube terminates about 1 inch below the top of the receiver and about 1 inch above the fuel level at 90% full. The coalescer and separator vessels each have a net volume (total volume less the elements) of about 31.3 inches. Each contains 9 elements in parallel (Facet models CC9234 and CS9235, respectively). Fuel enters the 9 coalescer elements simultaneously through a radial distribution manifold and exits the separator elements through a similar type manifold. These manifolds are machined into the covers of the coalescer and separator vessels. Appropriate valves are provided in the SSET to allow a choice of fuel flow configurations to the receiver:

1) through the coalescer only
2) through the separator only
3) through the coalescer and separator in series
4) directly into the receiver, bypassing both coalescer and separator.

The relaxation volume for fuel from the coalescer is primarily the net vessel volume. For fuel flow through the coalescer only, the SSET relaxation volume, including tubing is 33.8 cubic inches (0.15

gal.). For fuel flow from the separator, the SSET relaxation volume is the exit tubing volume and is equal to about 1.6 cubic inches (0.007 gal.). At flow rates of 2 gallons-per-minute (gpm) these volumes allow 4.4 and 0.2 seconds, respectively, for fuel charge relaxation before entering the receiver vessel. The receiver volume is about 5.1 gal. at 90% full.

Streaming currents to ground are measured with separate Keithly Model 445 digital picoammeters at the coalescer, separator, and receiver vessels. The reported charge densities are calculated from streaming currents by:

$$C.D. = 1.585 \cdot 10^{10} \cdot A/F$$

where A is streaming current in amps and F is fuel flow rate in gpm. Field strengths are measured with a HP-400E AC voltmeter connected to a Chevron fieldmeter mounted in the cover of the receiver vessel. The polarity of the streaming currents were indicated by the picoammeters but the field strength meter noted field strength magnitude only.

For these studies, the fuel and mechanical components of the SSET were located in a temperature controlled room at 0° to 70°F. The electronic and monitoring devices, including a Bell and Howell, Datagraph 5-234 recording oscillograph, were located outside of the cold room. The connecting cables are depicted by broken lines in Figure 1.

Fuel charging effects are very sensitive to minute differences in fuels. Since the fuel effects are often unpredictable, it was desirable to use a single lot of fuel for all comparative studies. For Jet A studies, fuel from a single refinery run was clay treated and drummed. A single drum of fuel was then used for each study, no fuel was re-used in the program. Two batches of JP-4 were drummed for this study. The first batch of JP-4 was clay treated and used in studies comparing Jet A and JP-4, a single drum of fuel was used for each study. The second drummed batch of JP-4 (from a different refinery than the first) was used for additive studies in JP-4, again, a separate drum of fuel was used in each additive study.

Test Program

The test program was divided into 6 specific tasks:

1) Modification of the SSET; preliminary charging tests; determining the effect of bladder and foam on fuel electrification.
2) The temperature-charging relationships of ASA-3 in Jet A; the effect of conductivity level on charging.
3) The temperature-charging relationship of ASA-3 in JP-4; the effect of conductivity level on charging; comparison of charging tendencies of Jet A vs. JP-4.
4) The temperature-charging relationship of Stadis 450 in base fuel; the effect of conductivity level on charging.
5) Additive charging and compatibility program.
6) Correlation between SSET and another fuel-charging tendency test.

SECTION II

RESULTS

SSET Results - Procedures Development

This section presents the results of experiments performed to establish the effects of key variables in the SSET additive study program.

SSET Modifications. In Task 1, the SSET was modified to simulate the fueling flow velocities of the aircraft types that have experienced static ignitions. The pumping system was enlarged to increase the linear fuel flow velocity in the primary piping to about 20 fps. A 0.01 inch (I.D.) discharge nozzle was installed so that the fuel discharged into the reservoir at a flow velocity of about 82 fps at a 2 gpm volumetric flow rate. As a safety precaution, nitrogen inerting was installed for the tests on JP-4.

Effect of Foam and Bladder Materials on Conductivity. The fuel reservoir was fitted with a USAF-type rubber bladder liner and various reticulated foams. The USAF bladder material and reticulated foams were supplied by the USAF Project Engineer, C. R. Martel of the USAF Aero Propulsion Laboratory, Wright-Patterson AFB. Seven samples of reticulated foams and one fuel tank bladder were soaked in approximately 3 gallons of fuel, each, to determine if the fuel would leach conductive components from the bladder or foams. No significant change in fuel conductivity was observed after soaking 2 weeks in the bladder or 4 weeks with the foams. Thus, it was concluded that there would be no appreciable conductivity effect from the bladder or foam materials during the course of an individual fuel study. These results are shown in Table 1.

Effect of Foam on Field Strenth Measurements. The effect of foam on field strength measurements was investigated with the field meter calibration arrangement. Here a 300V DC voltage is impressed across two parallel metal plates 1.0 inch apart to obtain a field strength of 12 KV/m. The field meter is affixed in an opening in the upper plate. When 1.0 inch of No. 4 red polyester foam was placed between the plates, field strengths of 50 and 55 KV/m were measured with dry and fuel-wetted foam, respectively. If it is assumed that there is no charge accumulation on the foam, 12 KV/m is the expected result. If it is assumed that the foam surface accepts all the applied voltage, an infinite surface voltage is expected. This assumption and data are in Table 2. When the foam surface was lowered to 0.5 inch, a field strength of 22 KV/m was measured. This is approximately the expected field strength if the applied voltage is at the foam surface. From these data, it is apparent that the foam is being charged and is affecting the field meter results. Fine pore, blue polyether foam also accepted the applied voltage but more slowly than the No. 4 red polyester foam. Further studies with No. 4 red polyester foam and fine pore blue polyether foam appear in a later section of this report.

TABLE 1

EFFECT OF FOAM & BLADDER ON FUEL CONDUCTIVITY

Pail No.	Designation	Initial	Conductivity (CU) After Indicated Storage Time 24 Hrs	1-Wk	2-Wk	3-Wk	4-Wk
10	Jet A Base Fuel #1	2.2	2.4	1.7	1.6	-	-
11	Base Fuel #1 + Fuel Tank Bladder*	3.0	3.7	1.7	2.5	-	-
1	Jet A Base Fuel #2	1.2	2.9	3.0	2.5	1.9	1.5
2	Jet A Base Fuel #2	1.3	2.9	2.4	1.4	1.0	1.0
3	Base Fuel #2 + F-5 Foam #1, Yellow, Medium Pore	4.7	3.2	2.6	1.9	2.3	1.8
5	Base Fuel #2 + Polyester Foam 3, Pink, Fine Pore	2.9	3.8	3.3	2.9	2.6	2.9
6	Base Fuel #2 + Used Polyester Foam 3, Pink, Fine Pore	2.7	3.1	2.9	2.5	3.0	4.7
7	Base Fuel #2 + A-10 F-15 #4, Red Polyester, Fine Pore	2.3	2.3	1.9	1.3	1.3	1.0
4	Base Fuel #2 + New Polyether Foam 2, Blue, Coarse Pore	3.2	4.7	5.2	5.4	5.6	5.7
8	Base Fuel #2 + New X5 Polyether Foam 2, Blue, Coarse Pore	3.3	4.9	5.6	5.9	6.4	6.4
9	Base Fuel #2 + Polyether #6, Orange, Medium Pore	3.3	5.0	6.0	5.9	4.3	4.0

*Uniroyal Type US-566-RL (nitrile fabric)

TABLE 2

EFFECT OF RETICULATED FOAM ON FIELD STRENGTH MEASUREMENTS

Air Gap Filler*	Measured Field Strength, KV/m	Calculated Field Strength from Foam Surface
None	12	-
0.5 inch No. 4, Red Polyester Foam, Dry	22	24
1.0 inch No. 4, Red Polyester Foam, Dry	55	∞
1.0 inch No. 4, Red Polyester Foam, Jet A Soaked	50	∞
0.75 inch Blue, Fine Pore Polyether Foam, Dry	29 (After 2.5 min.)	48

*300 vdc applied across 1 inch gap.

Effect of No. 4, Red Polyester Foam. This section focuses on specific foam effects but considers only No. 4 red polyester foam.

- Charge Generation and Accumulation: When fuel is dispensed from the drop tube into the receiver, in the absence of reticulated foam, severe fuel frothing occurs. This causes erratic field strength readings at about 75% full (and above) when the froth begins to contact the meter. Therefore, to avoid this problem and compare fuel charging effects with and without foam (No. 4 red polyester foam) and bladder, comparisons were made at 70% full. These data are summarized in Tables 3 and 4. Charge densities are calculated from streaming currents measured from the coalescer, separator and receiving vessels. Because these components are electrically isolated from each other, the charge densities reported in Tables 3 and 4 show no effects for foam and bladder in the receiver which is down stream from the detection point. Field strengths are assumed to be measures of charge accumulation in the receiver vessel. Generally, highest field strengths are obtained with fuel flow through the coalescer. In general, the foam and bladder have little effect on charge accumulation.

- Charge Relaxation: Fifty percent charge relaxation times are related to the effective fuel conductivity, k. This is obtained from the relation:

$$E_t = E_o \exp - (k\ t/\varepsilon\varepsilon_o)$$

where E_o and E_t are field strengths at time equal o and t seconds, respectively. ε_o is the absolute dielectric constant of a vacuum

(8.854 pA sec/V m) and ε is the dimensionless relative dielectric constant (equal to 2.0 for most hydrocarbon liquids). The effective conductivity in terms of the 50 percent relaxation time, $t_{1/2}$ is:

$$k(CU) = 12.27 / t_{1/2}$$

with dimension of k in conductivity units, CU, equivalent to units of picosiemens/m. Effective conductivity vs. rest conductivity differences would be of interest in distinguishing effects of different conductivity additives. Unfortunately, these fuels generally had fifty percent relaxation times of 1-2 seconds, or less, which could not be measured with better precision using the conventional methods of this study. Therefore, although static conductivities of nominal 100 CU generally yielded experimental $t_{1/2}$ of about 1 second, the resultant maximum effective conductivities of 12 CU are apparently too low and too insensitive to distinguish between additives.

At nominal 80°F, the data of Table 3 indicate that neither the flow configuration or the presence of No. 4, red polyester foam and bladder have a measurable effect on charge relaxation. At 25°F, charge relaxation times are longer than at 80°F and according to the data of Table 4, the foam and bladder result in apparent increases in fifty percent relaxation times of 400-900%. (Separate data were not obtained with bladder only or foam only at this temperature.) If charge relaxation were truly much longer with this foam and bladder, much greater charge accumulations should also occur. Since this was not observed, it is assumed that reticulated foam holds the charge giving an indicated

TABLE 3

EFFECT OF FOAM AND BLADDER ON SSET CHARGING PARAMETERS AT NOMINAL 80°F

Fuel Flow Configuration	w/o Foam* or Bladder: Charge Density, μC/m³	w/o Foam* or Bladder: Field Strength, KV/m	w/o Foam* or Bladder: 50% Charge Relaxation Time, Sec.	w/Foam* and Bladder: Charge Density, μC/m³	w/Foam* and Bladder: Field Strength, KV/m	w/Foam* and Bladder: 50% Charge Relaxation Time, Sec.
Through Coalescer						
Coalescer	+126	-	-	+130	-	-
Receiver	-114	60	9	-118	57	8
Through Separator						
Separator	-54	-	-	-47	-	-
Receiver	+41	54	8	+26	7	8
Through Coalescer and Separator						
Coalescer	+159	-	-	+105	-	-
Separator	-102	-	-	-83	-	-
Receiver	-48	108	8	-21	6	8
Through By-Pass						
Receiver	+3	14	7	-6	15	8

*No. 4, Red Polyester Foam

TABLE 4

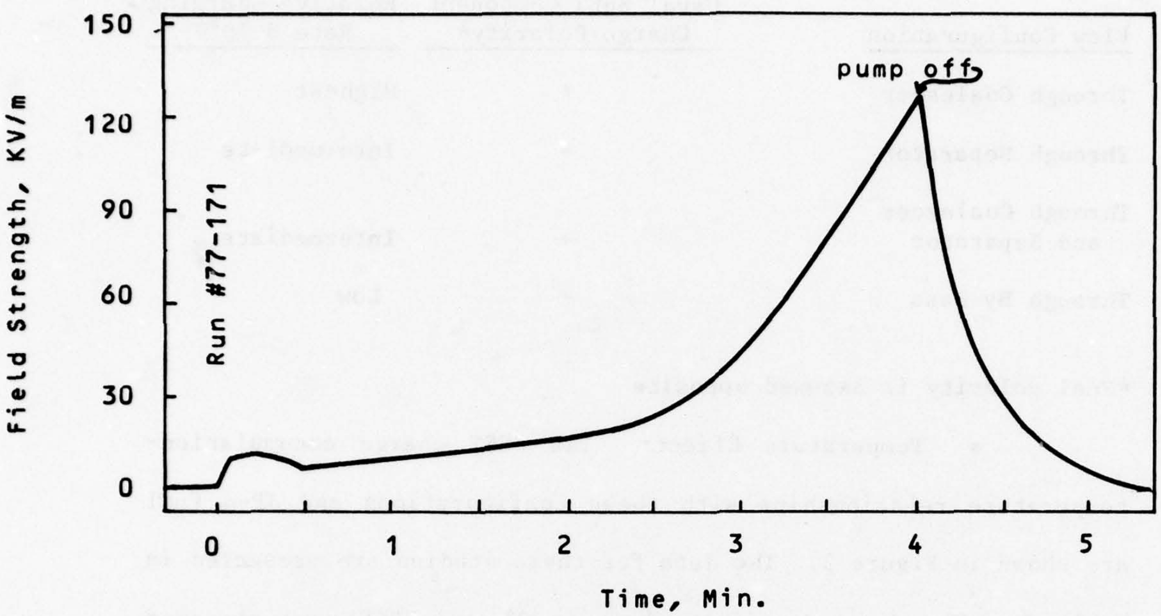
EFFECT OF FOAM AND BLADDER ON SSET CHARGING PARAMETERS AT NOMINAL 25°F

	w/o Foam* or Bladder			w/Foam* and Bladder		
Fuel Flow Configuration	Charge Density, μC/m3	Field Strength, KV/m	50% Charge Relaxation Time, Sec.	Charge Density, μC/m3	Field Strength, KV/m	50% Charge Relaxation Time, Sec.
Through Coalescer						
Coalescer	+61	-	-	+59	-	-
Receiver	-81	136	21	-71	176	128
Through Separator						
Separator	-46	-	-	-45	-	-
Receiver	+23	30**	11	+20	44	104
Through Coalescer and Separator						
Coalescer	+49	-	-	+53	-	-
Separator	-53	-	-	-44	-	-
Receiver	-20	71	16	-21	32	73
Through By-Pass						
Receiver	-19	50	15	-17	24	55

*No. 4, Red Polyester Foam
**Erratic Results: data varied from 6-58 KV/m

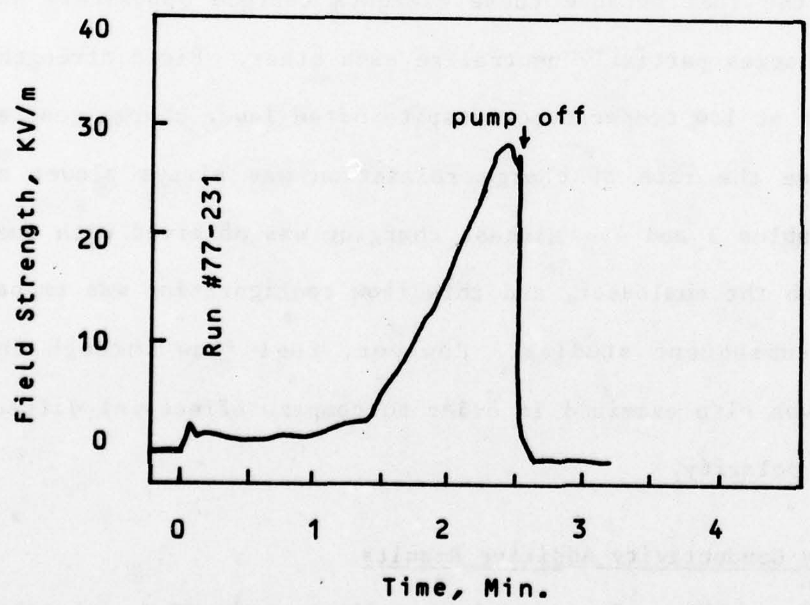
high field strength reading, while the bulk of the charge bleeds from the fuel as usual. Thus, the height of the reticulated foam in the SSET will affect the apparent field strength measurement. Typical experimental field strength recordings at two different foam heights are shown in Figure 2. Here fuel flow is through the coalescer and the receiver is lined with bladder and filled with No. 4 red polyester foam (red foam). With foam height equal to the fuel level at end-of-test, lower end-of-test field strengths are noted compared to foam height 1/2-inch above the final fuel level. Also, at end-of-test, the charge relaxes to negligible charge faster with fuel level at or above the foam surface compared to fuel level below the foam surface. These results further support the earlier assumption that the foam surface tends to become charged and the charge is relaxed more slowly from the foam than from the bulk fuel. In subsequent SSET studies, the height of the reticulated foams was cut to correspond to the final fuel level in order to minimize the foam effects on the SSET field strengths and relaxation times.

- Charge Polarity: Charge polarity was deduced from the observed sign of the streaming current from the respective electrically isolated SSET component. It was assumed that the resultant fuel polarity is opposite to that of the measured SSET component. The usual charge characteristics for the various SSET flow configurations are as follows:



No. 4 Red Foam Level About 1/2" Above Final Fuel Level

Fuel Velocity = 52 fps



No. 4 Red Foam Level Equal to Final Fuel Level

Fuel Velocity = 82 fps

Figure 2. Effect of No. 4 Red Foam Level on Field Strength Measurements

Flow Configuration	Usual SSET Component Charge Polarity*	Relative Charging Rate @ 70°F
Through Coalescer	+	Highest
Through Separator	-	Intermediate
Through Coalescer and Separator	+	Intermediate
Through By-Pass	-	Low

*Fuel polarity is assumed opposite

- Temperature Effect: The SSET charge accumulation-temperature relationships with these configurations and JP-4 fuel are shown in Figure 3. The data for these studies are presented in Table 5. The largest effects between 0° and 70°F were observed with fuel flow through the coalescer elements. Fuel flow through the combination of coalescer and separator imparted an intermediate charge to the fuel because these elements charged oppositely and thus the charges partially neutralize each other. Field strengths were higher at low temperatures despite often lower charge generation because the rate of charge relaxation was always slower as shown in Tables 3 and 4. Highest charging was observed with fuel flow through the coalescer, and this flow configuration was emphasized in subsequent studies. However, fuel flow through the separator was also examined in order to compare effects of different charge polarity.

Preliminary Conductivity Additive Results

The effect of conductivity additives in JP-4 and Jet A was investigated in Tasks 2, 3, and 4. Physical properties of the two fuels are listed in Table 6. The field strength results

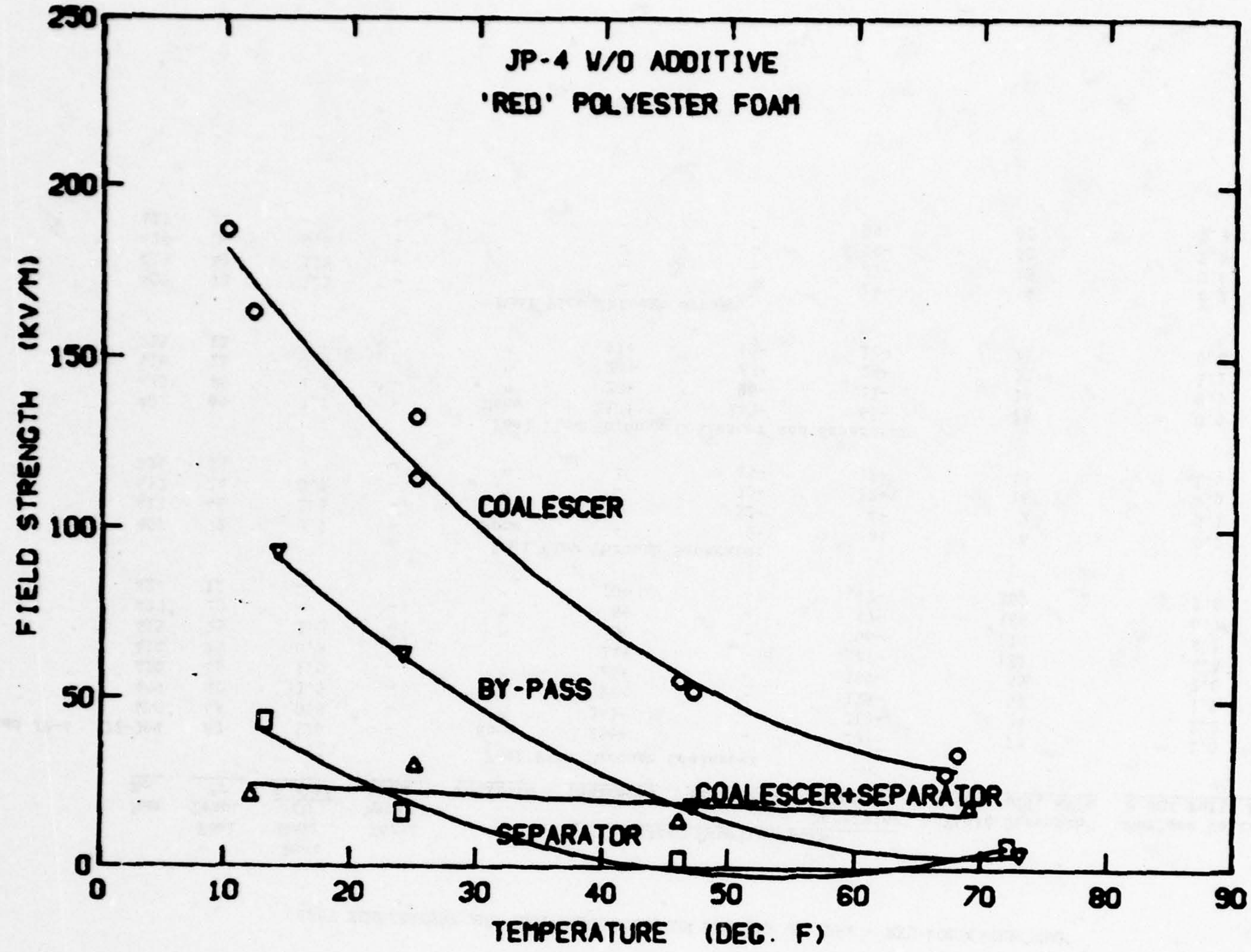


FIGURE 3. EFFECTS OF SSET FLOW CONFIGURATION

TABLE 5

SSET TEMPERATURE AND TEST CONFIGURATION RESULTS ON JP-4 - RED POLYESTER FOAM

Fuel	Run No.	Fuel Temp. °F	Rest Cond. CU D 3114	Total Water, ppm	Additive	Charge Density, $\mu C/m^3$ Coalescer	Separator	Receiving Vessel	Field Strength @ 90% Full, KV/m	Surface Voltage @ 90% Full, KV	50% Charge Relaxation Time, Sec.
					Fuel Flow Through Coalescer						
Clay Treated JP-4	77-399	67	1.0	-	None	256+	-	231-	28	1.0	4
B77-2, D1	400	68	0.8	-	"	241+	-	213-	34	1.2	5
	409	47	1.5	-	"	28+	-	115-	52	1.9	4
	410	46	1.5	-	"	26+	-	109-	55	2.0	4
	414	25	0.8	-	"	24+	-	87-	132	4.8	21
	415	25	1.0	-	"	10+	-	66-	114	4.1	20
	423	10	-	-	"	6+	-	47-	186	6.7	102
	424	12	-	-	"	10+	-	42-	162	5.8	82
					Fuel Flow Through Separator						
	402	72	1.2	-	None	-	6-	8+	6	0.2	5
	412	46	1.5	-	"	-	52-	4+	2	0.1	7
	417	24	0.9	-	"	-	70-	12+	16	0.6	19
	426	13	-	-	"	-	45-	8+	43	1.5	64
					Fuel Flow Through Coalescer and Separator						
	401	69	1.1	-	None	217+	143-	66-	18	0.6	4
	411	46	1.5	-	"	20+	96-	11-	14	0.5	4
	416	25	0.8	-	"	20+	88-	24-	30	1.1	20
	425	12	-	-	"	11+	59-	12+	21	0.8	75
					Fuel Flow Through Bypass						
	403	73	1.1	-		-	-	4-	4	0.1	2
	413	47	1.2	-		-	-	22-	18	0.6	7
	418	24	0.8	-		-	-	29-	62	2.2	33
	427	14	-	-		-	-	29-	92	3.3	34

TABLE 6

PROPERTIES OF SSET TEST FUELS

Properties	Jet A	JP-4
Gravity, °API	46.9	53.5
Distillation, °F		
IBP	325	133
10%	348	190
20%	357	214
50%	385	306
90%	467	441
E.P.	536	475
Hydrocarbon Type		
Aromatics, % Vol.	19.8	12.3
Vapor Pressure, lbs.	-	2.3
Flash Point, °F	125	-
Freeze Point, °F	-44	<-60
Viscosity @ -30°F	5.88	2.28
Existent Gum mg/1	0	0
Sulfur, % Wt.	-	0.079
Mercaptan Sulfur, ppm	-	7

of JP-4 and Jet A with ASA-3 at 65° and 85°F, respectively, with red foam and fuel flow through the coalescer are shown in Figure 4. These data are presented in Table 7. Charge accumulation, i.e. field strength, at 65° and 85°F decreased rapidly as fuel conductivity increased from the 1-2 CU of non-additized fuel to 5-10 CU. Increasing conductivity further caused an additional small decline in charge accumulation. JP-4 and Jet A responded similarly to increases in fuel conductivity at ambient temperature.

The effect of charge accumulation with temperature was examined for JP-4 and Jet A without additive and with each fuel additized to nominal 100 CU at 70°F with ASA-3. These results with red foam and fuel flow through the coalescer are shown in Figure 5. Both fuels accumulated charge similarly at room temperature. At low temperatures with fuel flow through the coalescer, JP-4 (solid line) base fuel charged significantly higher than Jet A (broken line) base fuel. However, with ASA-3 dosage to achieve 100 CU at 70°F, charge accumulation at low temperatures was considerably lower with JP-4 than Jet A. The data for these Jet A and JP-4 studies are presented in Table 8 and Table 9, respectively. From the data it is apparent that the differences between JP-4 and Jet A charging at low temperatures are not due to differences in fuel conductivity. Low temperature fifty percent charge relaxation times and charge accumulations (i.e. field strengths) tend to be higher for unadditized JP-4 than unadditized Jet A, while ASA-3 significantly reduced fifty percent charge relaxation times and field strengths in both fuels. These parameters tended to be lower

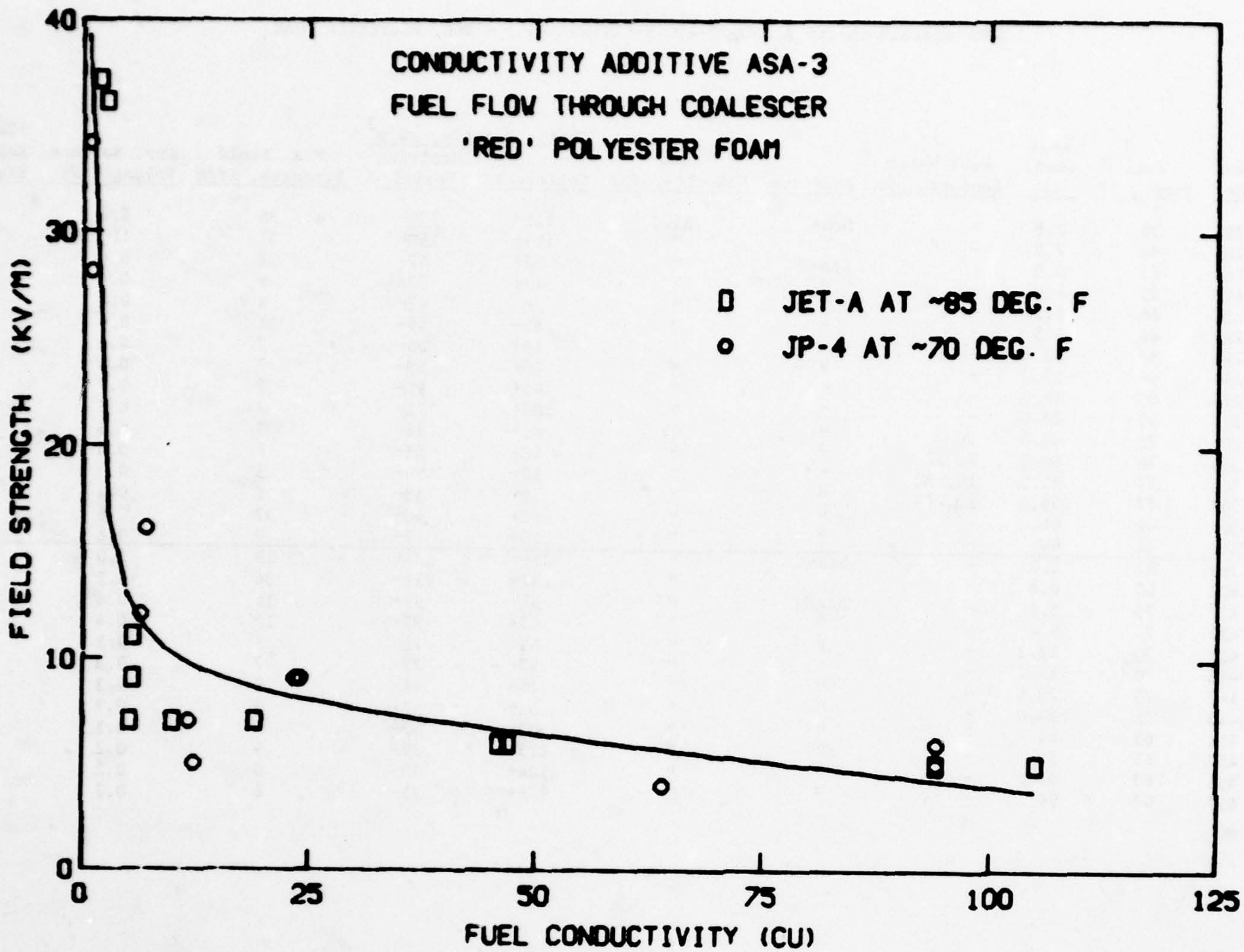


FIGURE 4. EFFECT OF FUEL CONDUCTIVITY ON CHARGE ACCUMULATION

TABLE 7

SSET RESULTS ON JET A AND JP-4 CONTAINING ASA-3 - RED, POLYESTER FOAM

Fuel	Run No.	Fuel Temp., °F	Rest Cond. CU	Fuel Water Content, ppm	Additive	Flow Velocity, fps	Charge Density, $\mu C/m^3$ Coalescer	Charge Density, $\mu C/m^3$ Receiving Vessel	Max. Field Strength, KV/m	Max. Surface Voltage, KV	50% Charge Relaxation Time, Sec.
Clay Treated	77-284	84	2.8	-	None	81.7	111+	139-	36	1.4	9
Jet A, B77-1,	285	84	2.0	-	"	"	115+	150-	37	1.3	9
D-7	286	85	5.3	-	ASA-3	"	67+	42-	7	0.4	6
"	287	85	5.6	-	"	"	40+	32-	9	0.4	9
"	288	86	5.5	-	"	"	-	47-	9	0.4	6
"	289	86	5.5	-	"	"	63+	49-	11	0.4	6
"	294	88	10.5	-	"	"	69+	55-	7	0.4	4
"	295	88	10.0	-	"	"	66+	53-	7	0.4	3
"	296	89	19.0	-	"	"	103+	91-	7	0.7	3
"	297	89	19.0	-	"	"	103+	71-	7	0.7	4
"	302	76	47.0	36	"	"	65+	58-	6	0.4	3
"	303	76	46.0	7, 12	"	"	63+	58-	6	0.4	2
"	304	77	94.0	10, 30	"	"	10+	54-	5	0.3	2
"	305	77	105.0	10, 14	"	"	10+	53-	5	0.4	2
"	309	44	64	-	"	"	42+	40-	7	0.6	3
"	310	44	64	-	"	"	53+	42-	7	0.6	3
Clay Treated	399	67	1.0	-	None	"	256+	231-	28	1.0	4
JP-4 B77-2,	400	68	0.8	-	"	"	241+	213-	34	1.2	5
D1	428	73	8.0	-	ASA-3	"	51+	97-	16	0.6	7
"	429	73	6.4	-	"	"	55+	87-	12	0.4	7
"	437	70	12.3	-	"	"	51+	73-	5	0.2	2
"	438	70	11.7	-	"	"	47+	73-	7	0.3	2
"	442	75	23.4	-	"	"	25+	91-	9	0.3	2
"	443	75	24.0	-	"	"	33+	97-	9	0.3	2
"	451	65	64	-	"	"	103+	82-	4	0.1	2
"	452	65	59	-	"	"	113+	79-	5	0.2	2
"	456	67	94	-	"	"	104+	70-	5	0.2	2
"	457	67	94	-	"	"	106+	75-	6	0.2	2

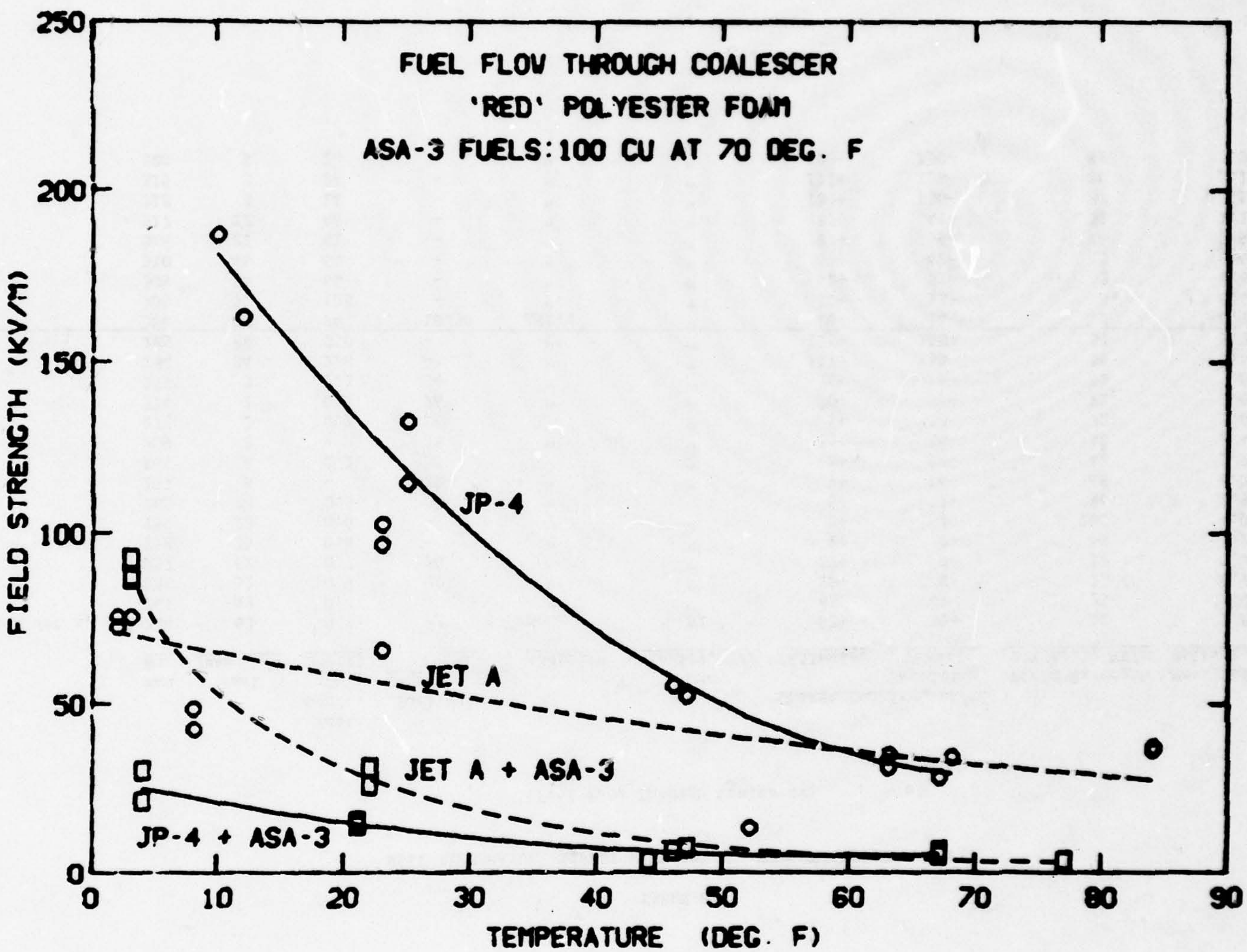


FIGURE 5. COMPARISON OF JET-A AND JP-4 CHARGE ACCUMULATION

TABLE 8

SSET TEMPERATURE EFFECT WITH JET A - RED, POLYESTER FOAM

(Fuel Flow Through Coalescer)

Fuel	Run No.	Fuel Temp., °F	Rest Cond., CU D 3114	Fuel Water Content, ppm Total	Additive	Flow Velocity, fps	Charge Density, μC/m³ Coalescer	Charge Density, μC/m³ Receiving Vessel	Field Strength 90% Full, KV/m	Max. Surface Voltage, KV	50% Charge Relaxation Time, Sec.
Clay Treated Jet A, D77-1, D7	77-244	63	0.9	-	None	82	63+	36-	31	1.8	5
	245	63	0.8	-	"	"	63+	47-	35	2.8	7
	256	52	0.9	30	"	"	26+	8-	13	0.9	9
	257	52	0.7	30	"	"	27+	9-	13	0.9	5
	258	23	0.6	-	"	"	8+	2-	69	3.2	23
	259	23	0.6	-	"	"	8+	2-	102	4.0	44
	260	23	0.5	30	"		6+	2-	96	3.9	4
	267	8	-	12	"	"	9+	16-	48	2.0	4
	268	8	0.2	15	"	"	8+	18-	42	1.7	4
	269	8	-	15	"	"	13+	16-	48	2.4	48
	273	2	0.2	26	"	"	5+	13-	72	3.0	48
	274	2	0.2	26	"	"	20+	5-	75	3.0	64
	275	3	0.2	34	"	"	20+	5-	75	3.0	76
	284	84	2.8	-	"	"	111+	139-	36	1.4	9
	285	84	2.0	-	"	"	115+	150-	37	1.3	9
	304	77	94	10,30	ASA-3	"	10+	54-	3	0.3	2
	305	77	105	-	"	"	10+	53-	3	0.4	2
	309	44	64	-	"	"	42+	51-	3	0.6	3
	310	44	64	-	"	"	53+	42-	3	0.6	3
	316	22	41	-	"	"	87+	59-	26	0.9	3
	317	22	44	-	"	"	87+	41-	31	1.1	3
	318	3	24	-	"	"	124+	130-	87	3.1	4
	319	3	26	-	"	"	111+	126-	86	3.1	4
	320	3	24	-	"	"	103+	150-	92	3.3	3

TABLE 9

SSET TEMPERATURE EFFECTS WITH JP-4 - RED, POLYESTER FOAM

(Fuel Flow Through Coalescer)

Fuel	Run No.	Fuel Temp., °F	Rest Cond CU D 3114	Water, ppm Total	Additive	Flow Velocity, fps	Charge Density, μC/m³ Coalescer	Charge Density, μC/m³ Receiving Vessel	Field Strength @ 90% Full, KV/m	Surface Voltage @ 90% Full, KV	50% Charge Relaxation Time, Sec.
Clay Treated, JP-4	77-399	67	1.0	-	None	82	256+	231-	28	1.0	4
B77-2, D1	400	68	0.8	-	"	"	241+	213-	34	1.2	5
	409	47	1.5	-	"	"	28+	115-	52	1.9	4
	410	46	1.5	-	"	"	26+	109-	55	2.0	4
	414	25	0.8	-	"	"	24+	87-	132	4.8	21
	415	25	1.0	-	"	"	10+	66-	114	4.1	20
	423	10	-	-	"	"	6+	47-	186	6.7	102
	424	12	-	-	"	"	10+	42-	162	5.8	83
	456	67	94	-	ASA-3	"	104+	70-	5	0.2	2
	457	67	94	-	"	"	106+	75-	6	0.2	2
	466	46	64	-	"	"	85+	52-	6	0.2	1
	467	47	64	-	"	"	75+	44-	7	0.3	2
	471	21	30	-	"	"	55+	41-	15	0.5	3
	472	21	35	-	"	"	45+	40-	14	0.5	3
	480	4	18	-	"	"	27+	51-	21	0.8	4
	481	4	18	-	"	"	25+	59-	30	1.1	5
	494	25	(180)*	-	ASA-3	"	51+	71-	10	0.4	2
	495	25	170	-	"	"	50+	65-	8	0.3	2
	485	6	94	-	"	"	32-	81-	24	0.9	2
	486	6	105	24	"	"	31-	92-	24	0.9	2

*ASTM D 2624

for JP-4 than Jet A. The sensitivity of the fuel response to the conductivity additive may depend upon the micro and macro composition and characteristics of the particular fuel, the SSET flow configuration (as it effects charge magnitude and polarity), or the nature of the foam.

The effect of SSET flow configuration with JP-4 was investigated (with red foam) with base fuel, and base fuel additized to 100 CU at 70°F and at 0°F with ASA-3 and Stadis 450. Results of fuel flow through the coalescer are presented in Figure 6 (and Table 9) for ASA-3 and Figure 7 (and Table 10) for Stadis 450. ASA-3 effectively reduces JP-4 charge accumulation down to 3°F, or lower, with either dosage. However, Stadis 450 is ineffective at low temperatures with red foam and this fuel flow configuration (Figure 7). Fuel additized to 100 CU at 70°F with Stadis 450 is pro-static, i.e. accumulates more charge than base fuel, when the temperature is decreased below about 13°F. This fuel had conductivity of 32 CU at 19°F. At 0°F, fuel additized to conductivity of 100 CU at 0°F with Stadis 450 accumulated about the same charge as base fuel with fuel flow through the coalescer.

Fuel flow through the separator charges fuel to opposite polarity compared to the coalescer and generally to lower charge magnitude. Results with red foam and with fuel flow through the separator are shown in Figure 8 (and Table 11) for ASA-3 and Figure 9 (and Table 10) for Stadis 450. With this SSET fuel flow configuration, ASA-3 usage at a concentration to provide 100 CU at 70°F is not effective below about 40°F (Figure 8) but Stadis 450 usage to provide similar conductivity at 70°F (Figure 9) does control

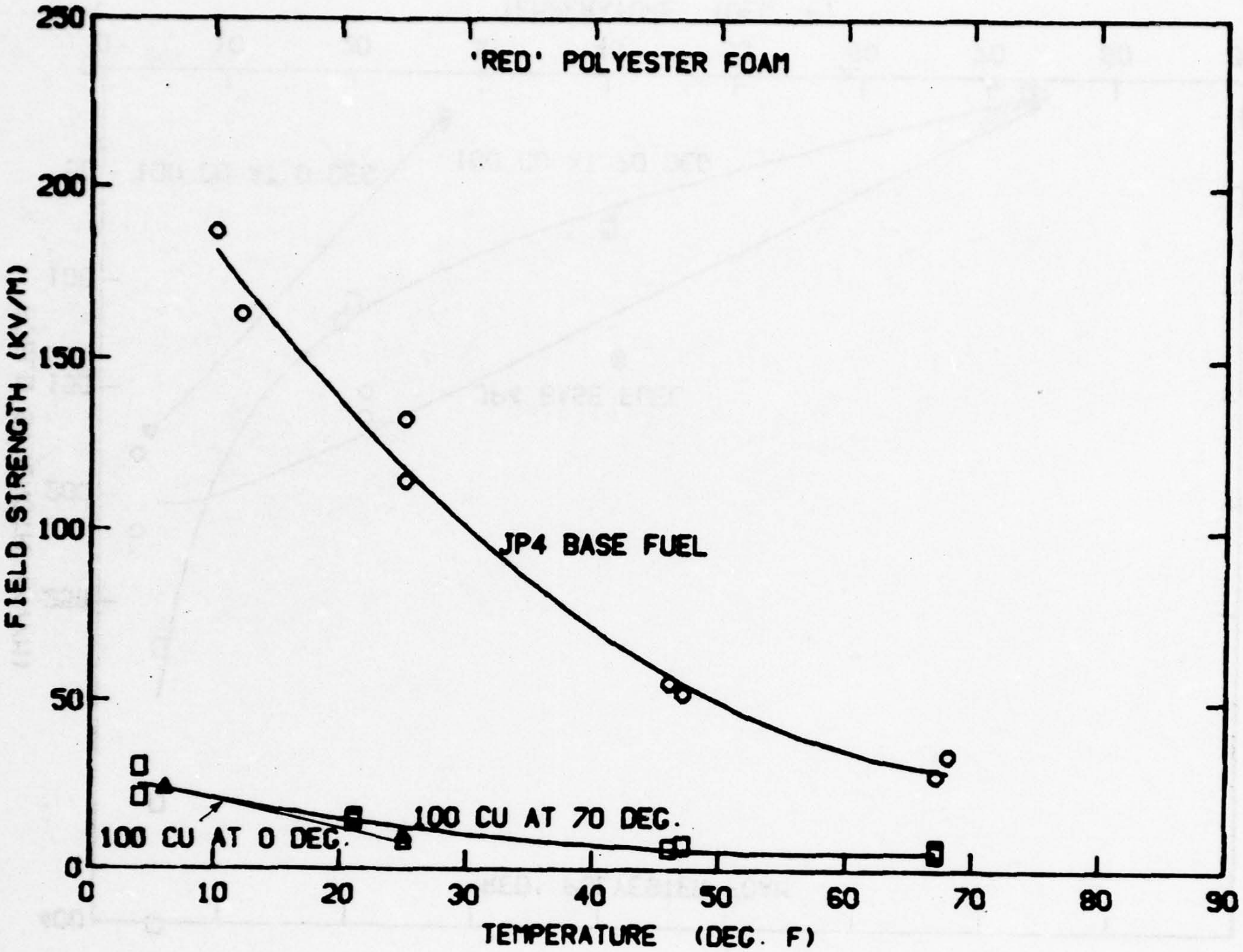


FIGURE 6. EFFECT OF ASA-3 ON JP-4 WITH FUEL FLOW THROUGH COALESCER

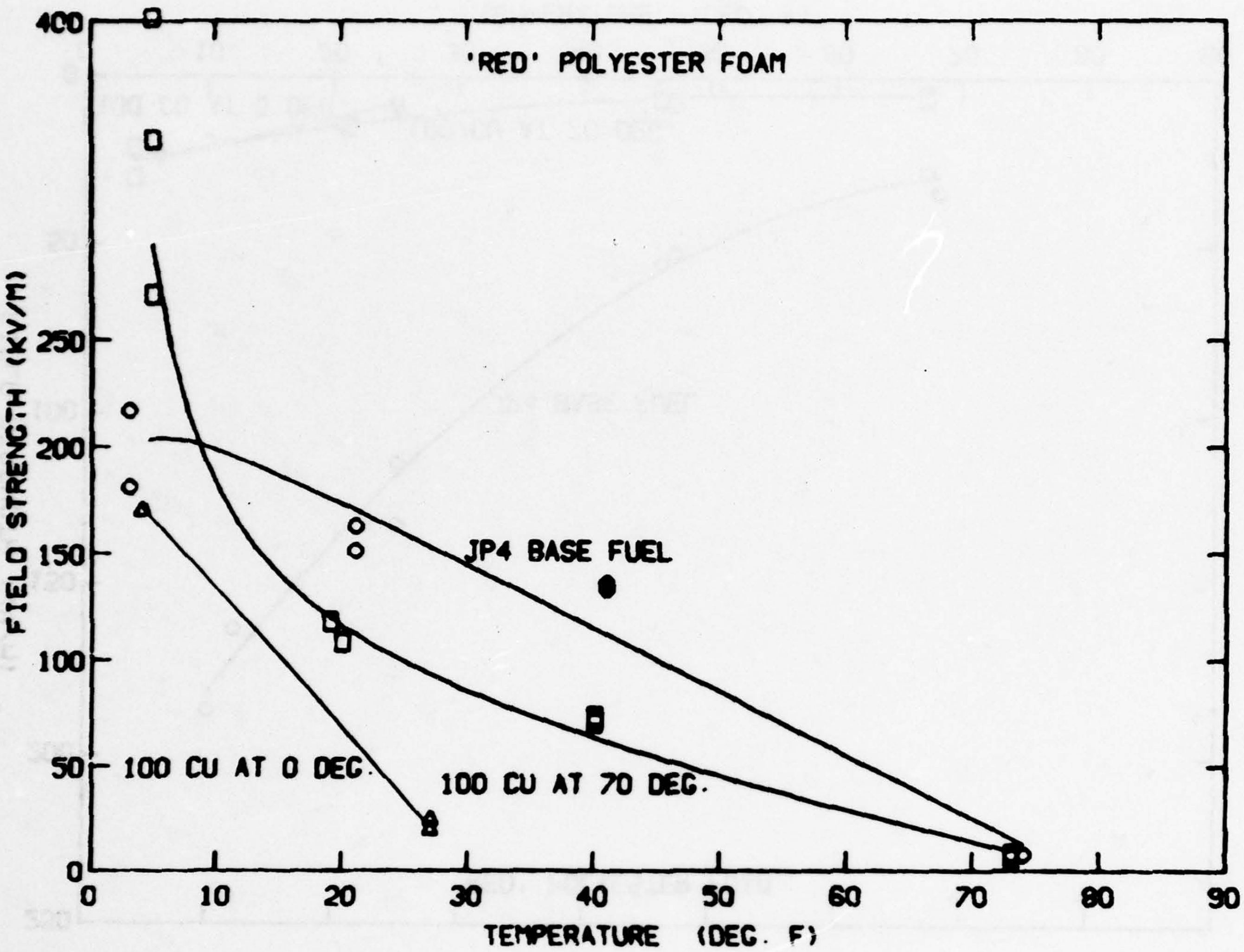


FIGURE 7. EFFECT OF STADIS 450 ON JP-4 WITH FUEL FLOW THROUGH COALESCER

TABLE 10

SSET RESULTS - JP-4 W/STADIS 450 - RED POLYESTER FOAM

Fuel	Run No.	Temp. °F	Rest Conductivity, CU D 3114	Rest Conductivity, CU D 2624	Total Water, ppm	Additive	Charge Density, $\mu C/m^3$ Coalescer	Charge Density, $\mu C/m^3$ Separator	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full, KV/m	Surface Voltage @ 90% Full, KV	50% Charge Relaxation Time, Sec.
						Fuel Flow Through Coalescer						
Clay Treated JP-4	77-508	73	1.9	-	78	None	174+	-	109-	7	0.3	3
B77-2, D3	509	74	1.9	-	82	"	167+	-	111-	7	0.3	3
	513	41	1.0	-	68	"	126+	-	111-	132	4.8	25
	514	41	0.9	-	48	"	129+	-	109-	135	4.9	24
	522	21	0.9	-	80	"	66+	-	58-	162	5.8	52
	523	21	1.0	-	-	"	65+	-	63-	150	5.4	39
	527	3	0.6	-	56	"	47+	-	47-	216	7.8	37
	528	3	0.6	-	32,36	"	41+	-	47-	180	6.5	43
	570	73	105	100	38	Stadis 450	191+	-	108-	6	0.2	2
	571	73	105	100	38	"	194+	-	111-	8	0.3	2
	575	40	44	40	44,60	"	295+	-	246-	70	2.5	3
	576	40	47	44	-	"	294+	-	245-	73	2.6	3
	585	20	34	-	52	"	321+	-	282-	108	3.9	4
	586	19	32	-	-	"	325+	-	293-	117	4.2	5
	590	5	23	28	48	"	176+	-	215-	168	6.0	4
	591	5	23	30	32	"	183+	-	179-	270	9.7	4
	592	5	23	28	-	"	182+	-	182-	342	12.3	3
	593	5	-	-	-	"	196+	-	199-	400	14.4	4
	616	27	110	130	42,48	"	336+	-	186-	20	0.7	2
	617	27	110	130	50,50	"	352+	-	194-	25	0.9	2
	609	4	105	120	52	"	363+	-	229-	170	6.1	2
	610	4	94	110	-	"	370+	-	235-	170	6.1	2
						Fuel Flow Through Separator						
	511	75	1.9	-	-	None	-	43-	73+	12	0.4	1
	516	40	1.0	-	-	"	-	64-	77+	97	3.5	23
	525	21	1.1	-	50	"	-	60-	56+	141	5.1	42
	531	4	1.0	-	-	"	-	55-	48+	180	6.5	108
	573	72	111	100	-	Stadis 450	-	31-	81+	9	0.3	2
	578	40	46	-	38	"	-	79-	88+	8	0.3	3
	588	19	34	-	-	"	-	98-	85+	6	0.2	7
	595	5	23	26	32	"	-	84-	59+	84	3.0	3
	619	27	-	-	-	"	-	24-	35+	1	0.04	-
	612	4	-	130	-	"	-	32-	17+	18	0.6	2

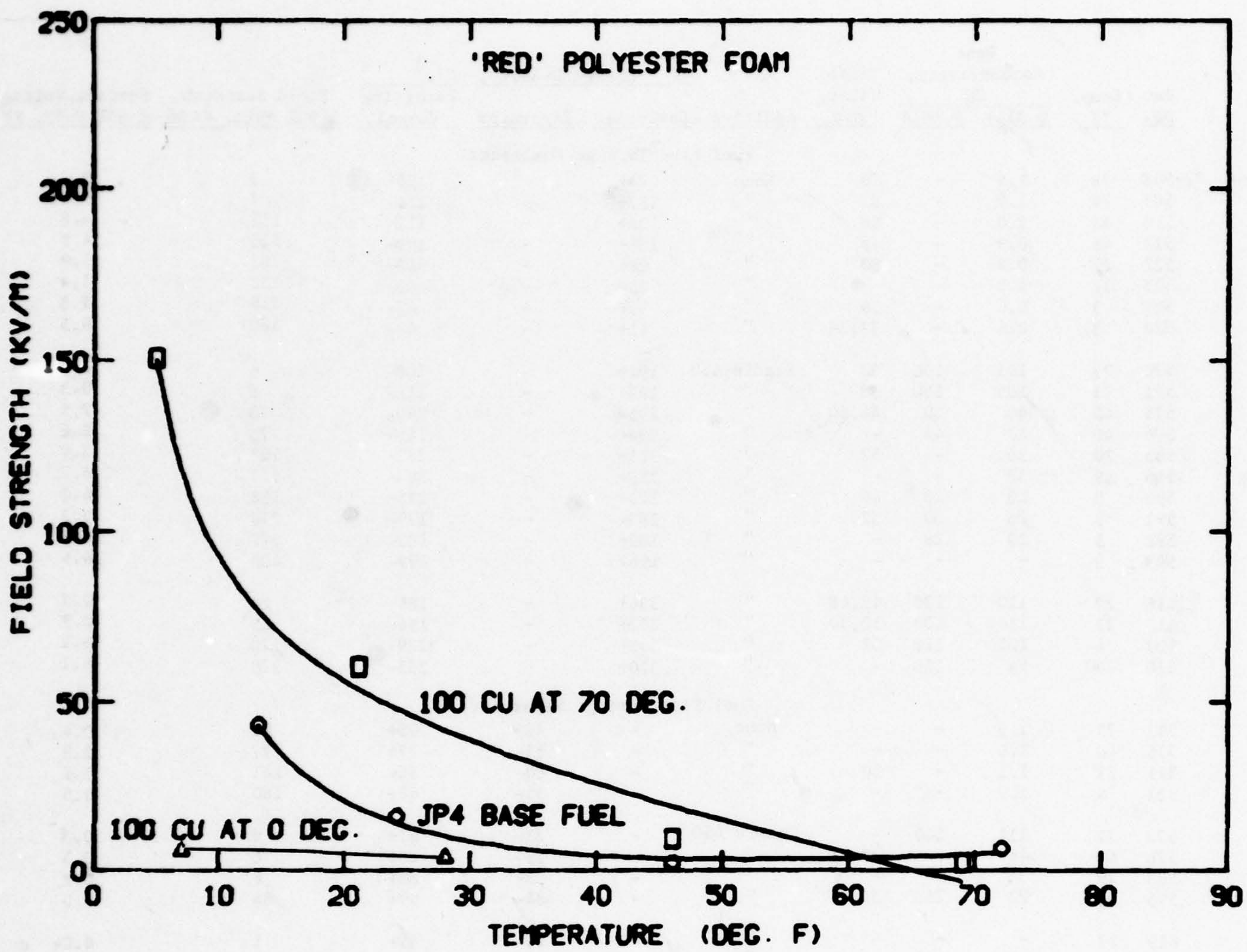


FIGURE 8. EFFECT OF ASA-3 ON JP-4 WITH FUEL FLOW THROUGH SEPARATOR

TABLE 11

SSET RESULTS - JP-4 W/ASA-3 - RED, POLYESTER FOAM

(Fuel Flow Through Separator)

Fuel	Run No.	Fuel Temp., °F	Rest Cond. CU D 3114	Water, ppm Total	Additive	Charge Density, $\mu C/m^3$ Coalescer	Charge Density, $\mu C/m^3$ Separator	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full, KV/m	Surface Voltage @ 90% Full, KV	50% Charge Relaxation Time, Sec.
Clay Treated, JP-4	77-402	72	1.2	-	None	-	6-	8+	6	0.2	5
B77-2, D1	412	46	1.5	-	"	-	52-	4+	2	0.1	7
	417	24	0.9	-	"	-	70-	12+	16	0.6	19
	426	13	-	-	"	-	45-	8+	43	1.5	64
	459	69	105	-	ASA-3	-	51-	71+	2	0.07	2
	469	46	76	-	"	-	115-	147+	9	0.3	2
	474	21	38	-	"	-	269-	273+	60	2.2	3
	484	5	19	-	"	-	304-	300+	150	0.2	4
	497	28	-	-	ASA-3	-	82-	25+	4	0.1	2
	488	7	105	38	"	-	31-	21+	6	0.2	2

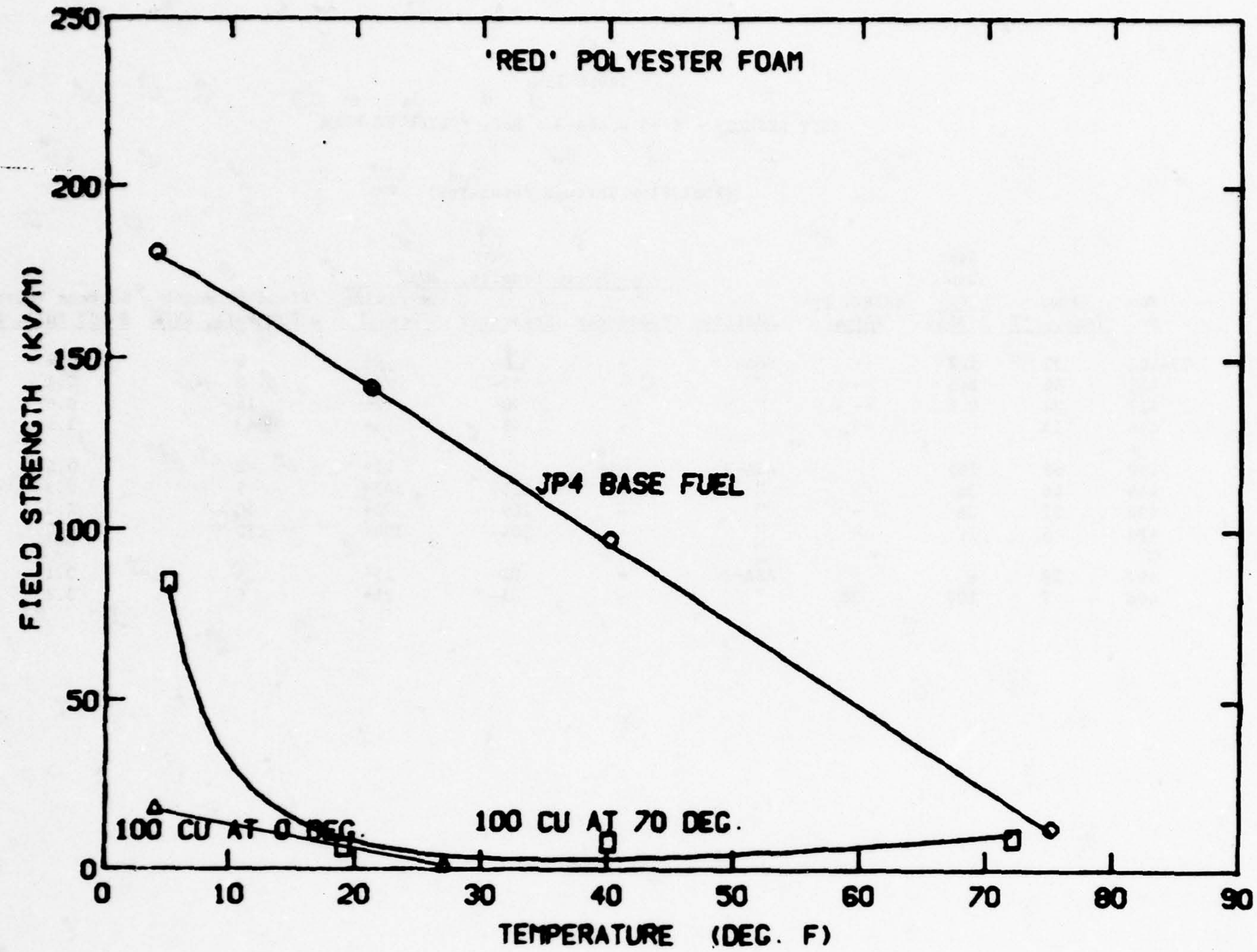


FIGURE 9. EFFECT OF STADIS 450 ON JP-4 WITH FUEL FLOW THROUGH SEPARATOR

static charge accumulation between 0° and 70°F. With conductivity additive dosage to provide 100 CU at 0°F, both additives satisfactorily control fuel charging. Since coalescer charged fuel was generally negative and separator charged fuel was generally positive, ASA-3 may be more efficient at controlling negative fuel charge while Stadis 450 may more efficiently control positive fuel charge. Alternately, there may be differences in coalescer and separator charging mechanisms with ASA-3 and Stadis 450 additized fuels. These results are not explained in terms of different fuel conductivities, since ASA-3 and Stadis 450 both responded similarly to temperature (Figure 10).

With red foam and fuel flow through SSET coalescer and separator, neither ASA-3 (Figure 11) nor Stadis 450 (Figure 12) are effective at both low conductivity (i.e. less than about 30 CU) and low temperature. Either charging or additive relaxation effects determine the combined result of flow through the SSET coalescer and separator elements with ASA-3 or Stadis 450. When the conductivity additive is most effective at controlling negative or coalescer charged fuel, as for ASA-3, essentially neutral charged fuel is delivered to the separator and separator charging and relaxation effects dominate. However, whenever high coalescer charging is not being controlled by the conductivity additive, as with Stadis 450, then the positive separator charge may not neutralize the unrelaxed negative charges and the effects of coalescer charging and relaxation dominate. The conductivity additive/JP-4 data for fuel flow through the SSET coalescer and separator are presented in Table 12.

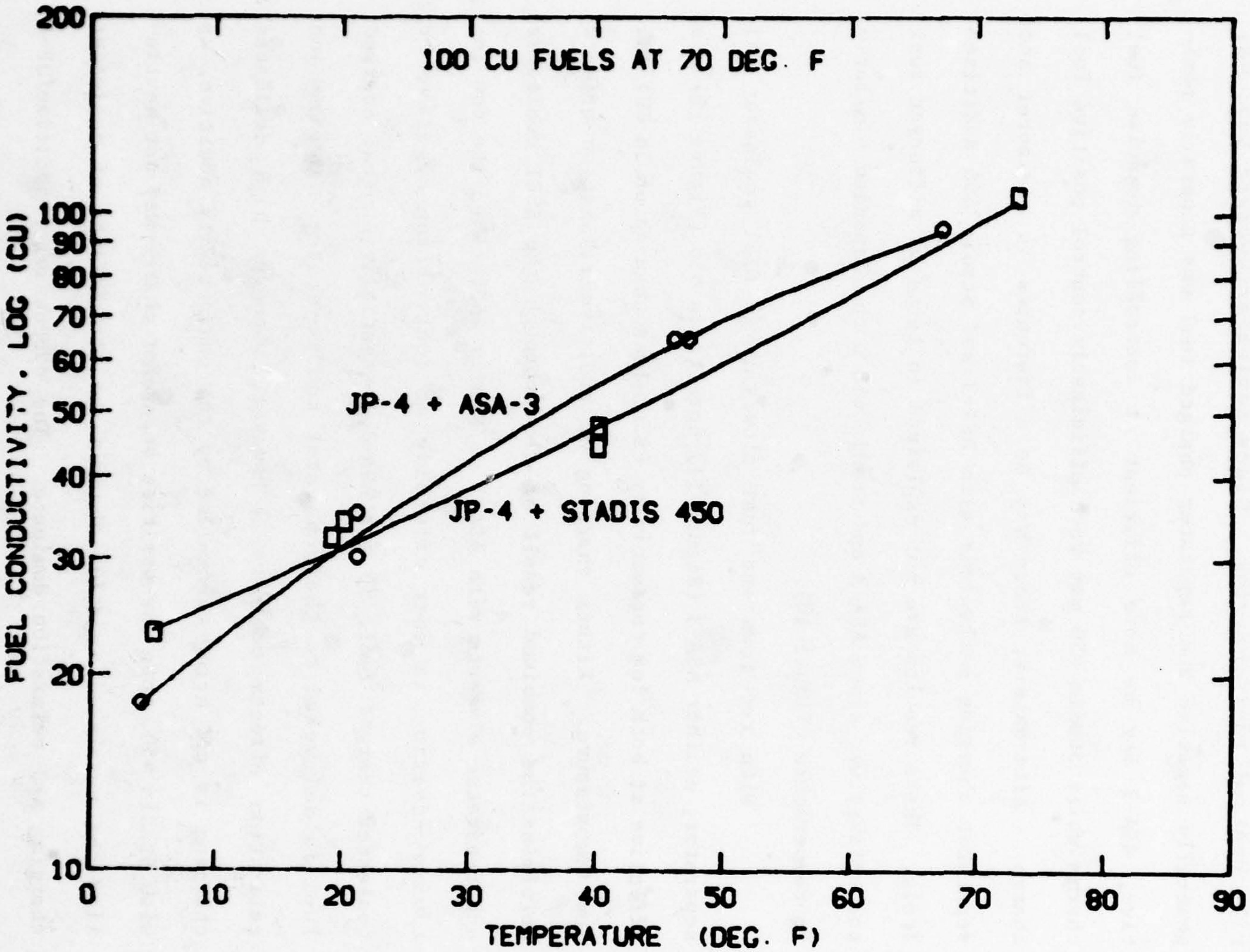


FIGURE 10. EFFECT OF TEMPERATURE ON JP-4 CONDUCTIVITY WITH ASA-3 AND STADIS 450

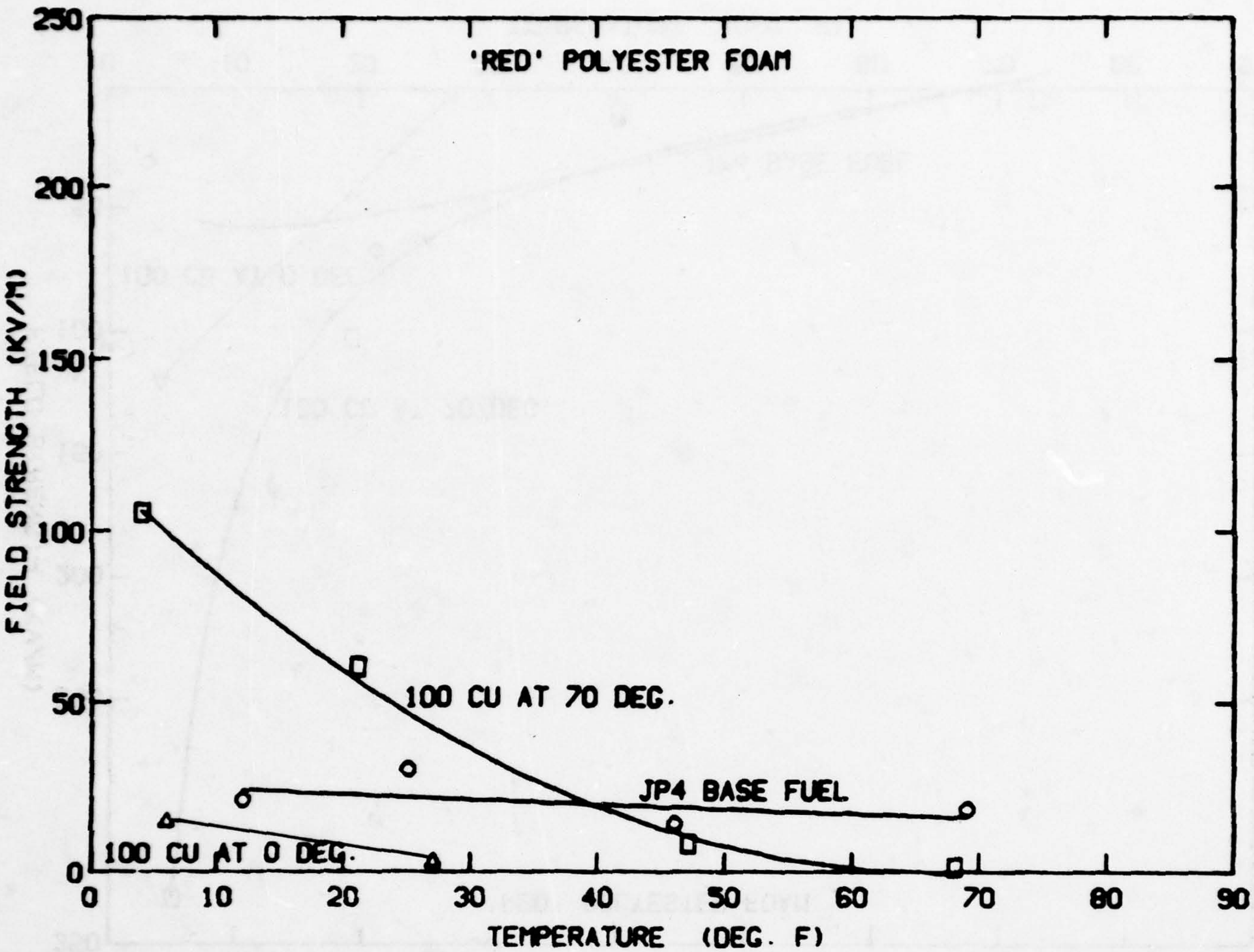


FIGURE 11. EFFECT OF ASA-3 ON JP-4 WITH FUEL FLOW THROUGH COAL. + SEPR.

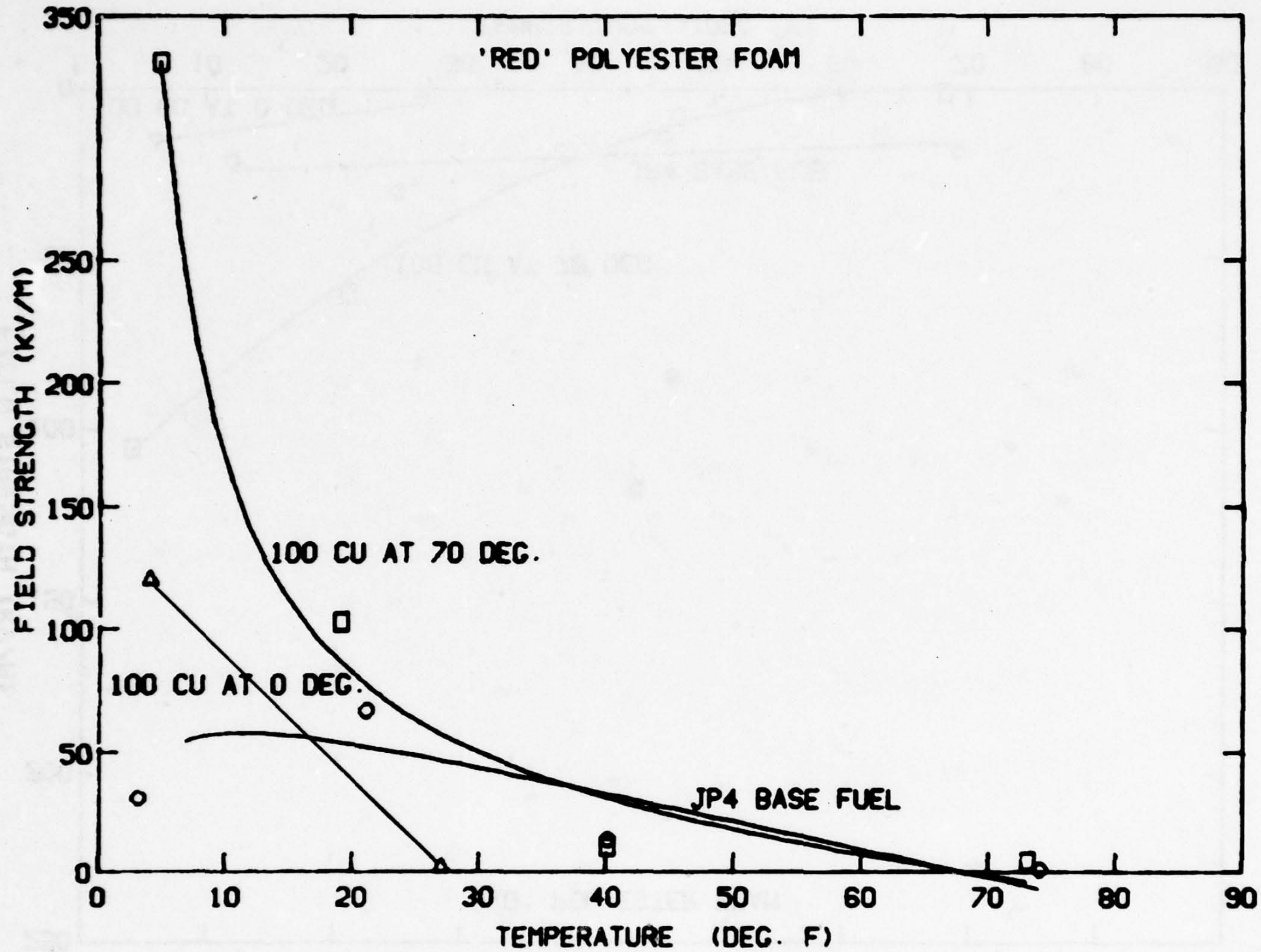


FIGURE 12. EFFECT OF STADIS 450 ON JP-4 WITH FUEL FLOW THROUGH COAL. + SEPR.

TABLE 12

SSET RESULTS ON JP-4 W/STADIS 450 AND ASA-3 - RED, POLYESTER FOAM

(Fuel Flow Through Coalescer and Separator)

Fuel	Run No.	Fuel Temp., °F	Rest Cond. CU D 3114	Water, ppm Total	Additive	Charge Density, μC/m³ Coalescer	Charge Density, μC/m³ Separator	Charge Density, μC/m³ Receiving Vessel	Field Strength @ 90% Full, KV/m	Surface Voltage @ 90% Full, KV	50% Charge Relaxation Time, Sec.
Clay Treated JP-4 B77-2, D3	77-510	74	2.0	-	None	161+	123-	8-	0	0	<1
	515	40	1.0	80	"	123+	103-	8-	13	0.5	30
	524	21	0.9	-	"	59+	87-	41+	66	2.4	37
	530	3	0.6	-	"	51+	75-	35+	30	1.1	-
	572	73	94	-	Stadis	190+	253-	80+	4	0.1	1
	577	40	42	43	450	294+	325-	55+	10	0.4	3
	587	19	35	-	"	314+	356-	79+	102	3.7	4
	594	5	23	42	"	178+	348-	36+	330	11.9	3
	618	27	-	-	"	321+	365-	17+	2	0.07	1
	611	4	94	48	"	356+	395-	99+	120	4.3	2
Clay Treated JP-4 B77-2, D1	401	69	1.1	-	None	217+	143-	66-	18	0.6	4
	411	46	1.5	-	"	20+	96-	11-	14	0.5	4
	416	25	0.8	-	"	20+	88-	24-	30	1.1	20
	425	12	-	-	"	11+	59-	12+	21	0.8	75
	458	68	100	-	ASA-3	95+	158-	73+	1	0.04	2
	468	47	70	-	"	62+	175-	120-	8	0.3	2
	473	21	38	-	"	356+	284-	234+	60	2.2	3
	482	4	19	-	"	205+	346-	303+	105	3.8	4
	496	27	-	-	ASA-3	51+	70-	22+	3	0.1	4
	487	6	94	22	"	153+	202-	32+	15	0.5	2

SSET Reticulated Foam Results

Effects of reticulated foam in the receiver vessel have been noted earlier. Field strengths obtained during the early portion of the run with conductivity additized fuel and the summary of effects between number 4, red polyester foam (red foam) and blue, fine pore, polyether foam (blue foam) are presented in this section.

Typical recorded SSET field strength traces as obtained while filling foam-filled receivers with fuel containing conductivity additive are shown in Figure 13. This example is for Jet A containing ASA-3 with fuel flow through the SSET coalescer and the receiver vessel lined with bladder and filled with red foam. Initially, there is an increase in the magnitude of the field strength during the first 10-40% of fill followed by a decrease in field strength. This is followed by another increase in field strength to a maximum at the end-of-test when the fuel level rises above the foam surface. While the field strength meter does not normally respond to field polarity, it was independently determined that this behavior represented, in some cases, an actual change of field polarity as the vessel fills. It is assumed that the initial maxima represent peak charge on the foam surface and the second maxima the charge on the fuel surface at end-of-test. The field strengths of this report are end-of-test field strengths. It is assumed that these field strengths reflect fuel effects while the shape, magnitude, or polarity of the field strength records when the receiver fuel level is below the foam surface, reflect foam effects and have minimal effect on fuel charging results. Future work should consider a detailed evaluation of these phenomena.

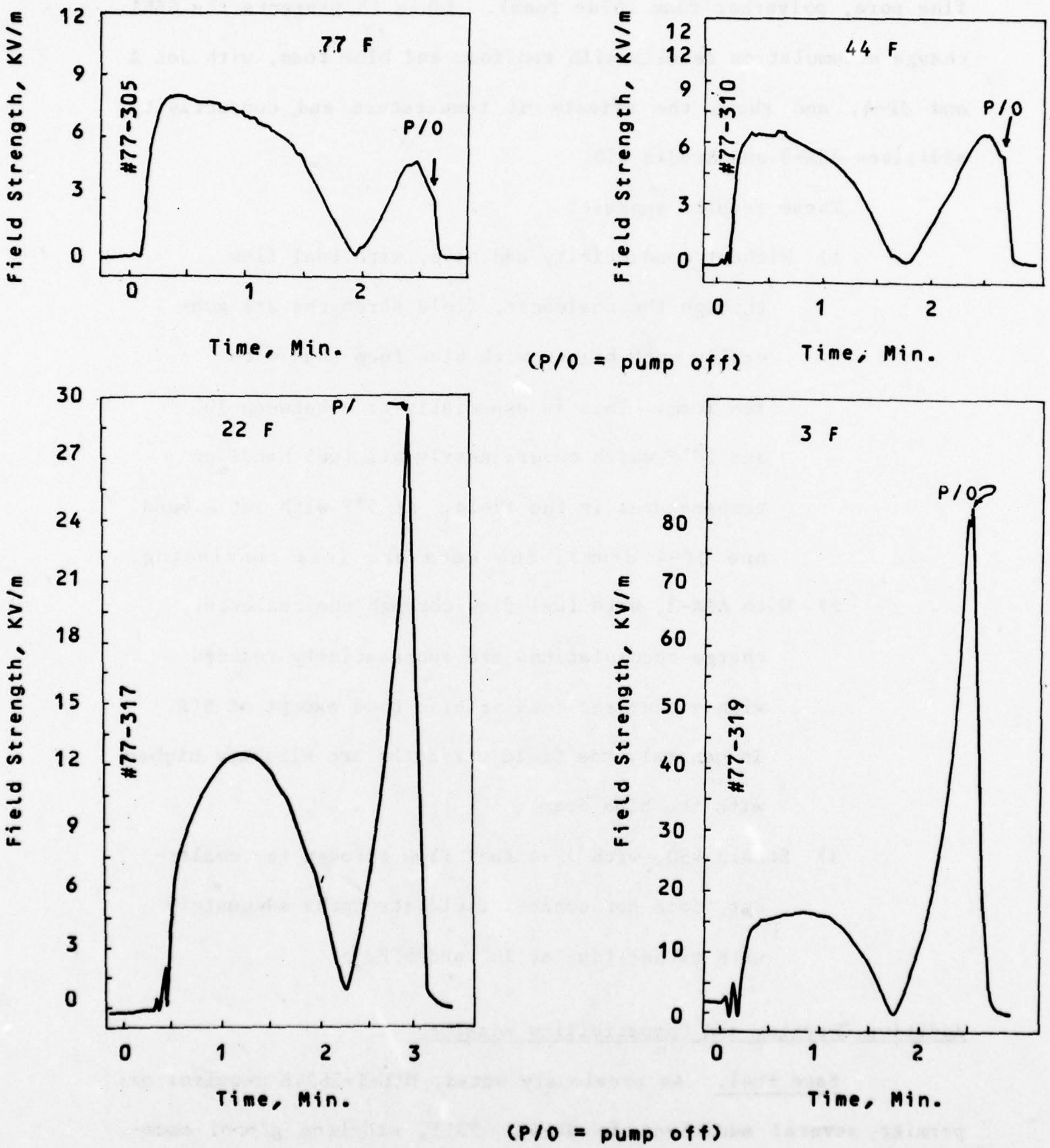


Figure 13. Typical SSET Field Strength Traces from Conductivity Additized Fuels at Various Temperatures. Jet A w/ASA-3 on Red Foam

Although the additive compatibility studies were all with No. 4, red polyester foam (red foam), charging comparisons have been made between SSET charging effects with red foam and blue, fine pore, polyether foam (blue foam). Table 13 presents the SSET charge accumulation results with red foam and blue foam, with Jet A and JP-4, and shows the effects of temperature and conductivity additives ASA-3 and Stadis 450.

These results suggest:

1) Without conductivity additive, with fuel flow through the coalescer, field strengths are generally much higher with blue foam than with red foam. This is especially true between 70° and 20°F which covers nearly all fuel handling temperatures in the field. At 5°F with Jet A (and one JP-4 drum), the data are less convincing.
2) With ASA-3, with fuel flow through the coalescer, charge accumulations are substantially reduced with either red foam or blue foam except at 5°F. In general, the field strengths are slightly higher with the blue foam.
3) Stadis 450, with JP-4 fuel flow through the coalescer, does not control field strengths adequately with either foam at 20° and 5°F.

Additive Charging and Compatibility Results

Base Fuel. As previously noted, MIL-T-5624K requires or permits several additives in JP-4. FSII, ethylene glycol monomethyl ether (EGME) is a required additive and, therefore, 0.15%

TABLE 13

COMPARISON OF CHARGING WITH RED AND BLUE FOAMS
FUEL FLOW THROUGH COALESCER

Fuel	Field Strength, KV/m w/Red Foam 70°F	20°F	5°F	Field Strength, KV/m w/Blue Foam 70°F	20°F	5°F
Base Fuels w/o Additive						
Jet A, B77-1, D7	33	60	68	220	104	45
JP-4, B77-1, D2	10	133	193	130	335	305
JP-4, B77-2, D1	30	137	206	250	253	255
JP-4, B77-2, D3	25	175	190	230	150	40
Base Plus ASA-3 (100 CU @ 70 F)						
Jet A, B77-1, D7	4	33	80	5	50	96
JP-4, B77-2, D1	5	15	24	15	40	70
Base Plus Stadis 450 (100 CU @ 70 F)						
JP-4, B77-2, D3	20	120	375	5	370	625

EGME was used in the base fuel. Figure 14 and Table 14 show the effect of EGME on charge accumulation between 20° and 65°F with red foam and fuel flow through the coalescer. At 25° and 65°F the JP-4 base fuel field strengths are similar to those of EGME additized fuel but higher at 42°F. In general, measured field strengths tended to increase as fuel temperature decreased. While the opposite effect (decrease in field strength as temperature is reduced) was generally not observed, effects similar to the base fuel field strengths of Figure 14 did occur in several test series. It is assumed that charging differences may be attributed to undetermined fuel or SSET factors. All JP-4 fuels for these additive studies were from a single production run and were stored in separate fifty-five gallon drums for each additive study. Small differences in impurities were thus possible between various drums of fuel. Also for each additive study, nine new coalescer and nine separator elements are installed in the appropriate vessels and it is assumed that individual coalescer or separator elements may not charge identically. (Nine elements would tend to average small differences in charging properties but some small variations are still possible.) Further, each additive study used a fresh red foam sample in the receiver. These possible drum-to-drum variations of fuel, element-to-element variance of coalescers and separators, and the sample-to-sample differences of reticulated red foams are not independently controlled. Instead, the drum of fuel is sequentially additized and charging effects analyzed on the same fuel before and after additization. In summary, the results for this fuel, with fuel flow through the coalescer and red foam in the

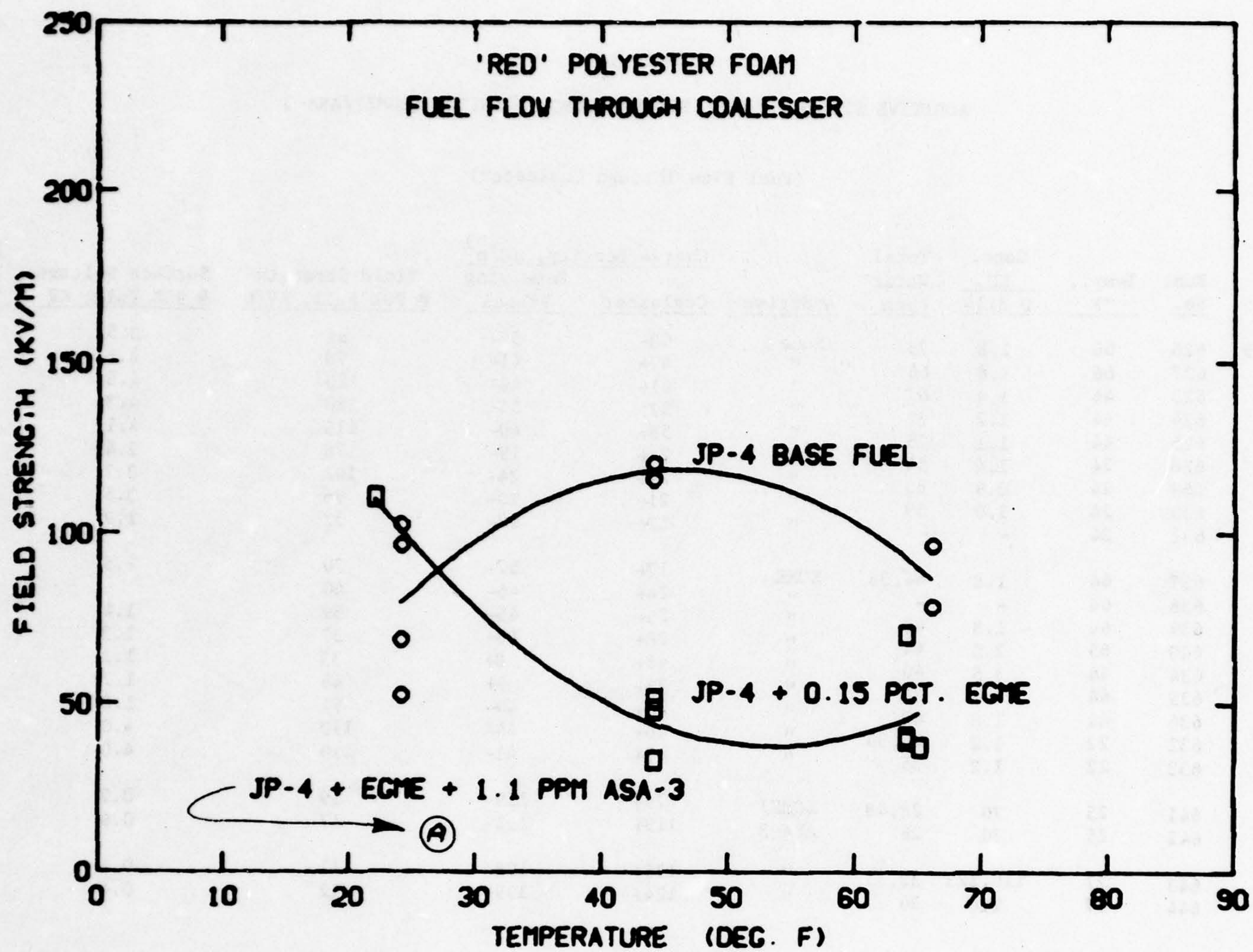


FIGURE 14. EFFECT OF FSII ON CHARGE ACCUMULATION

TABLE 14

ADDITIVE STUDIES - FUEL SYSTEM ICING INHIBITOR (EGME)/ASA-3

(Fuel Flow Through Coalescer)

Fuel	Run. No.	Temp., °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, $\mu C/m^3$ Coalescer	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full, KV/m	Surface Voltage @ 90% Full, KV	50% Charge Relaxation Time, Sec.
JP-4, 77D-3299	626	66	1.8	75	None	63+	51-	96	3.5	24
	627	66	1.8	66	"	47+	41-	78	2.8	37
	623	44	1.4	67	"	61+	42-	120	4.3	76
	624	44	1.2	82	"	57+	54-	120	4.3	65
	625	44	1.1	75	"	58+	40-	115	4.1	65
	628	24	1.4	54	"	24+	19-	78	2.4	123
	269	24	0.9	60	"	21+	24-	102	3.7	54
	630	24	1.0	59	"	21+	20-	96	3.5	78
	631	24	-	-	"	17+	18-	52	1.9	32
	637	64	1.8	44,38	EGME	17+	57-	70	2.5	10
	638	64	-	-	"	24+	46-	40	-	13
	639	64	1.8	45	"	25+	45-	39	1.4	8
	640	65	2.0	44	"	28+	43-	37	1.3	9
	634	44	3.5	40	"	48+	8+	33	1.2	6
	635	44	1.8	32	"	33+	9+	48	1.7	12
	636	44	1.8	40	"	28+	40-	51	1.8	7
	632	22	1.2	26,30	"	46+	44-	110	4.0	26
	633	22	1.2	35	"	47+	41-	110	4.0	43
	641	25	70	28,48	EGME/	79+	119-	19	0.7	1
	642	25	70	26	ASA-3	119+	154-	17	0.6	2
	643	27	116,123	32,35	"	126+	198-	11	0.4	1
	644	27	116	36	"	124+	199-	12	0.4	1

receiver indicate that EGME has no significant effect on charge accumulation at 23° and 65°F but may be pro-static, i.e. increases charge accumulation, at intermediate temperatures. After the tests with EGME, ASA-3 was added to the fuel and the fuel then retested. With fuel flow through the coalescer and red foam in the receiver, ASA-3 effectively reduces charge accumulation.

<u>Fractional Change in Field Strength.</u> In the preliminary SSET charging studies, absolute values of the field strength in the receiver (at 90% full) were applied for assessment of resultant charge accumulation. A slightly different approach was used to compare additive charging effects. As previously noted, in the additives and additive combination studies, a fresh drum of JP-4 fuel (all from the same batch) was used with new coalescer and separator elements and new red polyester foam in the receiver vessel. A base fuel (JP-4 + EGME) run was made each time and the effect of the additives determined relative to the respective base fuel. This relative comparison compensated for individual variations among drummed fuels, coalescer/separator elements and foam samples. The parameter, fractional change in field strength, dF, was defined:

$$dF = \frac{F - F_o}{F_o}$$

where F is absolute value of Field Strength with the additive and F_o is absolute value of field strength without the additive.

To illustrate: a negative value of dF indicates the additive is antistatic, i.e. results in less fuel charging. Complete elimination of static charge accumulation, i.e. F = 0, leads to:

$$dF = \frac{-F_o}{F_o} = -1.0$$

If the additive has no effect on charge accumulation, $F = F_o$, and

$$dF = 0$$

If the additive is pro-static and causes an increase in charge accumulation, dF is positive. For example, if the field strength doubles or triples, i.e. $F = 2F_o$ or $3F_o$ then

$$dF = \frac{2F_o - F_o}{F_o} = +1.0$$

or

$$dF = \frac{3F_o - F_o}{F_o} = +2.0$$

The fractional change in field strength, dF, calculated from best-fit curves of the experimental field strength data, permitted comparable comparisons of different fuel charging conditions. In order to focus attention on the additive and additive combination effects in this report, only dF comparisons are made. Data summaries and absolute field strength plots for all additive and combinations studies are in the appendix. The order of the additive presentation does not correspond to the order in which the runs were made so that run numbers in the tables are not necessarily consecutive.

At temperatures around 70°F, absolute field strengths in the SSET were generally low. It is expected that static electric charging in the field is also low in this temperature range.

Thus, increases in field strength of less than 100%, i.e. up to double the base fuel field strength, were generally considered not significant around 70°F. With fuel flow through the SSET separator, the absolute field strengths were generally low at all temperatures. However, the SSET separator generated a specific type of charge and it cannot be assumed that this type of charge is small in the field and thus are considered in these SSET studies in spite of their low magnitude. Therefore, although dF parameters from low field strength separator charging data are less precise than results from high field strength coalescer charging, the same dF criteria were used for noting significant effects. The test for dF significance in either SSET flow configuration (at temperatures below about 50°F) was that changes greater than ± 0.5 are to be considered significant.

Additive Study Procedures. In the additive and additive combination studies, the following experimental procedures were applied. Since FSII is mandatory in JP-4 fuel, 0.15% EGME was used in all base fuels. The usual practice was to add EGME at room temperature and then obtain at least duplicate runs with fuel flow through the coalescer followed by runs with fuel flow through the separator. After each test run, the fuel in the SSET receiver was returned to the supply drums. The temperature of the room was then lowered overnight to nominal 35°F and the run sequence repeated at the new temperature. The same procedures were repeated at nominal 0°F. After the base fuel runs were completed at 0°F, the approved additive or additive combination was added to the supply drum at 0°F. The fuel was pumped between the reserve drum and the supply drum to achieve complete mixing of the additives. The SSET charging of base fuel plus additive was then examined successively at nominal 0°, 35° and 70°F. Following these tests at 70°F, the fuel was divided into two parts, one part was additized with ASA-3 and the other with Stadis 450. The fuel was circulated through the coalescer and separator elements to effect mixing and to condition these devices to the conductivity additive. SSET charging tests were run at nominal 25°F and 0°F with one additive before the second portion of fuel was additized and the test sequence repeated. To avoid contamination of the conductivity additives after the first conductivity additive had been examined, the coalescer, separator and receiver vessels (containing elements and foam, respectively) were flushed with clean Jet A until the conductivity of the effluent fuel was equivalent to fresh fuel. The test sequence of ASA-3 and Stadis 450 was alternated in successive additive studies. After each study, the fuel was discarded, i.e. a fresh drum of fuel is used for each study, no fuel is re-used.

The following list of fifteen additives or combinations were examined without and with conductivity additives, Shell ASA-3 and DuPont Stadis 450 (Fuel System Icing Inhibitor (FSII) ethylene glycol monomethyl ether @ 0.15% vol. was included in all fuels.):

1) Five corrosion inhibitor additives.
   - (a) DuPont DCI-4A @ 8 lbs./1000 bbl.
   - (b) UOP Unicor J @ 8 lbs./1000 bbl.
   - (c) Petrolite Tolad 246 @ 8 lbs./1000 bbl.
   - (d) Hitec E-515 @ 16 lbs./1000 bbl.
   - (e) Apollo PRI-19 @ 8 lbs./1000 bbl.

2) Two antioxidant additives.

(1) Ethyl 733 @ 8.4 lbs./1000 bbl.

(b) DuPont AO-33 @ 8.4 lbs./1000 bbl.

3) Metal Deactivator Additive (MDA).

N,N'-disalicylidene-1,2-propanediamine @ 2 lbs./ 1000 bbl.

On the basis of these tests, the following additive combinations were tested.

4) Three corrosion inhibitor/antioxidant combinations.

(a) DuPont DCI-4A/Ethyl 733 @ 8.0 and 8.4 lbs./ 1000 bbl., respectively.

(b) Hitec E-515/Ethyl 733 @ 16.0 and 8.4 lbs./ 1000 bbl., respectively.

(c) Petrolite Tolad 246/Ethyl 733 @ 8.0 and 8.4 lbs./ 1000 bbl., respectively.

5) Two corrosion inhibitor/MDA combinations.

(a) Hitec E-515/MDA @ 16.0 and 2.0 lbs./ 1000 bbl., respectively.

(b) Petrolite Tolad 246/MDA @ 8.0 and 2.0 lbs./ 1000 bbl., respectively.

6) One antioxidant/MDA combination.

Ethyl 733/MDA @ 8.4 and 2.U lbs./1000 bbl., respectively.

7) One corrosion inhibitor/antioxidant/MDA combination

Petrolite Tolad 246/Ethyl 733/MDA @ 8.0, 8.4, and 2.0 lbs./1000 bbl., respectively.

Coalescer Charging Studies.

1. DuPont DCI-4A (corrosion inhibitor)

With fuel flow through the SSET coalescer, 8.0 lbs./1000 bbl. DuPont DCI-4A significantly increased the charge accumulation of base fuel, JP-4 + 0.15% EGME, between about 20° and 10°F. However, around 3°F the additized fuel accumulated only about half as much charge as base fuel. The trend reversal at 3°F was not typical. Generally, as the SSET temperature decreased, lower charge densities were obtained but these charges relaxed more slowly at low temperatures. The effect of longer relaxation times generally resulted in greater charge accumulation in the receiver at low temperatures. The results at 3°F with base fuel containing DuPont DCI-4A are not readily explained relative to other additive results. Increasing fuel conductivity to nominal 100 CU at 0°F with ASA-3 or Stadis 450 effectively reduces charge accumulation almost 100%. The DuPont DCI-4A results are shown in Figure 15. For DuPont DCI-4A with conductivity additives, studies were performed at 0°F only. The field strength results are presented in Appendix Figure A1. All data for this additive study are in Appendix Table A1.

2. UOP Unicor-J (corrosion inhibitor)

With fuel flow through the SSET coalescer, UOP Unicor J was antistatic, i.e. accumulated less charge relative to base fuel, between 20° and 70°F. Increasing fuel conductivity to nominal 100 CU at 20°F with ASA-3 or Stadis 450 reduced charge accumulation further by 70-80%. Data were not obtained below 25°F for this additive. These results are shown in Figure 16. The

2) Two antioxidant additives.

(1) Ethyl 733 @ 8.4 lbs./1000 bbl.

(b) DuPont AO-33 @ 8.4 lbs./1000 bbl.

3) Metal Deactivator Additive (MDA).

N,N'-disalicylidene-1,2-propanediamine @ 2 lbs./1000 bbl.

On the basis of these tests, the following additive combinations were tested.

4) Three corrosion inhibitor/antioxidant combinations.

(a) DuPont DCI-4A/Ethyl 733 @ 8.0 and 8.4 lbs./1000 bbl., respectively.

(b) Hitec E-515/Ethyl 733 @ 16.0 and 8.4 lbs./1000 bbl., respectively.

(c) Petrolite Tolad 246/Ethyl 733 @ 8.0 and 8.4 lbs./ 1000 bbl., respectively.

5) Two corrosion inhibitor/MDA combinations.

(a) Hitec E-515/MDA @ 16.0 and 2.0 lbs./1000 bbl., respectively.

(b) Petrolite Tolad 246/MDA @ 8.0 and 2.0 lbs./1000 bbl., respectively.

6) One antioxidant/MDA combination.

Ethyl 733/MDA @ 8.4 and 2.U lbs./1000 bbl., respectively.

7) One corrosion inhibitor/antioxidant/MDA combination

Petrolite Tolad 246/Ethyl 733/MDA @ 8.0, 8.4, and 2.0 lbs./1000 bbl., respectively.

field strength data are presented in Appendix Figure A2. All data are presented in Appendix Table A2.

3. Petrolite Tolad 246 (corrosion inhibitor)

With fuel flow through the SSET coalescer, 8.0 lbs./1000 bbl. Petrolite Tolad 246 had no significant effect on base fuel from about 5°F to 70°F within the dF tolerances of ± 0.5. Increasing fuel conductivity to nominal 100 CU at 0°F with ASA-3 or Stadis 450 significantly reduced charge accumulation by more than 80%. Conductivity additives were added at 0°F only. These results are shown in Figure 17. Field strength data are plotted in Appendix Figure A3; all data are in Appendix Table A3.

4. Hitec E-515 (corrosion inhibitor)

With fuel flow through the SSET coalescer, 16 lbs./1000 bbl. Hitec E-515 was anti-static to base fuel between 0° and 70°F. Increasing fuel conductivity to nominal 100 CU at 0°F with ASA-3 or Stadis 450 decreased charge accumulations by more than 90%. These results are shown in Figure 18. Field strength data are plotted in Appendix Figure A4; the data are tabulated in Appendix Table A4.

5. Apollo PRI-19 (corrosion inhibitor)

With fuel flow through the SSET coalescer, 8.0 lbs./1000 bbl. Apollo PRI-19 was pro-static (dF > 0.5) below about 10°F. The pro-static effects above about 68°F may not be significant because, as noted, charge accumulation is generally low around ambient temperature and fractional increases less than 1.0 may not represent a static hazard. Apollo PRI-19 generally had no static effects on base fuel between 30°and 65°F. Increasing fuel conductivity to nominal 100 CU at 0° and 25°F with ASA-3 or Stadis 450

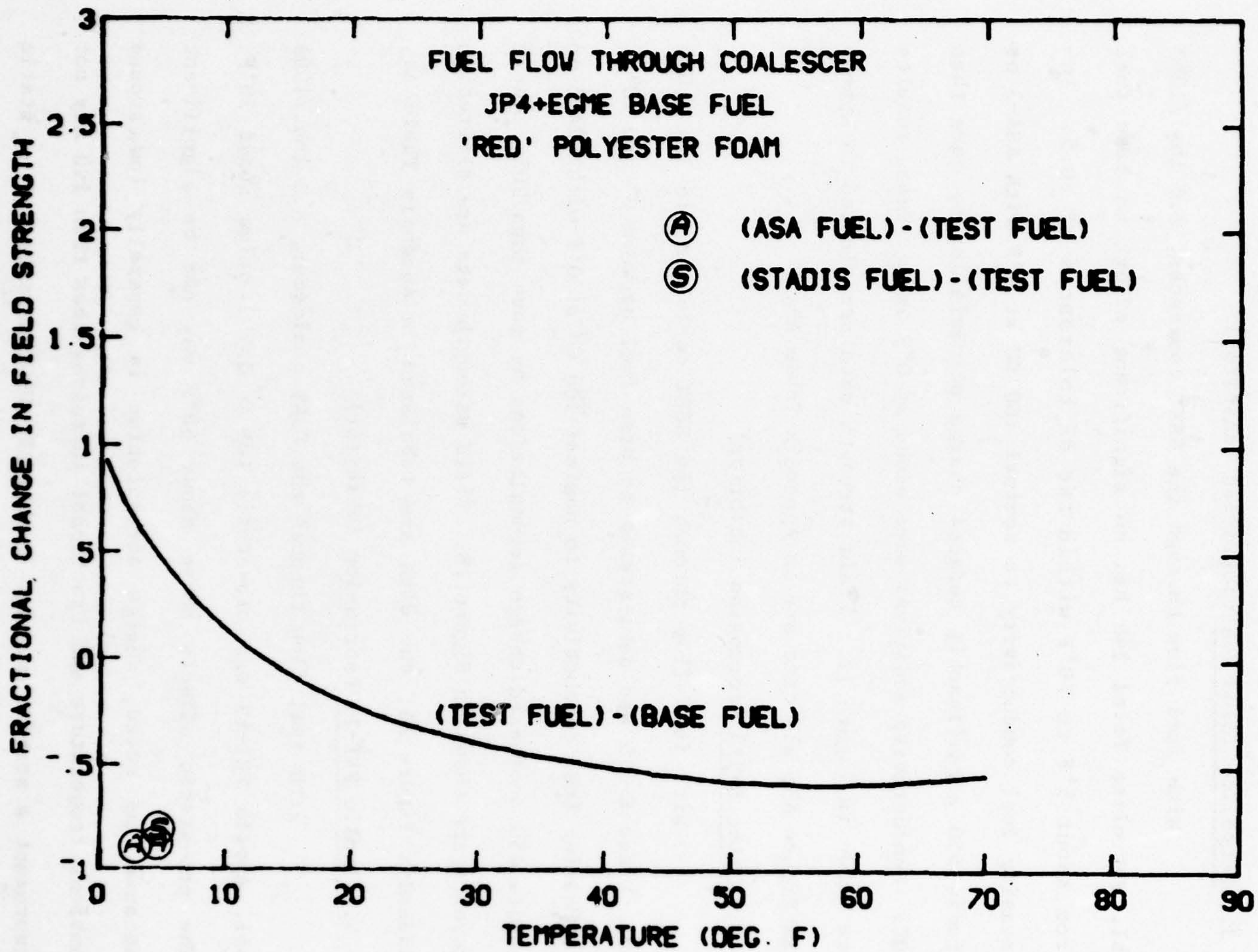


FIGURE 17. EFFECT OF PETROLITE TOLAD 246 ON FRACTIONAL CHANGE IN FIELD STRENGTH

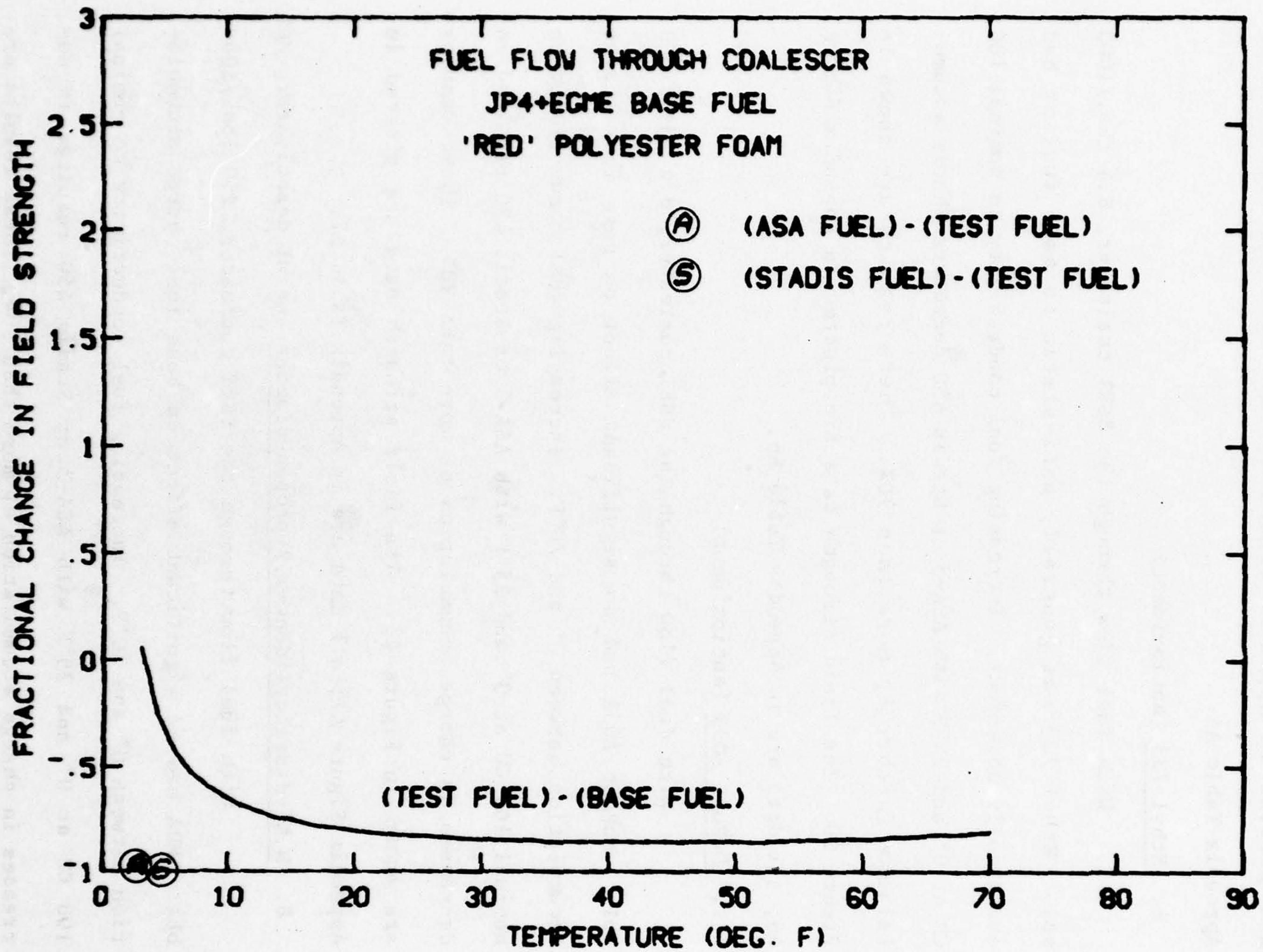


FIGURE 18. EFFECT OF HITEC E-515 ON FRACTIONAL CHANGE IN FIELD STRENGTH

significantly decreased charge accumulation by more than 90%. These results are shown in Figure 19. The field strength data are plotted in Appendix Figure A5; all data are presented in Appendix Table A5.

6. Ethyl 733 (antioxidant)

With fuel flow through the SSET coalescer, 8.4 lbs./1000 bbl. Ethyl 733 was generally anti-static to base fuel or had essentially no effect. Increasing fuel conductivity to nominal 100 CU at 0° and 25°F with ASA-3 or Stadis 450 decreased charge accumulations further by more than 90%. These results are shown in Figure 20. The field strength data are plotted in Appendix Figure A6; all data are in Appendix Table A6.

7. DuPont A033 (antioxidant)

With fuel flow through the SSET coalescer, 8.4 lbs./1000 bbl. DuPont A033 had no significant effect on base fuel charge accumulation between 0° and 70°F. Increasing fuel conductivity to nominal 100 CU at 0° and 25°F with ASA-3 or Stadis 450 resulted in decreases in charge accumulation of more than 90%. These results are shown in Figure 21. The field strength data are plotted in Appendix Figure A7; all data are in Appendix Table A7.

8. N,N'-disalicylidene-1,2-propanediamine (metal deactivator, MDA)

With fuel flow through the SSET coalescer, 2.0 lbs./1000 bbl. MDA had no significant effect on base fuel charge accumulation between 0° and 70°F. Increasing fuel conductivity to nominal 100 CU at 0° and 25°F with ASA-3 or Stadis 450 resulted in decreases in charge accumulation of more than 90%. These results are

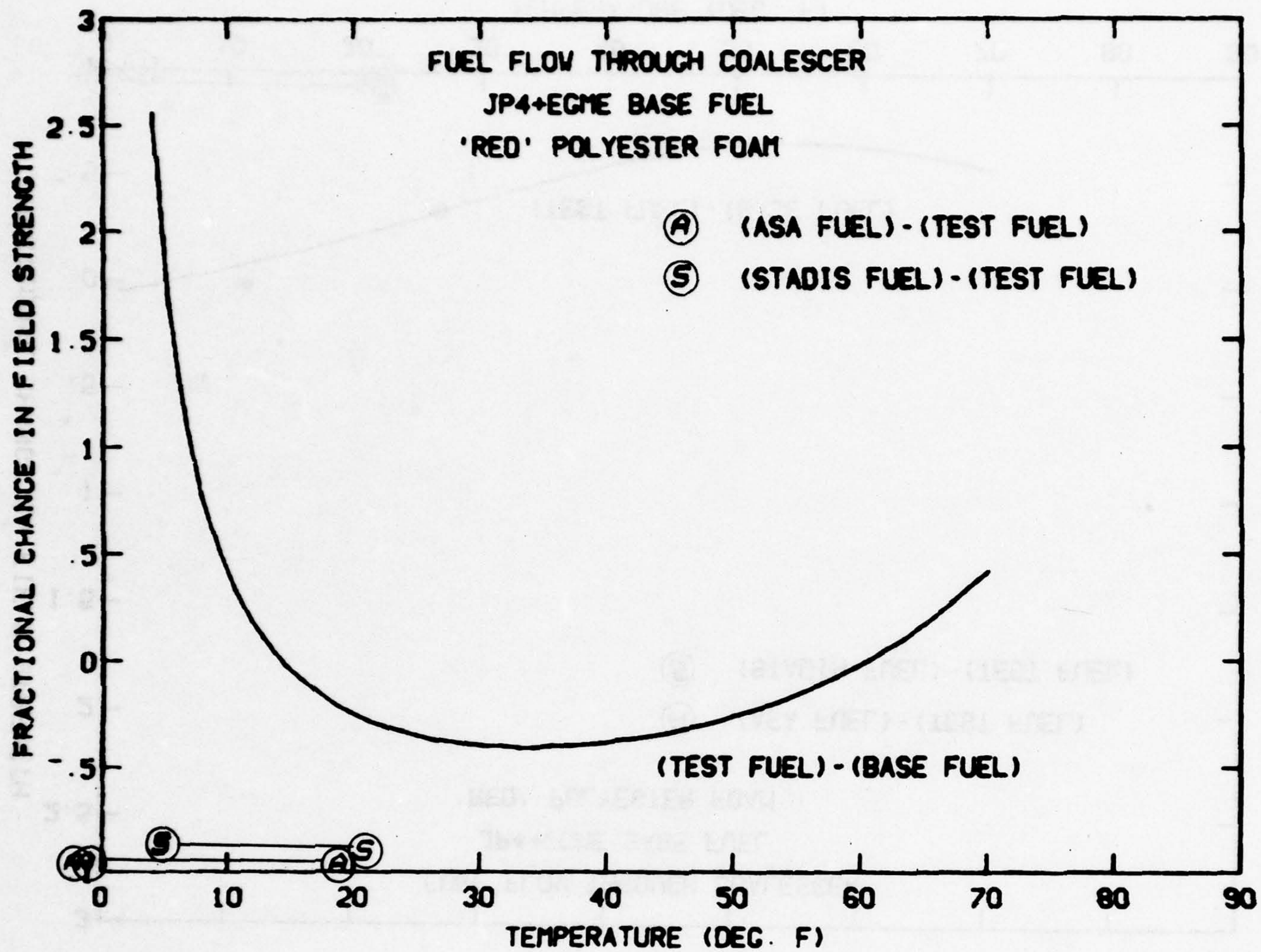


FIGURE 19. EFFECT OF APOLLO PRI-19 ON FRACTIONAL CHANGE IN FIELD STRENGTH

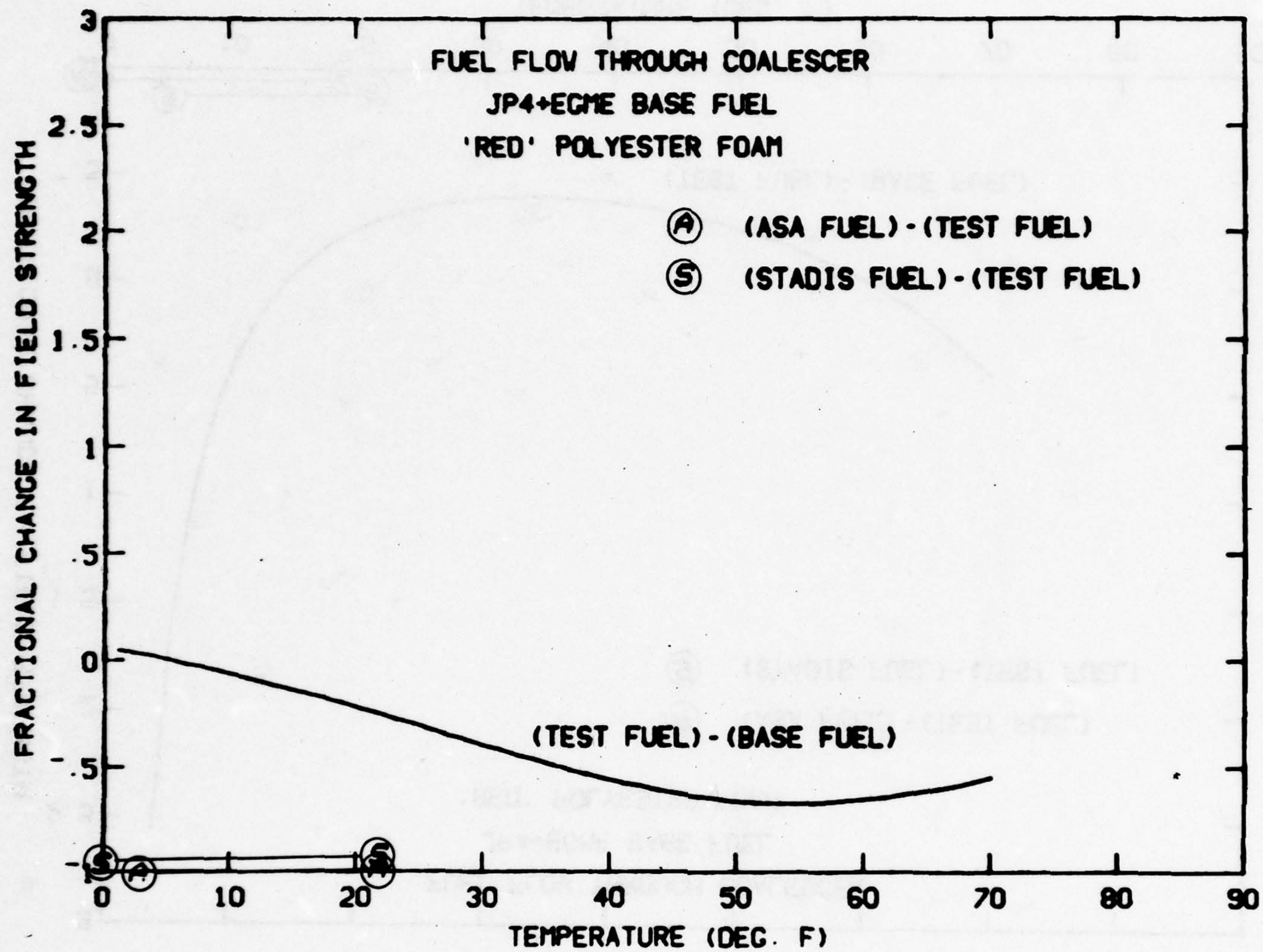


FIGURE 20. EFFECT OF ETHYL 733 ON FRACTIONAL CHANGE IN FIELD STRENGTH

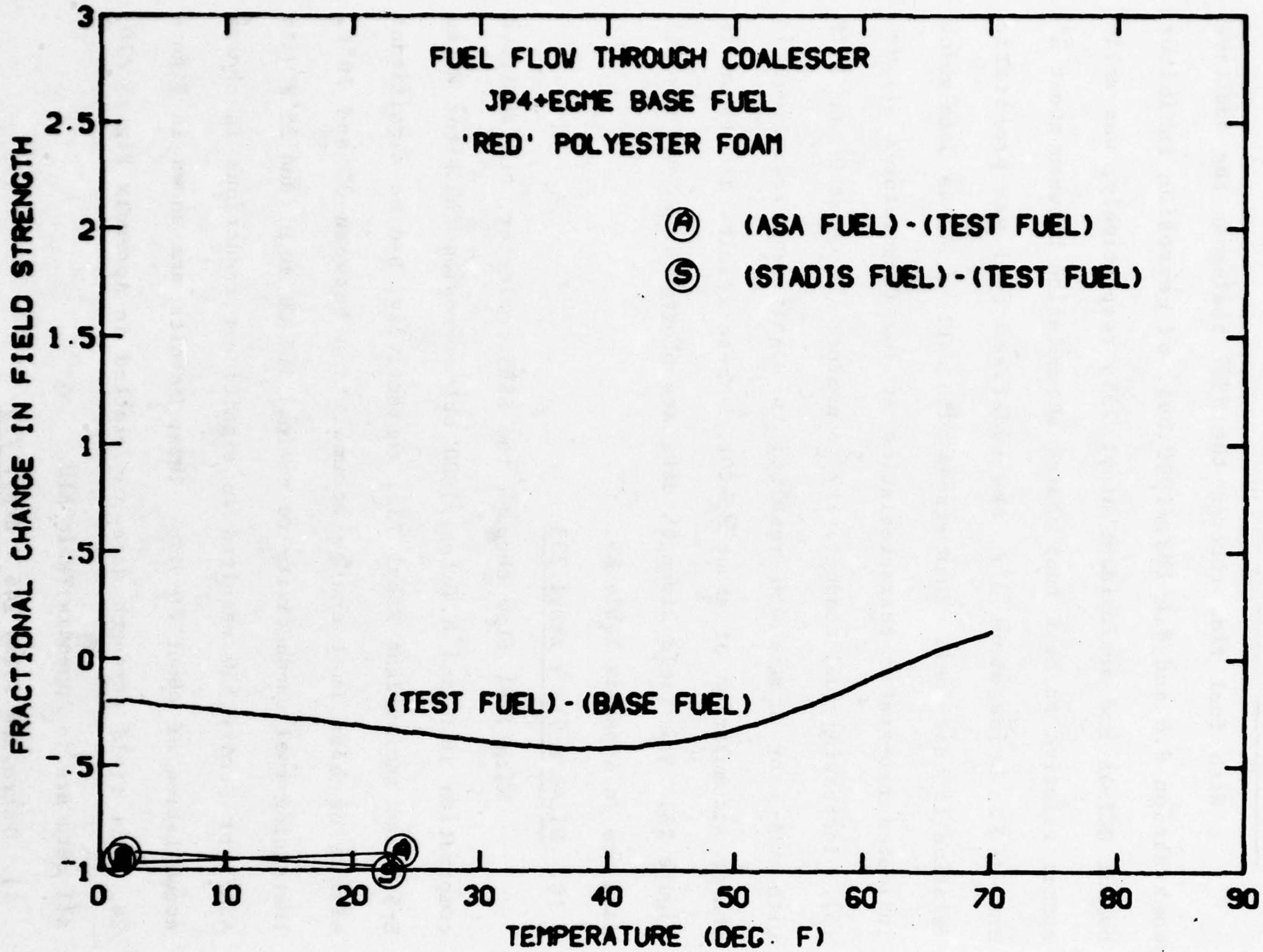


FIGURE 21. EFFECT OF DU PONT A033 ON FRACTIONAL CHANGE IN FIELD STRENGTH

shown in Figure 22. The field strength data are plotted in Appendix Figure A8; all data are in Appendix Table A8.

9. DuPont DCI-4A + Ethyl 733

With fuel flow through the SSET coalescer the additive combination 8.0 and 8.4 lbs./1000 bbl. of corrosion inhibitor DuPont DCI-4A and antioxidant Ethyl 733, respectively, was antistatic relative to base fuel charge accumulation between about 3° and 70°F. Below about 3°F, the additized fuel was pro-static relative to base fuel. This agrees with earlier DCI-4A data which indicated pro-static characteristics at low temperatures (Figure 15). Increasing fuel conductivity to nominal 100 CU at 0° and 25°F with ASA-3 or Stadis 450 resulted in significant reductions in charge accumulation of about 85-90%. These results are shown in Figure 23. The field strength data are plotted in Figure A9; all data are in Appendix Table A9.

10. Hitec E-515 + Ethyl 733

With fuel flow through the SSET coalescer, the additive combination 16.0 and 8.4 lbs./1000 bbl corrosion inhibitor Hitec E-515 and antioxidant Ethyl 733, respectively, had no significant effect on base fuel charge accumulation between 0° and 70°F. Increasing fuel conductivity to nominal 100 CU at 0° and 25°F with ASA-3 or Stadis 450 resulted in significant reductions in charge accumulation of about 80-90%. These results are shown in Figure 24. The field strength data are plotted in Appendix Figure A10; all data are in Appendix Table A10.

11. Petrolite Tolad 246 + Ethyl 733

With fuel flow through the SSET coalescer, the additive

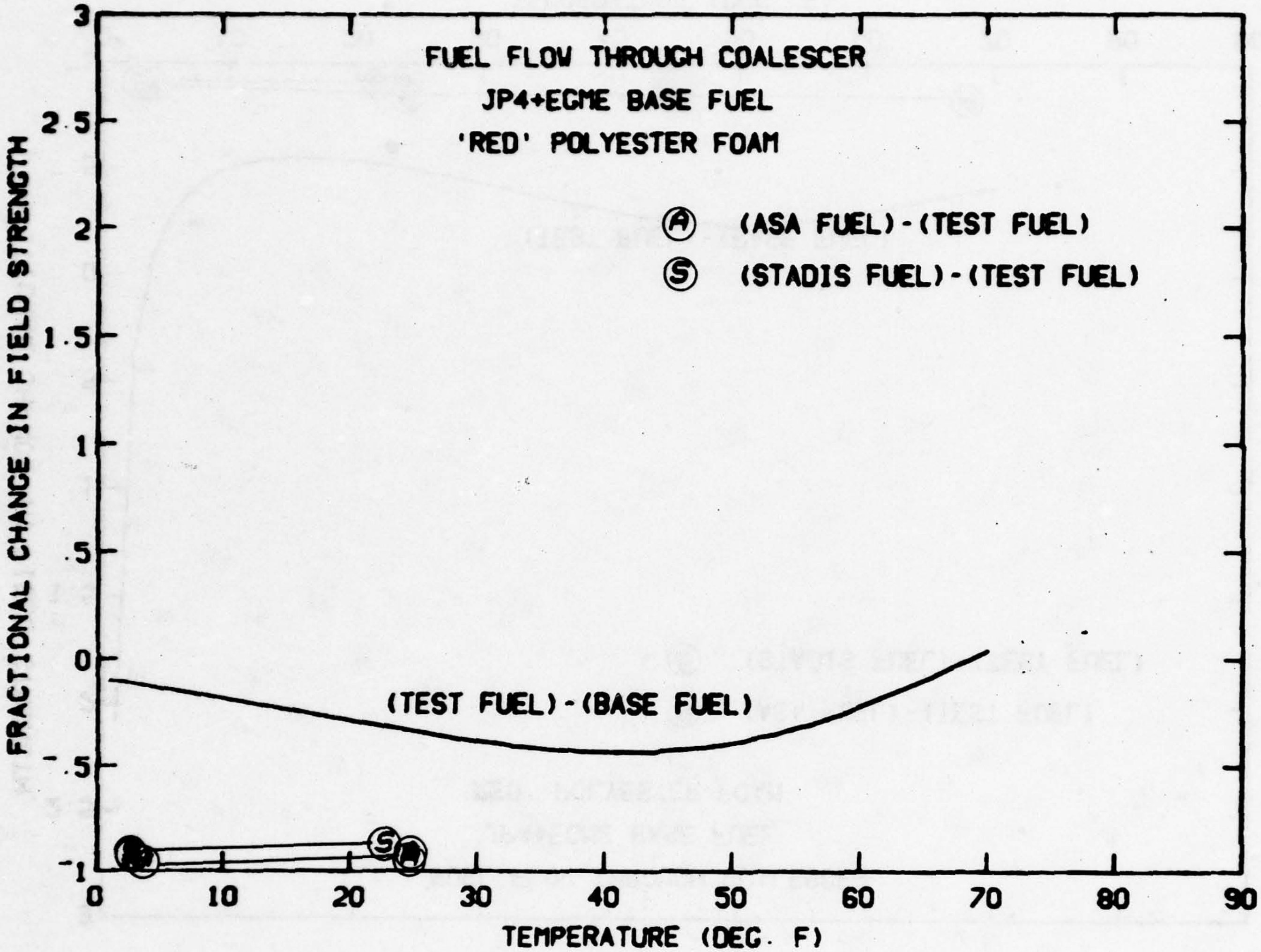


FIGURE 22. EFFECT OF METAL DEACTIVATOR ON FRACTIONAL CHANGE IN FIELD STRENGTH

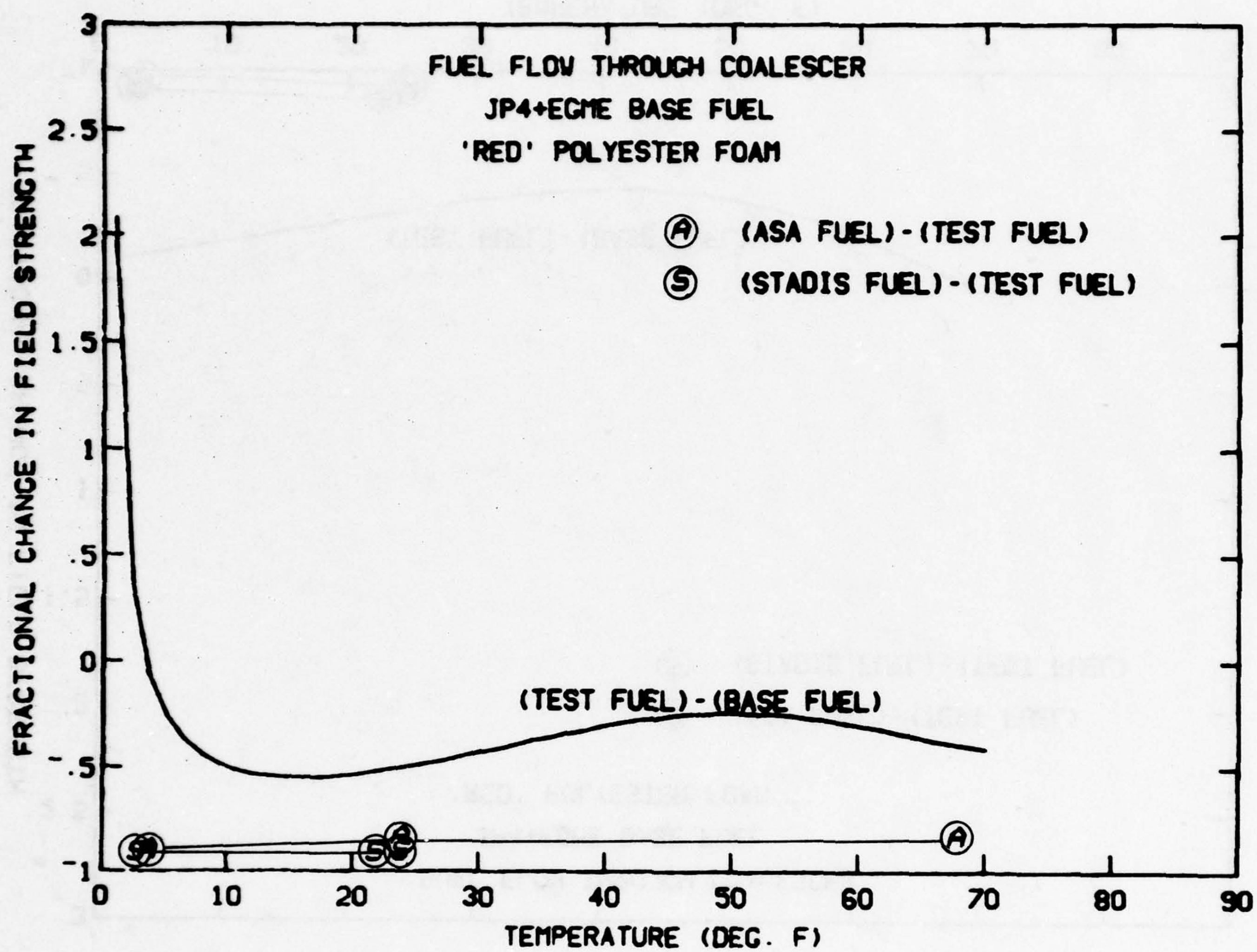


FIGURE 23. EFFECT OF DUPONT DCI4A+ETHYL 733 ON FRACTIONAL CHANGE IN FIELD STRENGTH

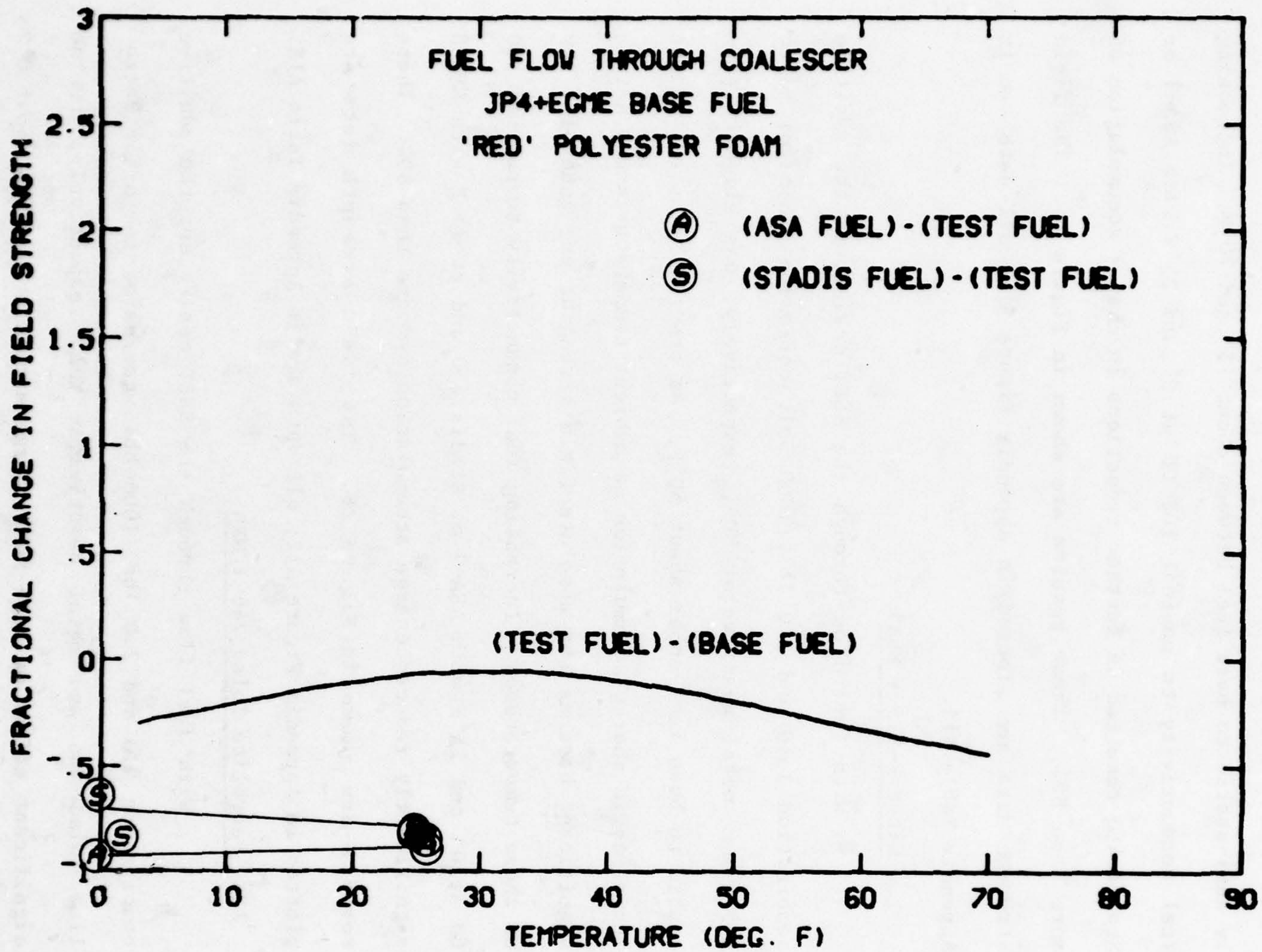


FIGURE 24. EFFECT OF HITEC E515+ETHYL 733 ON FRACTIONAL CHANGE IN FIELD STRENGTH

combination 8.0 and 8.4 lbs./1000 bbl corrosion inhibitor Petrolite Tolad 246 and antioxidant Ethyl 733, respectively, was significantly anti-static to base fuel between about 13° and 70°F. Increasing fuel conductivity to nominal 100 CU at 0° and 25°F with ASA-3 or Stadis 450 resulted in further reductions in charge accumulation of more than 80%. These results are shown in Figure 25. The field strength data are plotted in Appendix Figure A11; all data are in Appendix Table A11.

12. Hitec E-515 + MDA

With fuel flow through the SSET coalescer, the additive combination 16.0 and 2.0 lbs./1000 bbl. corrosion inhibitor Hitec E-515 and metal deactivator MDA, respectively, was slightly pro-static to base fuel above about 50°F. As previously noted, modest increases in charge accumulation at ambient temperatures may not be significant because the absolute field strengths are generally low at these temperatures. Increasing fuel conductivity to nominal 100 CU at 0° and 25°F with ASA-3 or Stadis 450 and at 75 F with ASA-3 significantly reduced charge accumulation by more than 80%. These results are shown in Figure 26. The field strength data are plotted in Appendix Figure A12; all data are in Appendix Table A12.

13. Petrolite Tolad 246 + MDA

With fuel flow through the SSET coalescer, the additive combination 8.0 and 2.0 lbs./1000 bbl. corrosion inhibitor Petrolite Tolad 246 and metal deactivator MDA, respectively, had no significant effect on base fuel charge accumulation from about 0°F to 70°F. Increasing fuel conductivity to nominal 100 CU at 0° and 25°F with ASA-3 or Stadis 450 and at 70°F with Stadis 450 resulted

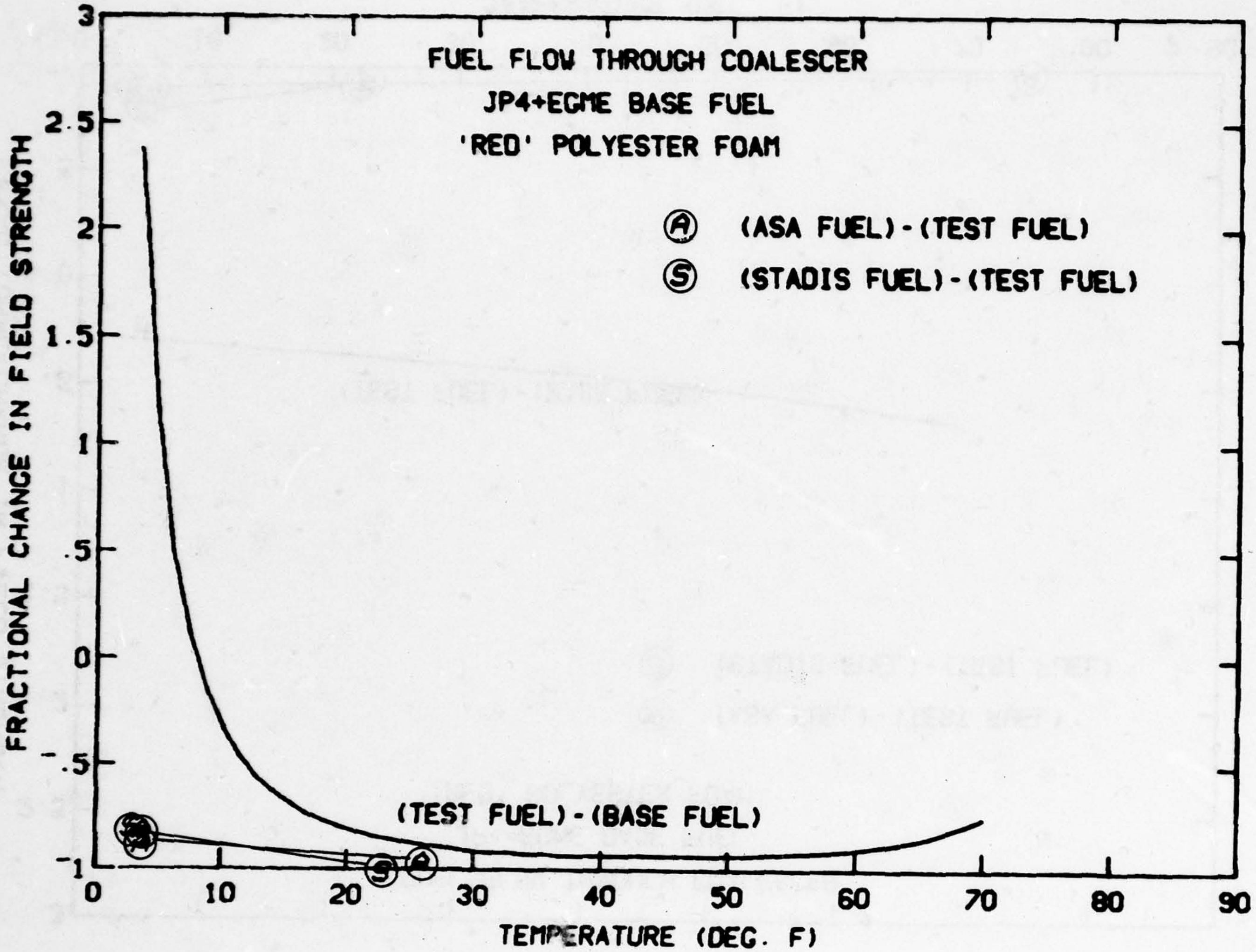


FIGURE 25. EFFECT OF TOLAD 246+ETHYL 733 ON FRACTIONAL CHANGE IN FIELD STRENGTH

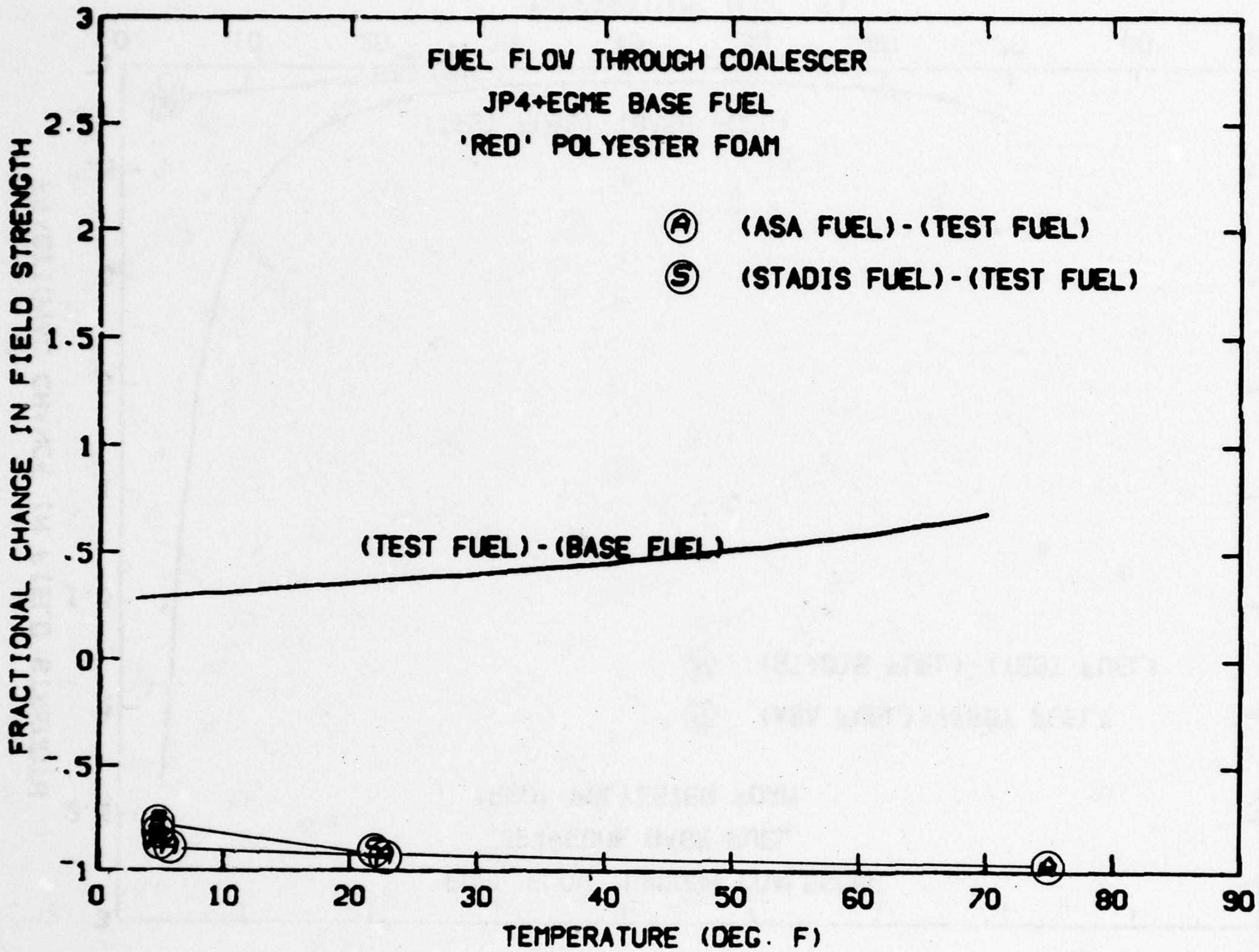


FIGURE 26. EFFECT OF HITEC E515+MDA ON FRACTIONAL CHANGE IN FIELD STRENGTH

in reductions in charge accumulation of more than 90%. Those results are shown in Figure 27. The field strength data are plotted in Appendix Figure A13; all data are in Appendix Table A13.

14. <u>Ethyl 733 + MDA</u>

With fuel flow through the SSET coalescer, the additive combination 8.4 and 8.0 lbs./1000 bbl antioxidant Ethyl 733 and metal deactivator MDA, respectively, was insignificantly anti-static to base fuel between 0° and 70°F. Increasing fuel conductivity to nominal 100 CU at 0° and 25°F with ASA-3 or Stadis 450 and at 70°F with Stadis 450 resulted in significant reductions in charge accumulation of more than 90%. These results are shown in Figure 28. The field strength data are plotted in Appendix Figure A14; all data are in Appendix Table A14.

15. <u>Petrolite Tolad 246 + Ethyl 733 + MDA</u>

With fuel flow through the SSET coalescer, the additive combinations 8.0, 8.4, and 2.0 lbs./1000 bbl. corrosion inhibitor Petrolite Tolad 246, antioxidant Ethyl 733, and metal deactivator MDA, respectively, had no significant effect on base fuel from about 0° to about 65°F. The increase in charge accumulation relative to base fuel at ambient temperature may not be significant. Increasing fuel conductivity to nominal 100 CU at 0° and 25°F with ASA-3 or Stadis 450 and at 70°F with ASA-3 resulted in significant reductions in charge accumulation of more than 90%. These results are shown in Figure 29. The field strength data are plotted in Appendix Figure A15; all data are in Appendix Table A15.

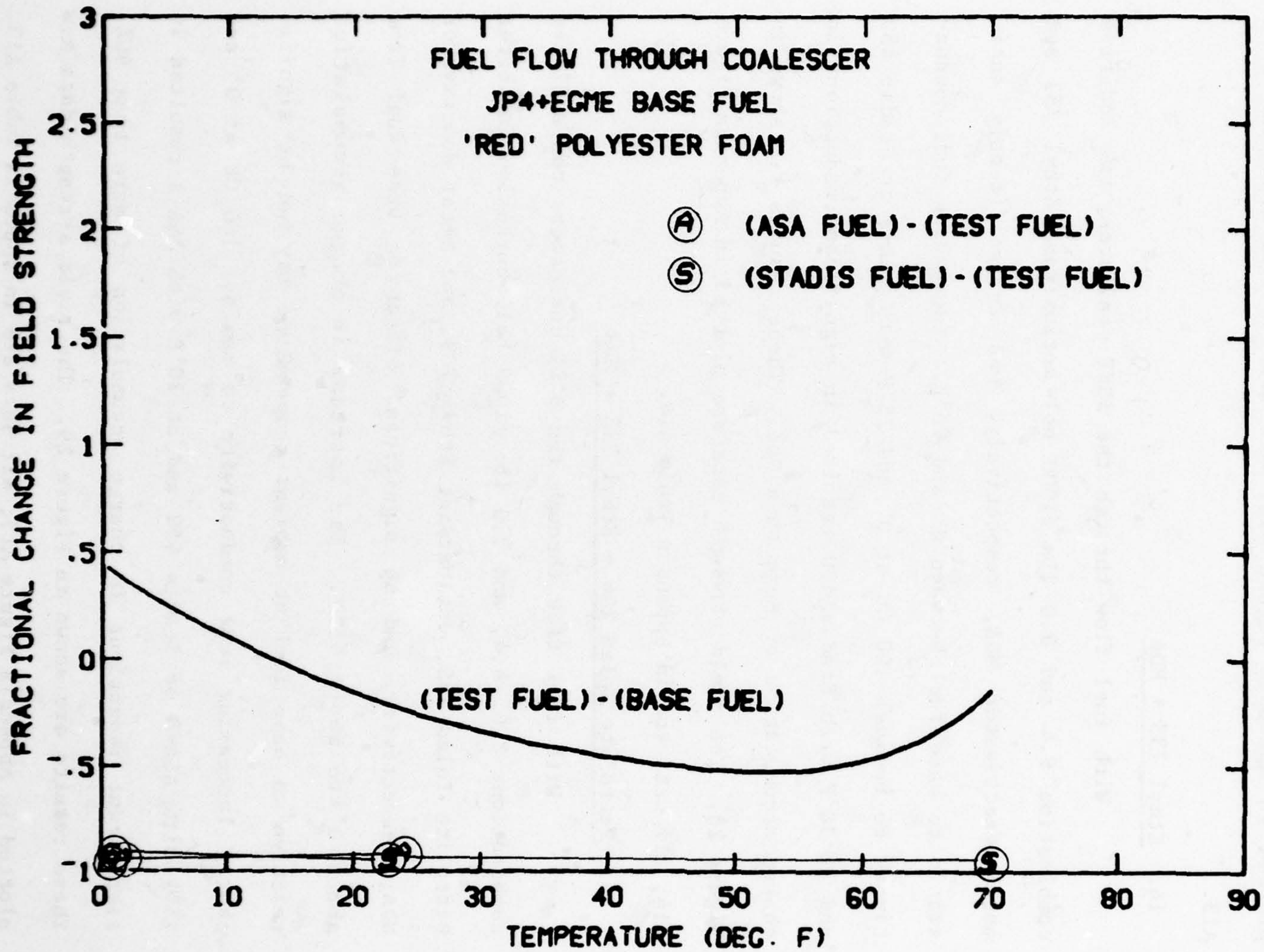


FIGURE 27. EFFECT OF TOLAD 246+MDA ON FRACTIONAL CHANGE IN FIELD STRENGTH

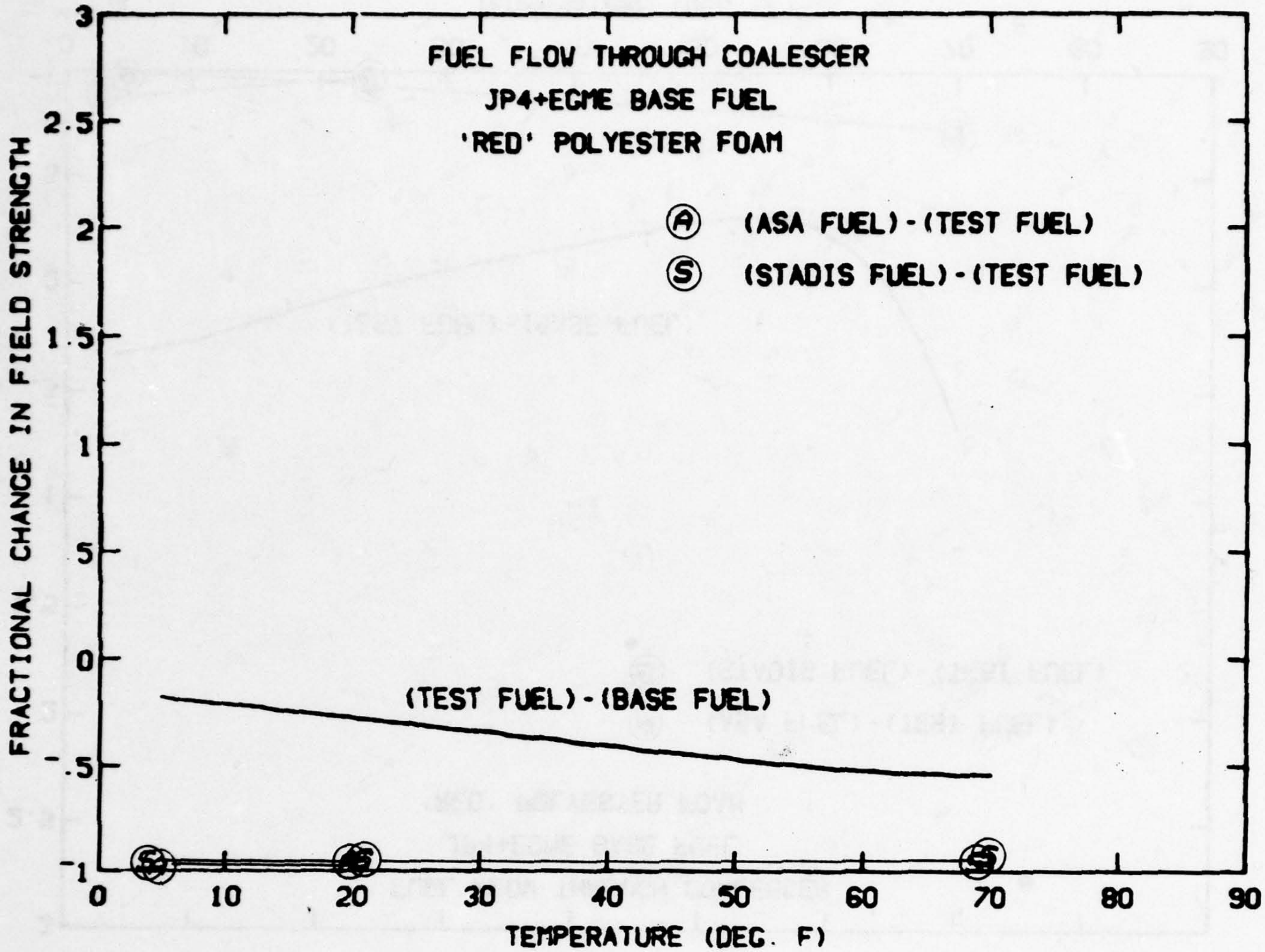


FIGURE 28. EFFECT OF ETHYL 733+MDA ON FRACTIONAL CHANGE IN FIELD STRENGTH

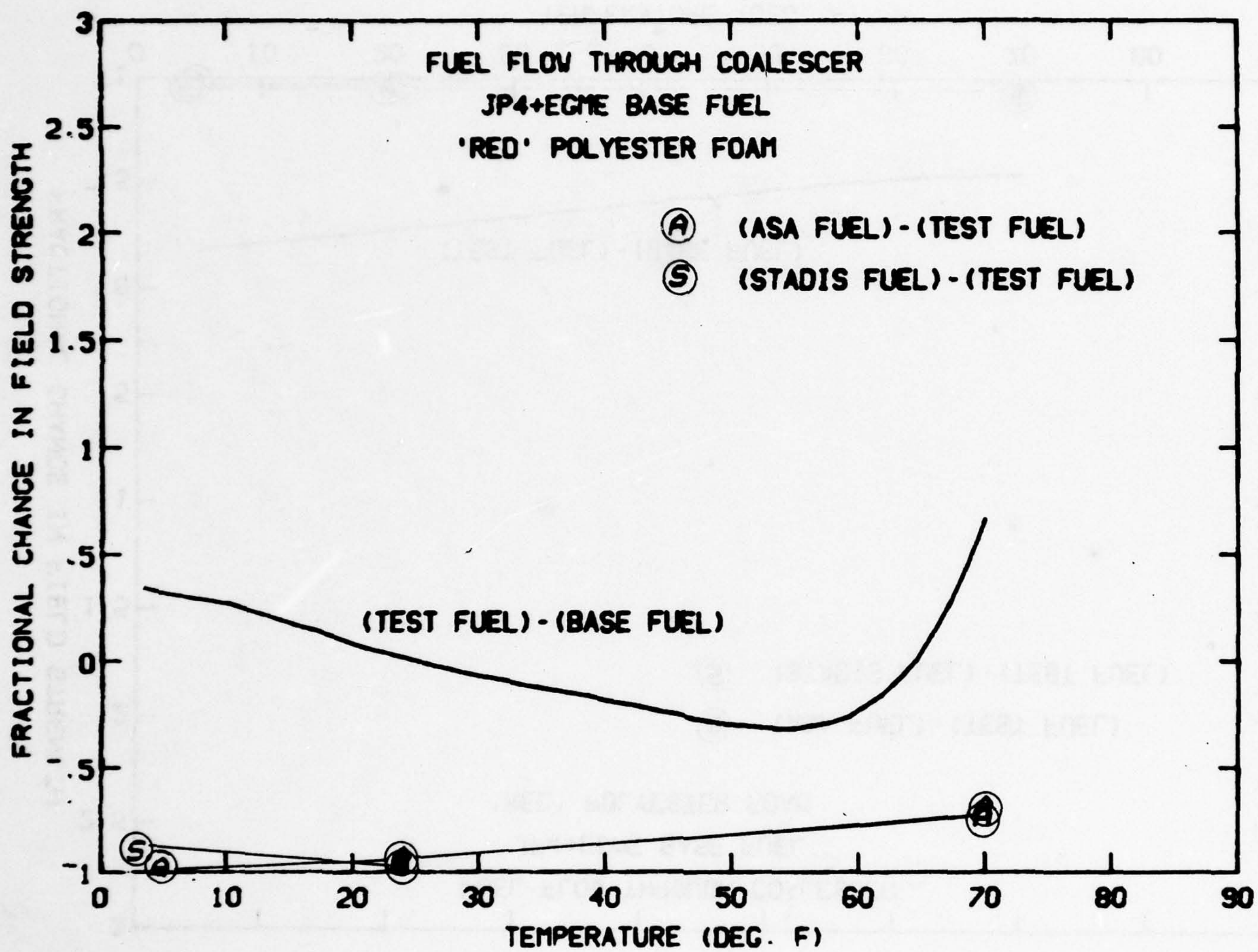


FIGURE 29. EFFECT OF TOLAD 246+ETHYL 733+MDA ON FRACTIONAL CHANGE IN FIELD STRENGTH

16. Summary of Coalescer Charging Results

The corrosion inhibitor results are summarized in Figure 30. With fuel flow through the SSET coalescer, Petrolite Tolad 246 generally had no significant (dF less than 0.5) electrostatic charging effect on base fuel, JP-4 + 0.15% EGME. Hitec E-515 and UOP Unicor J were generally anti-static relative to base fuel. However, DuPont DCI-4A and Apollo PRI-19 showed significant pro-static effects below about 30° and 10°F, respectively. Thus, in the absence of conductivity additives, DuPont DCI-4A and Apollo PRI-19 may be electrostatic hazards at low temperatures. Both conductivity additives, ASA-3 and Stadis 450, were significantly anti-static at 25° and 0°F for all JP-4/additive and additive combinations studied. (Conductivity additives were examined only at 0°F for DuPont DCI-4A and Petrolite Tolad 246; and only at 25°F for UOP Unicor J.)

Separator Charging Studies. Fuel flow through the SSET separator generally generates charges of opposite polarity than coalescer flow. Also, generally, the magnitude of the separator generated charge accumulation was lower. During the course of this study, the separator element manufacturer changed suppliers for the filter paper media used in the SSET separator elements. The magnitude of charging was much greater in these "new" separator elements although polarity and trends with temperature were as the "old" separators. In general, dF, fractional change in field strength, trends were not affected by the change in charging magnitude. Although the experimental data precision was generally

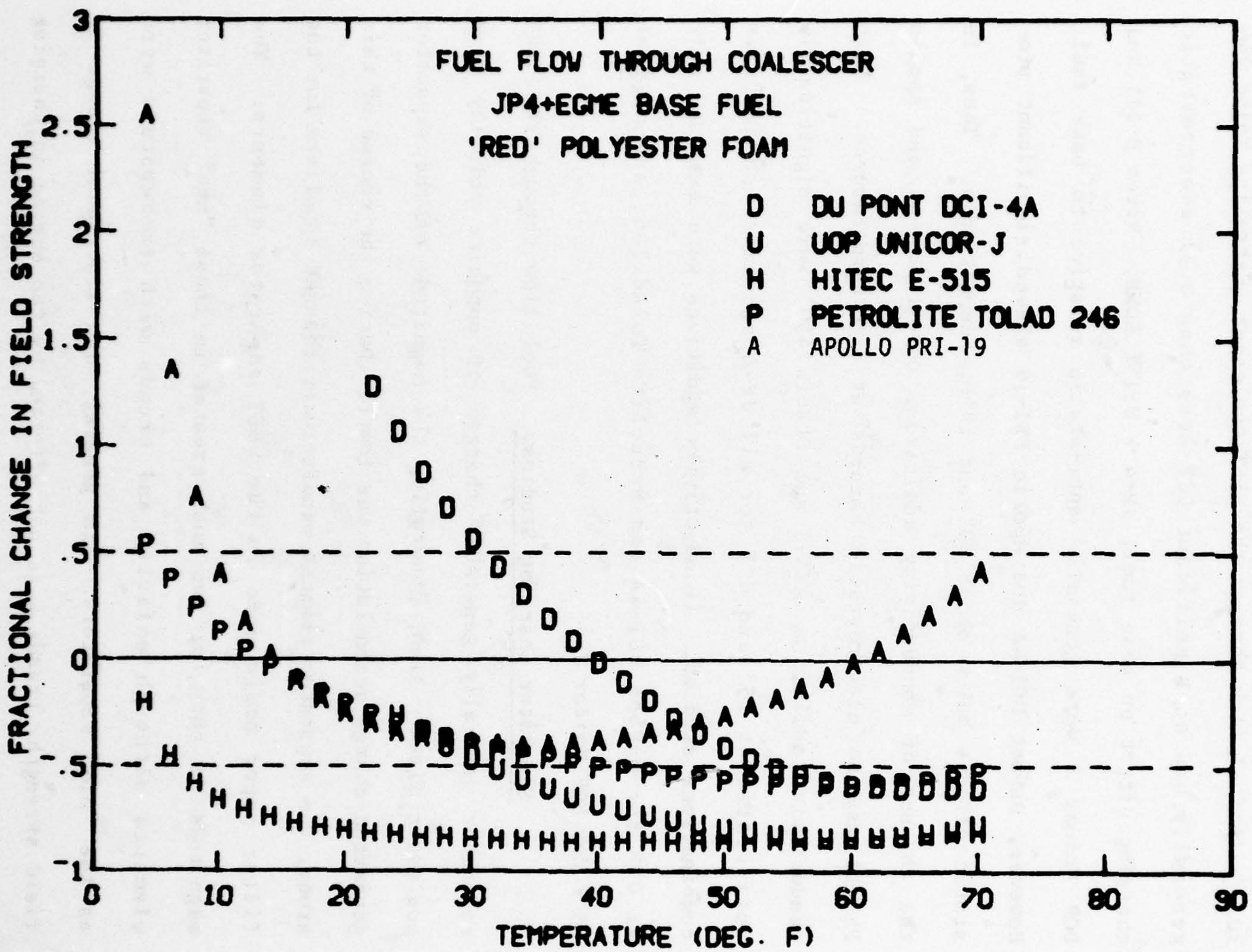


FIGURE 30. EFFECT OF CORROSION INHIBITORS ON FRACTIONAL CHANGE IN FIELD STRENGTH

less with fuel flow through the separator, the same significance criteria, i.e. dF greater than 0.5, was applied as for coalescer charged fuel.

In each additive study at a given temperature, charging was first examined with fuel flow through the coalescer followed by studies with fuel flow through the separator. Thus, data were alternately obtained with both configurations with the same fuels. In the following presentation of the separator charging results, additive concentrations are as presented earlier and are not repeated.

1. DuPont DCI-4A

Similar to previously observed coalescer charged fuel, separator charged fuel containing DuPont DCI-4A was significantly pro-static below about 45°F. Anti-static tendencies were observed above 50°F but this may not be significant because of generally low charging at these temperatures. These results are shown in Figure 31. Field strength data for this additive with fuel flow through the separator are plotted in Appendix Figure A16; the complete SSET data are in Appendix Table A16. In spite of the strong pro-static effects with this additive, increasing the conductivity of the generally negatively charged fuel to nominal 100 CU at 0°F with ASA-3 or Stadis 450 resulted in almost 100% reduction of the charge accumulation.

2. UOP Unicor J

With fuel flow through the SSET separator, this additive had a significant pro-static influence on JP-4 + EGME base fuel

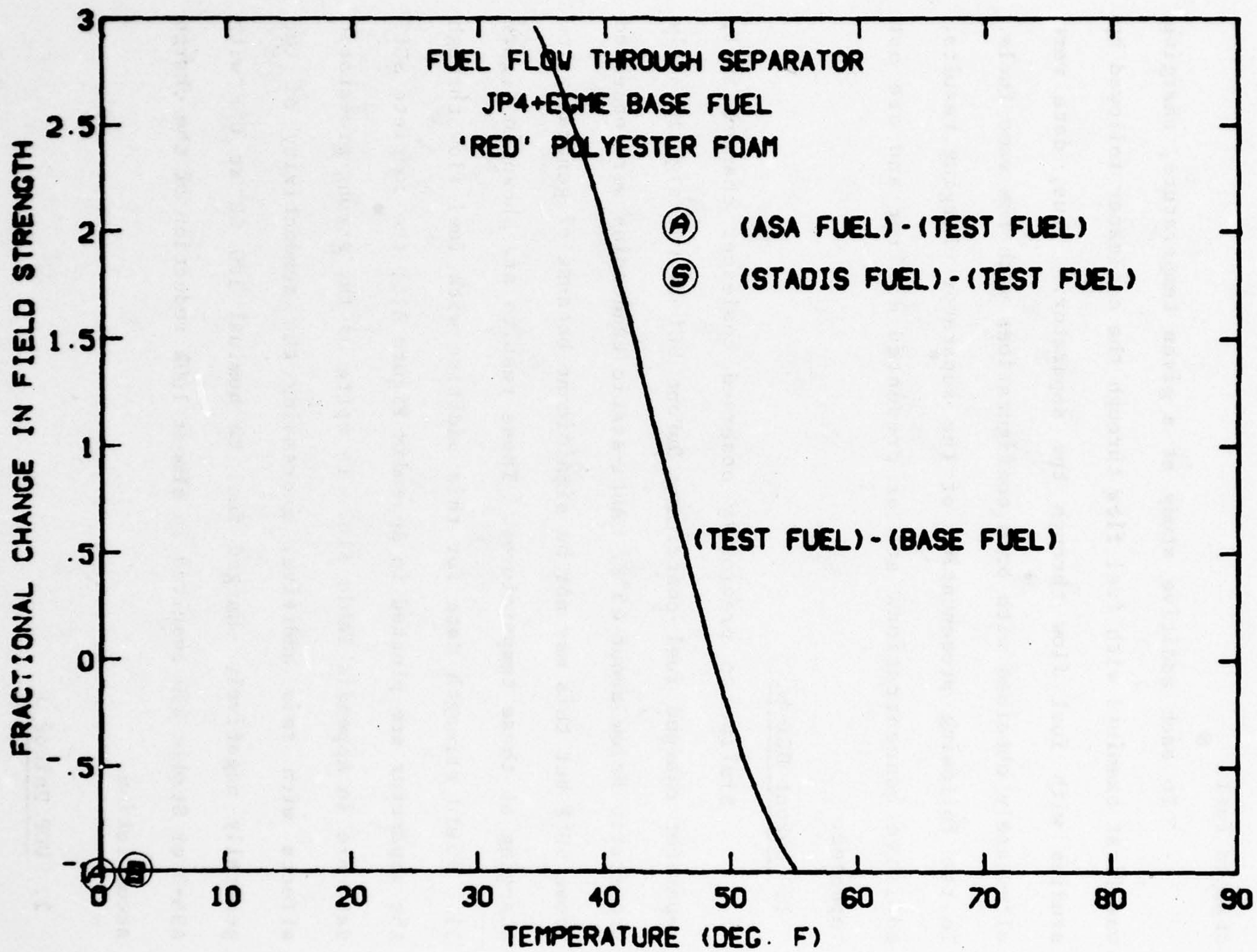


FIGURE 31. EFFECT OF DU PONT DCI-4A ON FRACTIONAL CHANGE IN FIELD STRENGTH

below about 30°F. Similarly, pro-static activity was noted above 62°F but this may not be significant as previously noted. Increasing conductivity to nominal 100 CU at 23°F with either ASA-3 or Stadis 450 effectively reduced separator charge accumulation to negligible values. These results are plotted in Figure 32. Field strength data are plotted in Appendix Figure A17; all data are in Appendix Table A17.

3. Petrolite Tolad 246

With fuel flow through the SSET separator, this additive had no significant effect on base fuel charge accumulation between about 4° and 70°F. Increasing fuel conductivity to nominal 100 CU with either Stadis 450 or ASA-3 significantly reduced charge accumulation at about 5°F. Results for Petrolite Tolad 246 with fuel flow through the SSET separator are presented in Figure 33. The field strength are plotted in Appendix Figure A18; all data are in Appendix Table A18.

4. Hitec E-515

With fuel flow through the SSET separator, Hitec E-515 had a significant pro-static effect on base fuel from about 13° to 70°F. Increasing fuel conductivity to nominal 100 CU at about 5°F significantly reduced the charge accumulation at this temperature. Results for Hitec E-515 with fuel flow through the separator are shown in Figure 34. The field strength data are plotted in Appendix Figure A19; the complete data set for this additive and flow configuration are in Appendix Table A19.

5. Apollo PRI-19

With fuel flow through the SSET separator, Apollo PRI-19

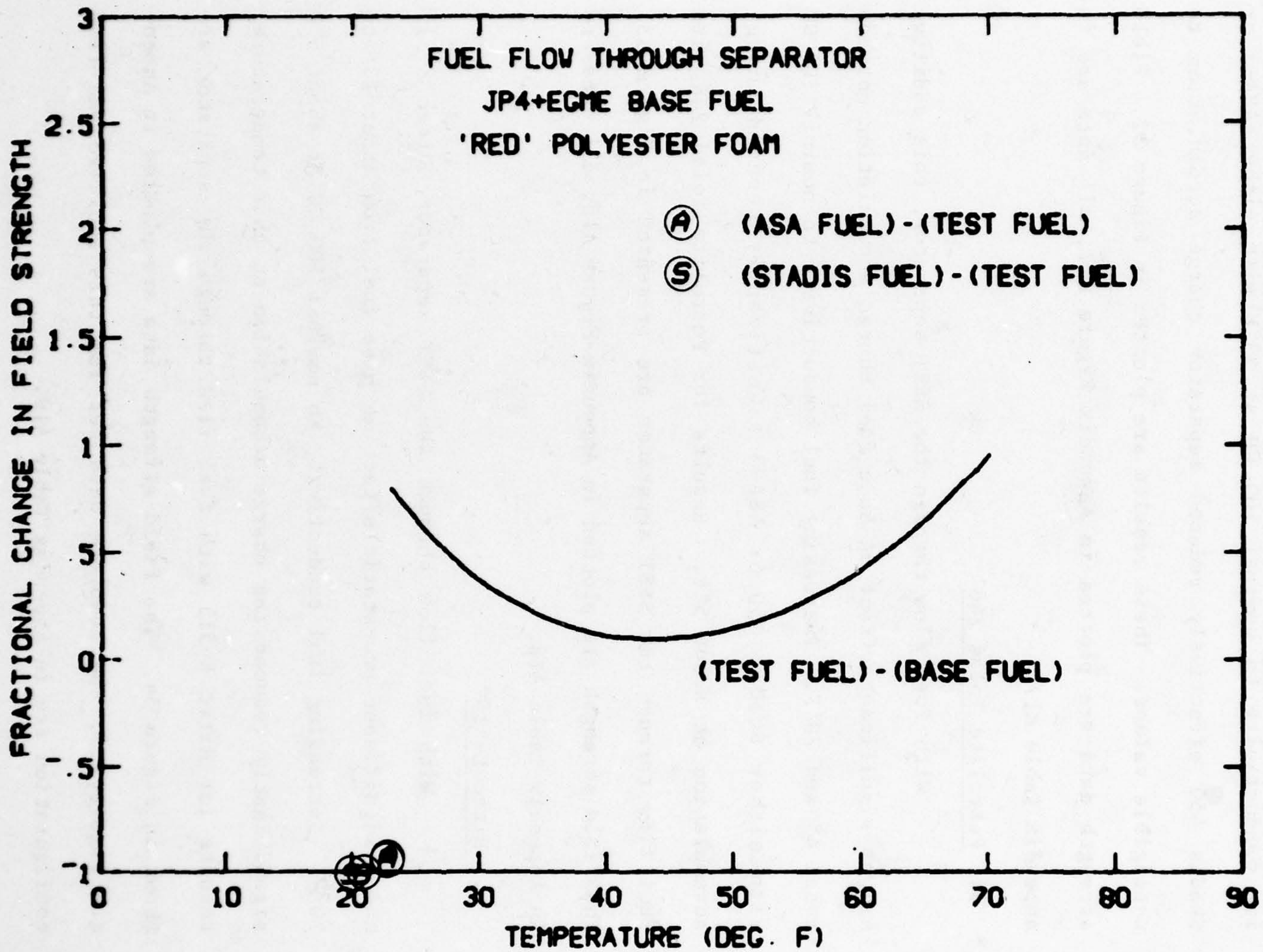


FIGURE 32. EFFECT OF UOP UNICOR-J ON FRACTIONAL CHANGE IN FIELD STRENGTH

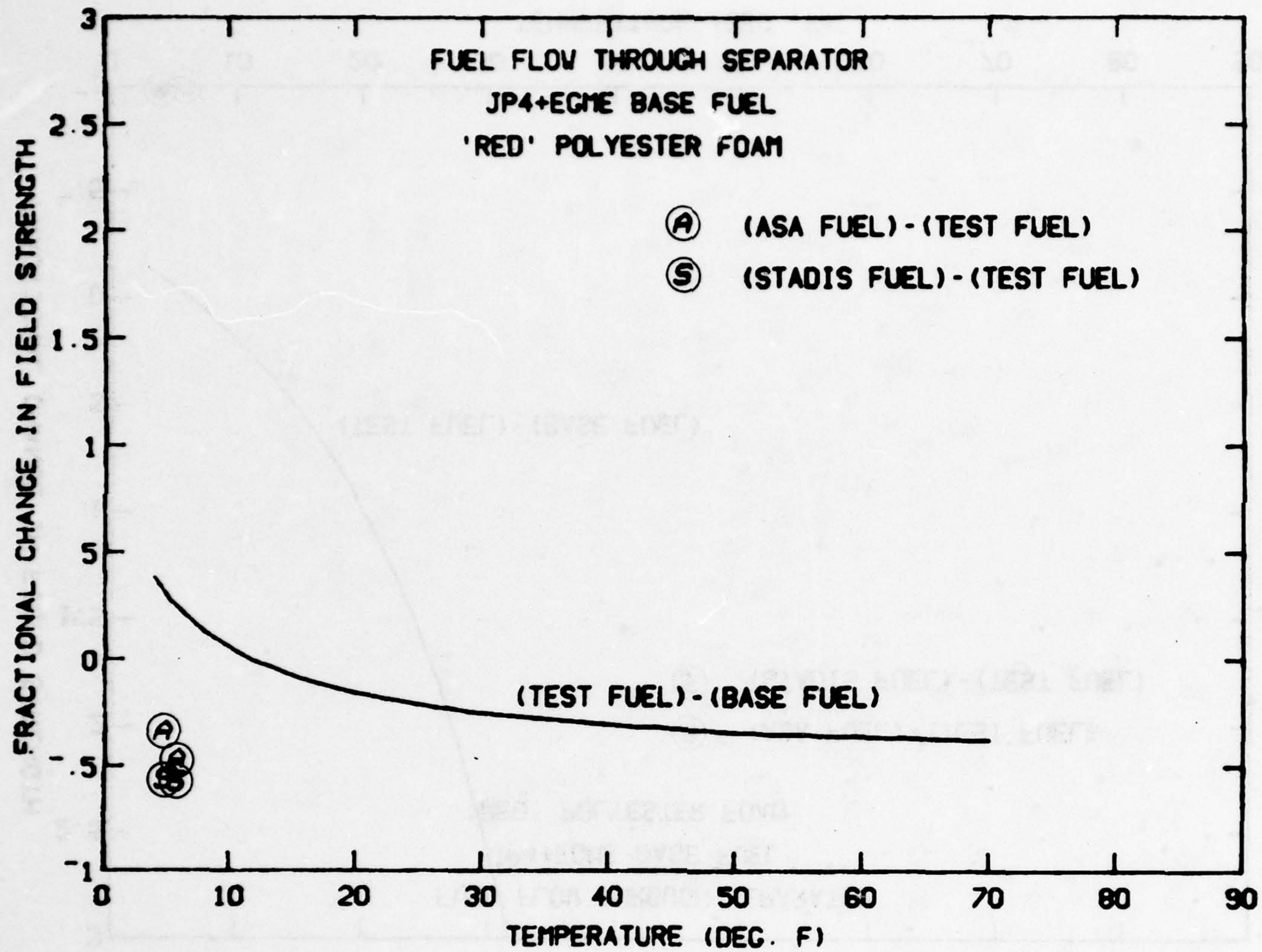


FIGURE 33. EFFECT OF PETROLITE TOLAD 246 ON FRACTIONAL CHANGE IN FIELD STRENGTH

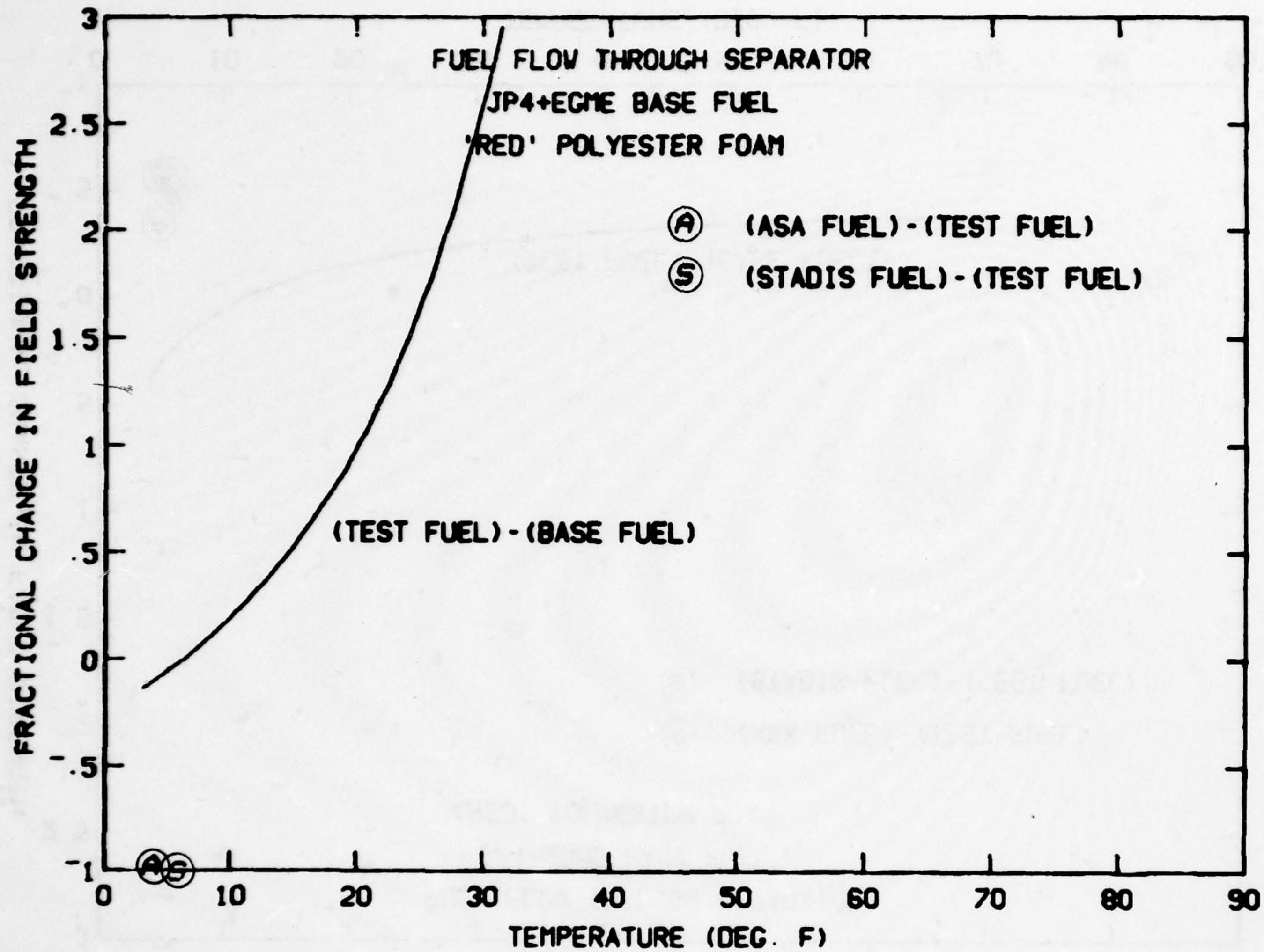


FIGURE 34. EFFECT OF HITEC E-515 ON FRACTIONAL CHANGE IN FIELD STRENGTH

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FACTORS AFFECTING ELECTROSTATIC HAZARDS.(U)
DEC 78 P W KIRKLIN, D L RHYNARD F33615-77-C-2047
UNCLASSIFIED AFAPL-TR-78-89 NL

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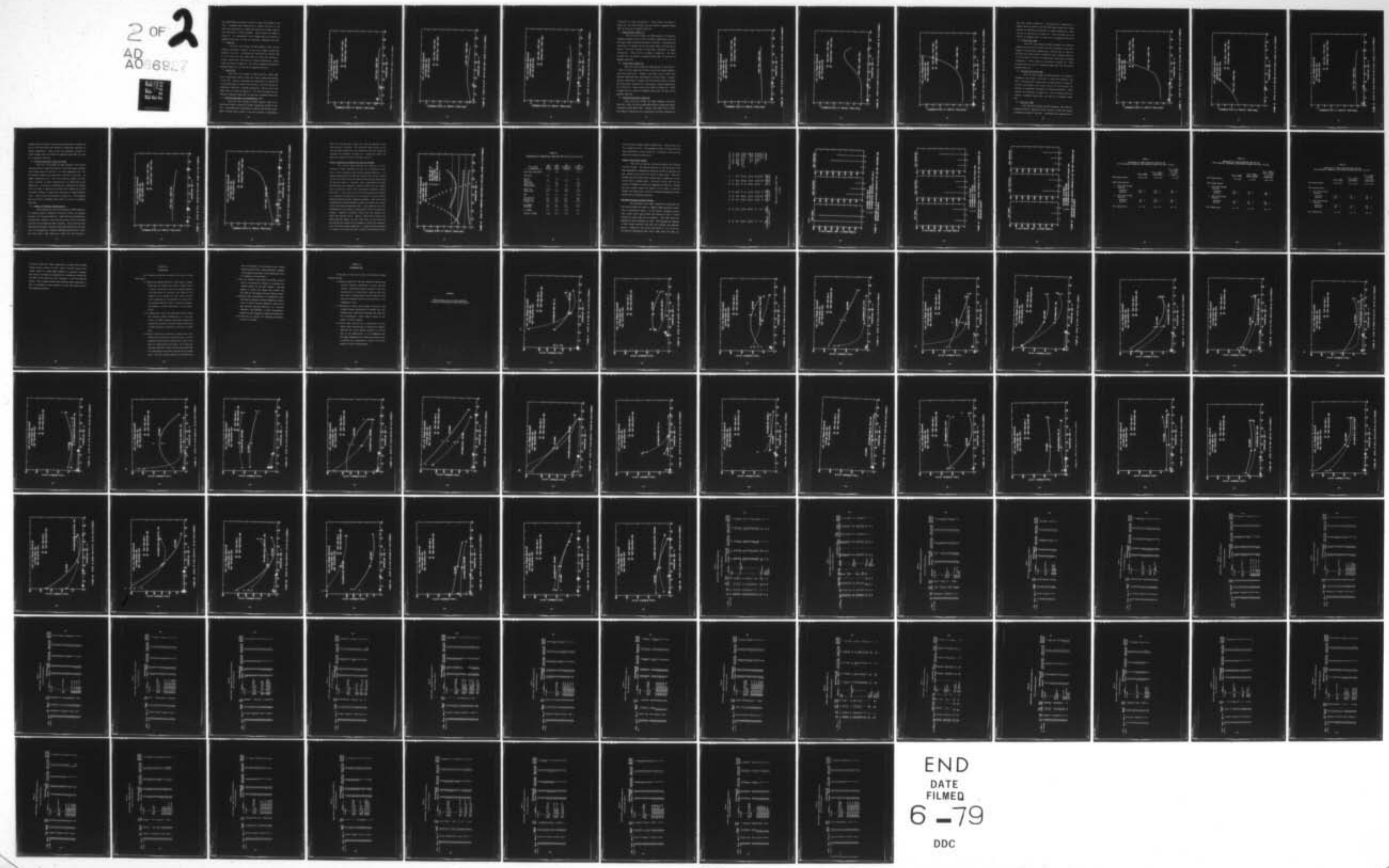

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was significantly anti-static relative to base fuel between 0° and 70°F. Increasing fuel conductivity to nominal 100 CU at 0° and 20°F with either ASA-3 or Stadis 450 resulted in further significant reductions in field strength. These results are shown in Figure 35. The experimental field strength data are plotted in Appendix Figure A20; all data are tabulated in Appendix Table A20.

6. Ethyl 733

With fuel flow through the SSET separator, Ethyl 733 was slightly anti-static relative to base fuel charge accumulation between 0° and 70°F. Increasing fuel conductivity to nominal 100 CU at 0°F and 22°F with either ASA-3 or Stadis 450 resulted in further significant reductions in charge accumulation. These results are shown in Figure 36. The field strengths are plotted in Appendix Figure A21; all data are in Appendix Table A21.

7. DuPont A033

With fuel flow through the SSET separator, DuPont A033 had no appreciable effect on base fuel charge accumulation between 0° and 70°F. However, increasing fuel conductivity to nominal 100 CU with either ASA-3 or Stadis 450 at about 3° and 25°F resulted in significant reductions in charge accumulation. These results with DuPont A033 are shown in Figure 37. The field strength data are plotted in Appendix Figure A22; all data are in Appendix Table A22.

8. N,N'-disalicylidene-1,2-propanediamine (MDA)

With fuel flow through the SSET separator, MDA had no significant effect on base fuel charge accumulation between 0° and 70°F. Increasing fuel conductivity to nominal 100 CU with either ASA-3 or Stadis 450 at about 5° and 25°F resulted in significant

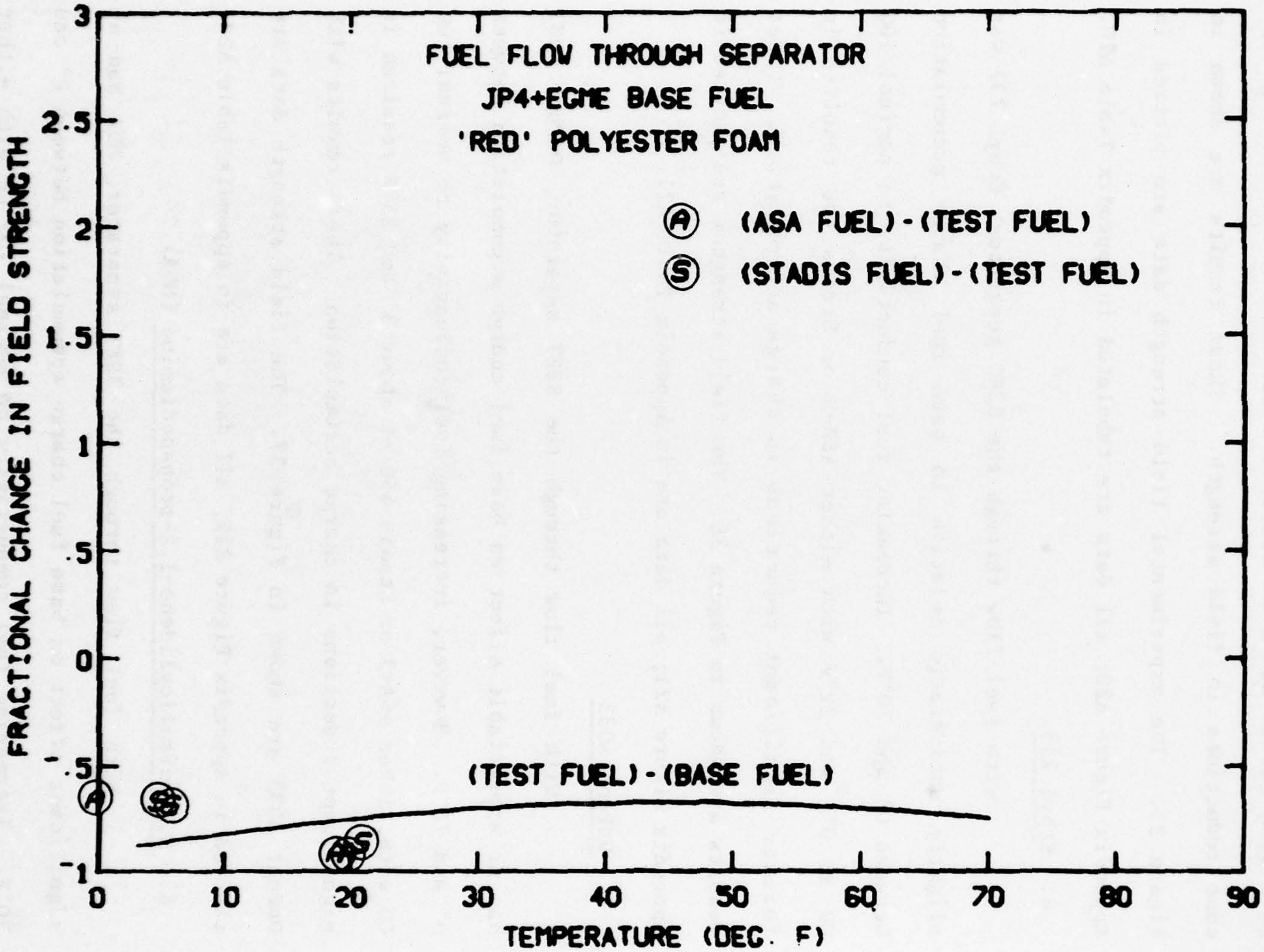


FIGURE 35. EFFECT OF APOLLO PRI-19 ON FRACTIONAL CHANGE IN FIELD STRENGTH

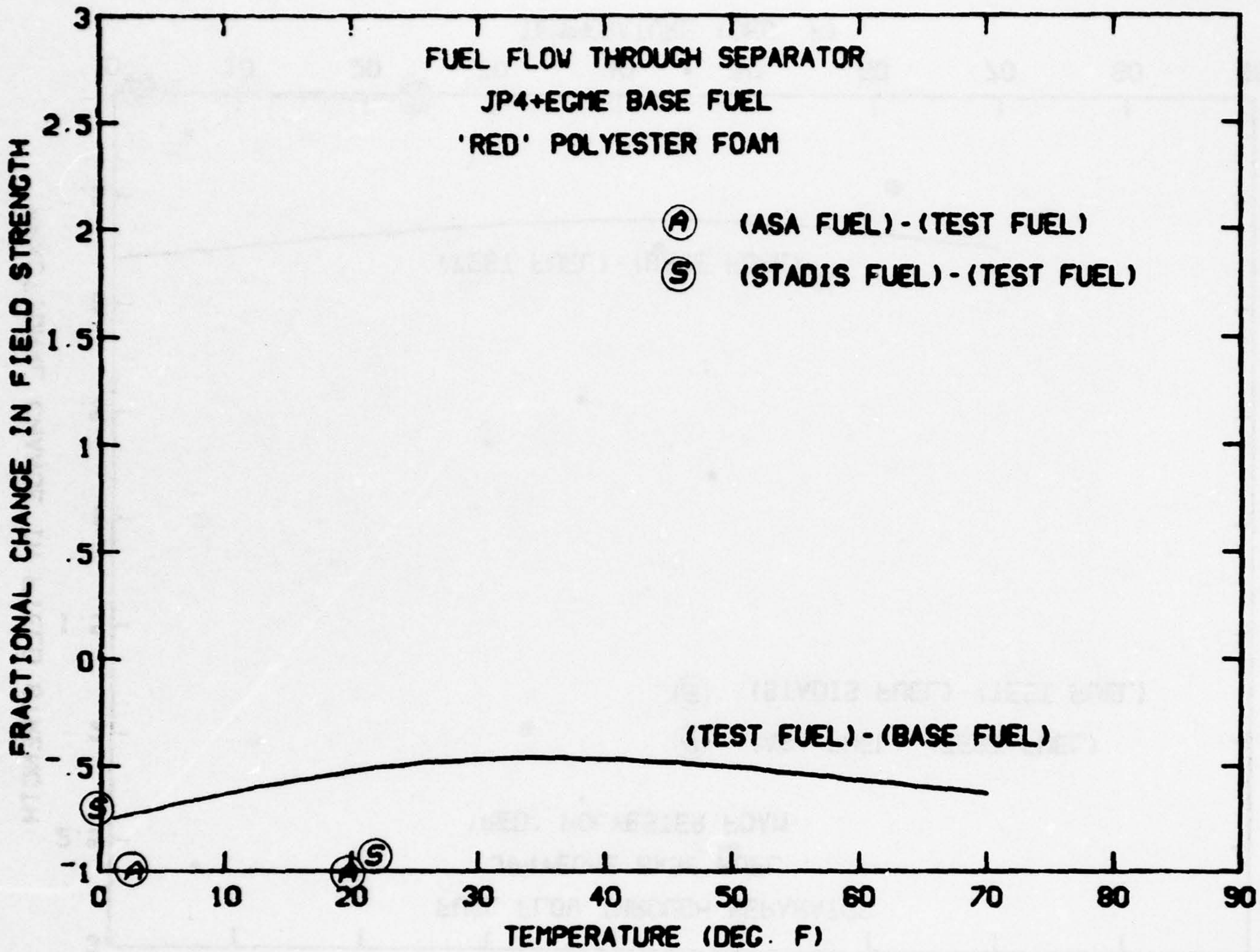


FIGURE 36. EFFECT OF ETHYL 733 ON FRACTIONAL CHANGE IN FIELD STRENGTH

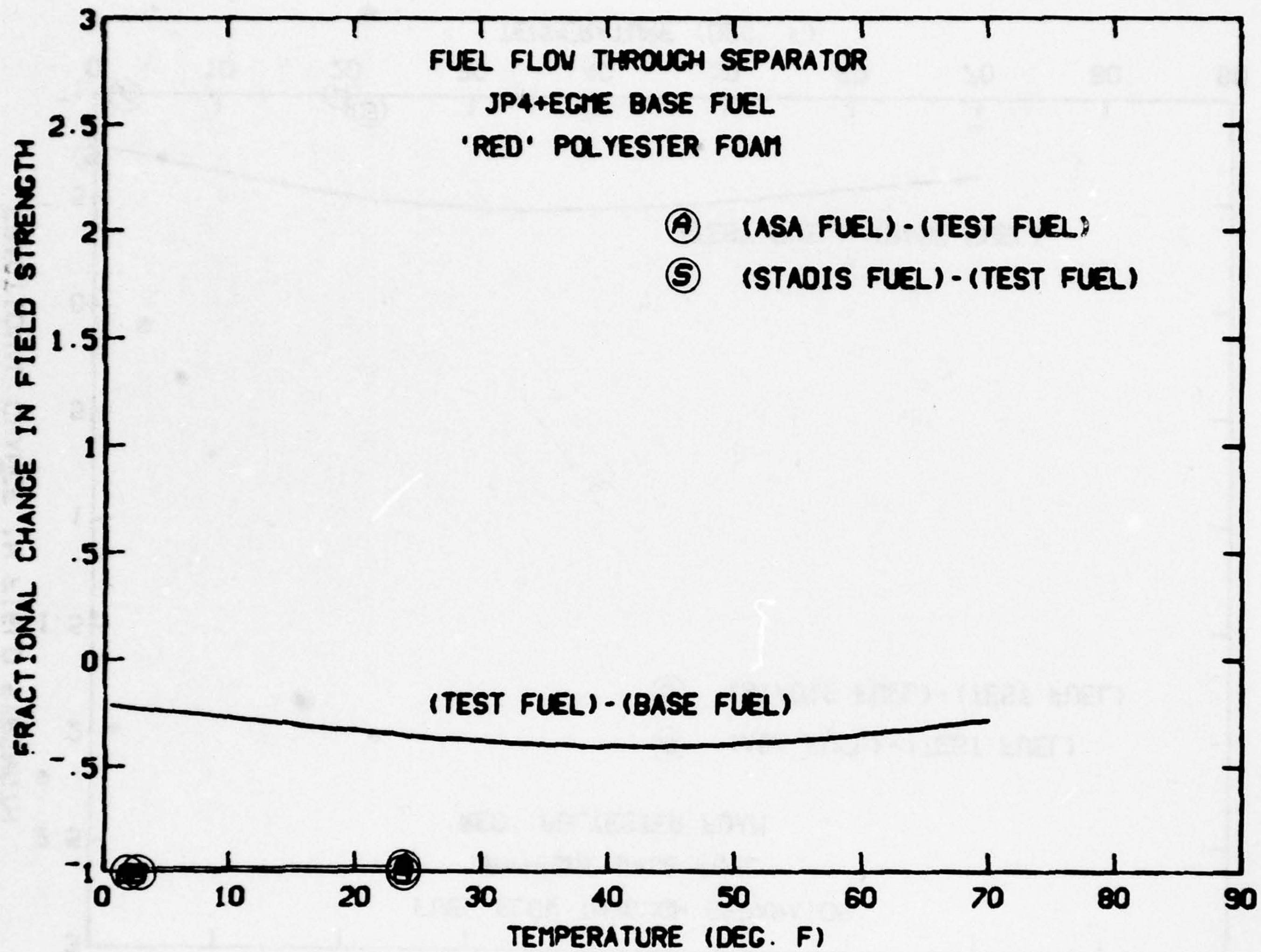


FIGURE 37. EFFECT OF DU PONT A033 ON FRACTIONAL CHANGE IN FIELD STRENGTH

reductions in charge accumulation. These results are shown in Figure 38. The field strength data are plotted in Appendix Figure A23; all data are in Appendix Table A23.

9. DuPont DCI-4A + Ethyl 733

With fuel flow through the SSET separator, the additive combination DuPont DCI-4A + Ethyl 733 had no significant effect on base fuel charge accumulation between 0° and 50°F. Increasing fuel conductivity to nominal 100 CU with either ASA-3 or Stadis 450 at about 5° and 25°F resulted in significant reductions in charge accumulation. These results are shown in Figure 39. The field strength data are plotted in Appendix Figure A24; all data are in Appendix Table A24.

10. Hitec E-515 + Ethyl 733

With fuel flow through the SSET separator, Hitec E-515 + Ethyl 733 had no appreciable effect on base fuel charge accumulation below about 45°F. However, from about 45°F to 70°F, this additive combination had a significant pro-static effect. Increasing fuel conductivity to nominal 100 CU with either ASA-3 or Stadis 450 effectively controlled the electrostatic charge accumulations at 0° and 25°F. These results are shown in Figure 40. Field strength data are plotted in Appendix Figure A25; all data are in Appendix Table A25.

11. Petrolite Tolad 246 + Ethyl 733

With fuel flow through the SSET separator, Petrolite Tolad 246 + Ethyl 733 had no appreciable effect on base fuel charge accumulation below about 45°F. However, from about 45°F to 70°F, this additive combination had a significant pro-static influence on

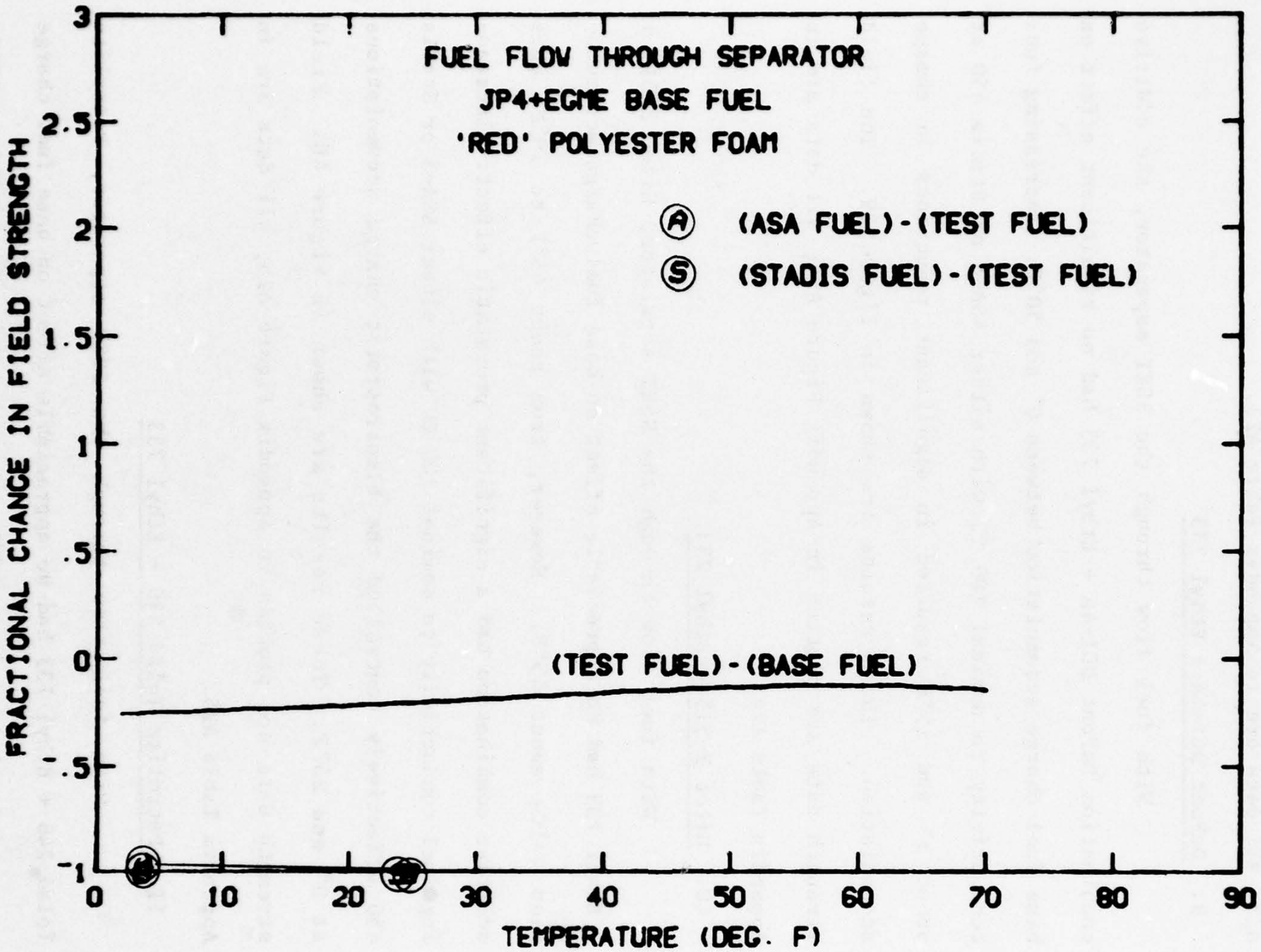


FIGURE 38. EFFECT OF METAL DEACTIVATOR ON FRACTIONAL CHANGE IN FIELD STRENGTH

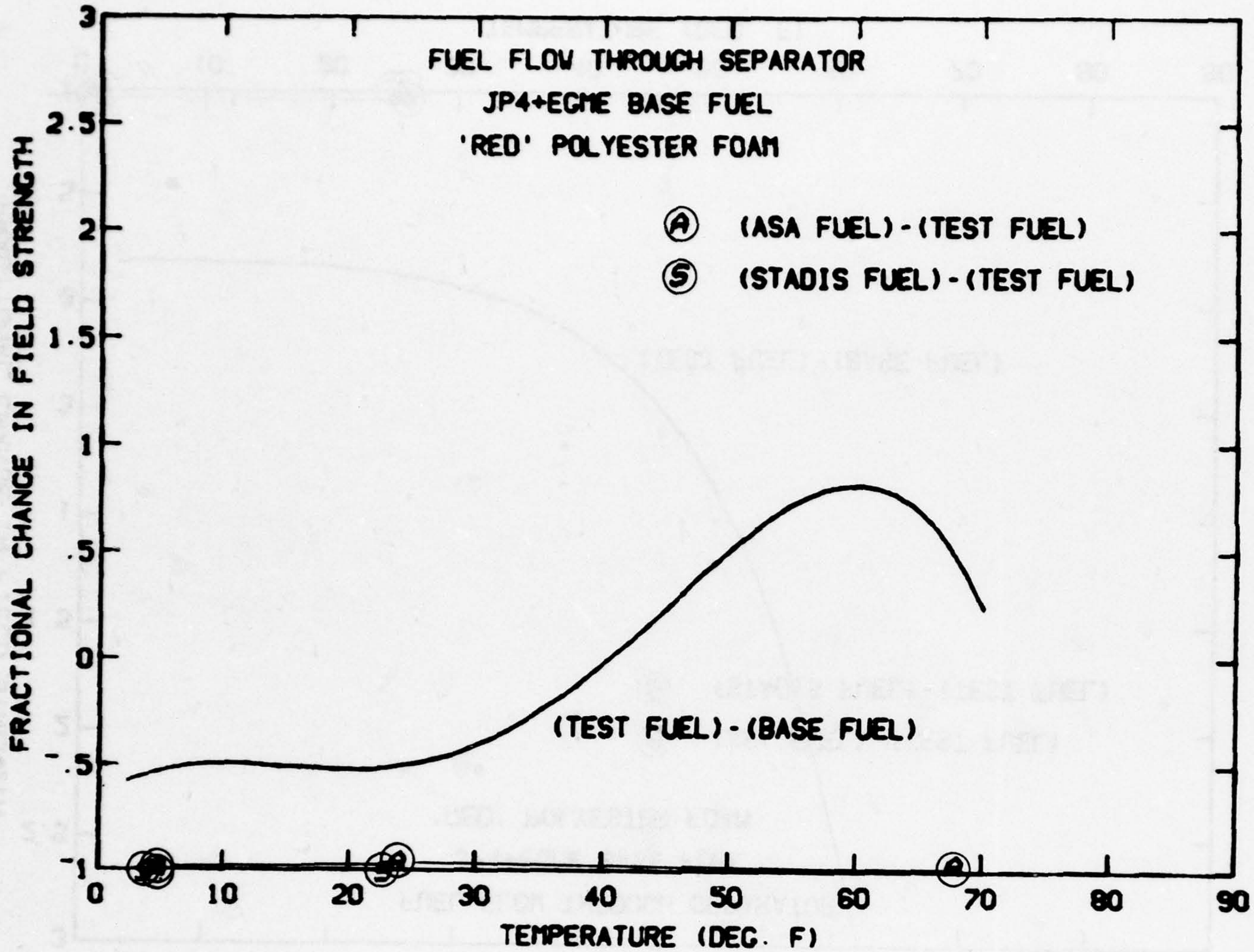


FIGURE 39. EFFECT OF DUPONT DCI4A+ETHYL 733 ON FRACTIONAL CHANGE IN FIELD STRENGTH

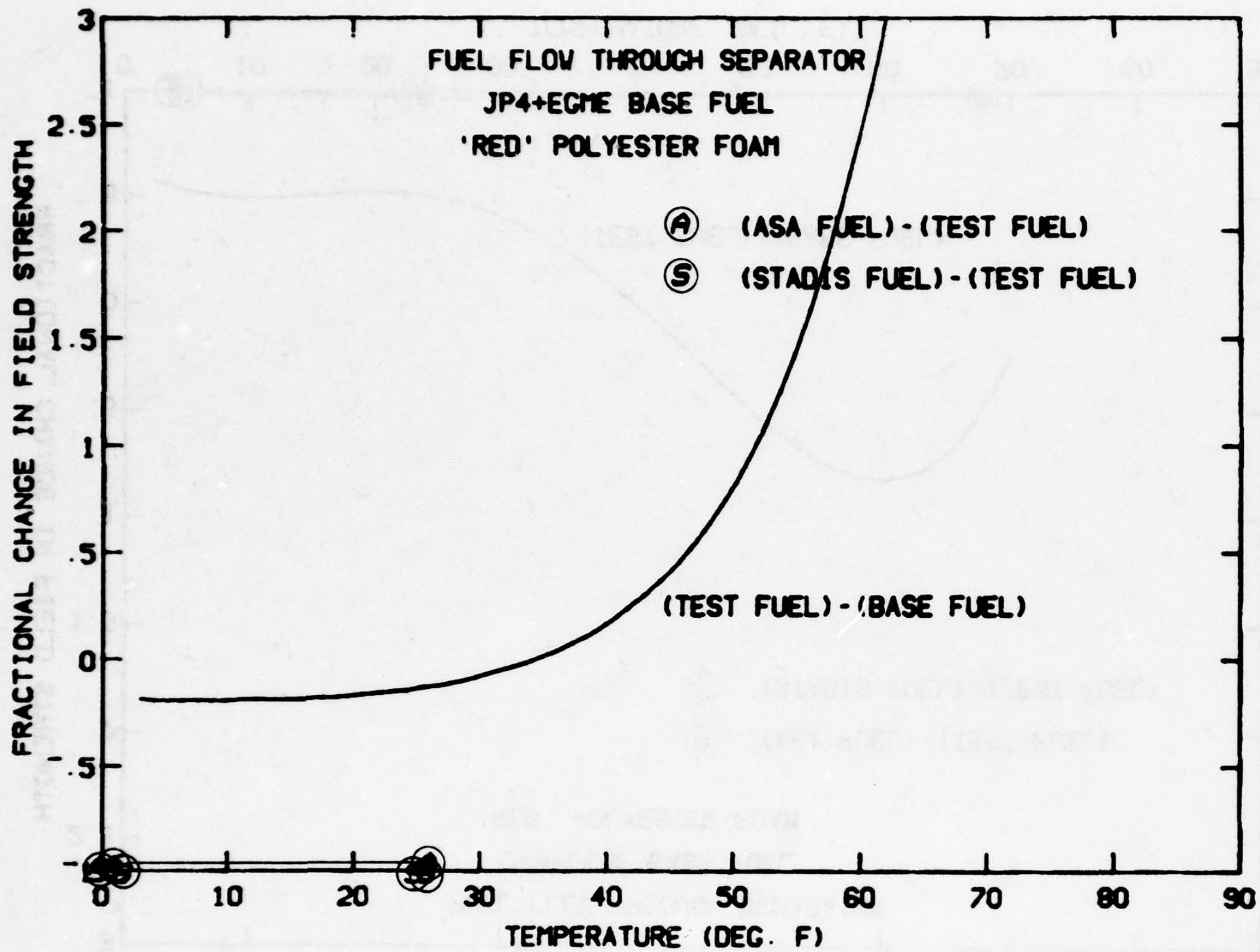


FIGURE 40. EFFECT OF HITEC E515+ETHYL 733 ON FRACTIONAL CHANGE IN FIELD STRENGTH

base fuel charge accumulation. Increasing fuel conductivity to nominal 100 CU at about 5° and 25°F with either Stadis 450 or ASA-3 resulted in significant reductions in charge accumulation. These results are presented in Figure 41. Field strength data are plotted in Appendix A26; all data are in Appendix Table A16.

12. <u>Hitec E-515 + MDA</u>

With fuel flow through the SSET separator, this additive combination was significantly pro-static between 0° and 70°F. However, increasing fuel conductivity to nominal 100 CU at about 5° and 20°F with either ASA-3 or Stadis 450 and to nominal 100 CU at 75°F with ASA-3, resulted in significant reductions in charge accumulation. These results are presented in Figure 42. Field strength data are plotted in Appendix Figure A27; all data are in Appendix Table A27.

13. <u>Petrolite Tolad 246 + MDA</u>

With fuel flow through the SSET separator, this additive combination was slightly anti-static to base fuel between 0° and 70°F. Increasing fuel conductivity to nominal 100 CU at about 5° and 25°F with Stadis 450 or ASA-3 and at 70°F with Stadis 450 resulted in significant reductions in charge accumulation. These results are presented in Figure 43. Field strength data are plotted in Appendix Figure A28; all data are in Appendix Table A28.

14. <u>Ethyl 733 + MDA</u>

With fuel flow through the SSET separator, this additive combination had no significant effect relative to base fuel charge accumulation between 0° and 70°F. Increasing fuel conductivity to

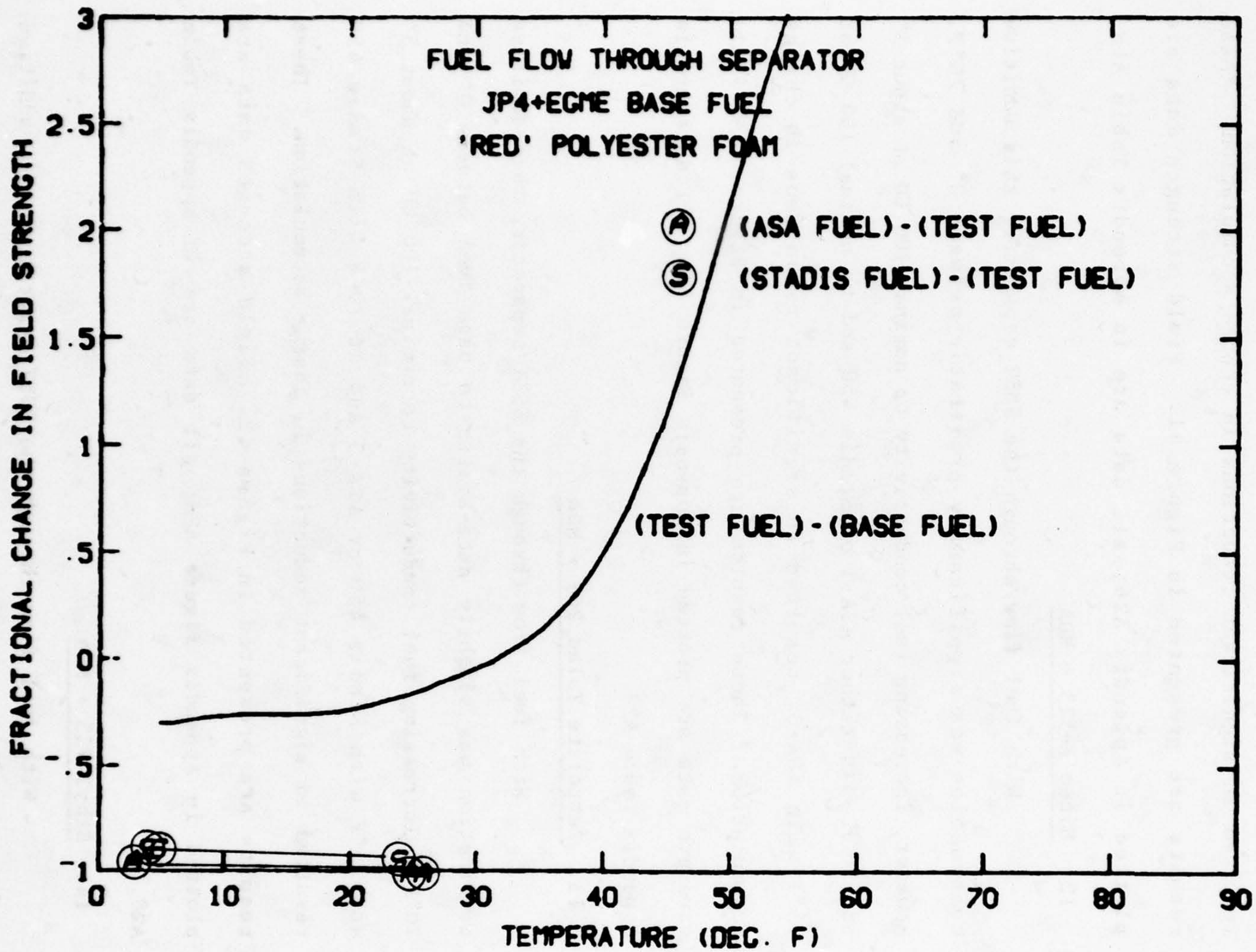


FIGURE 41. EFFECT OF TOLAD 246+ETHYL 733 ON FRACTIONAL CHANGE IN FIELD STRENGTH

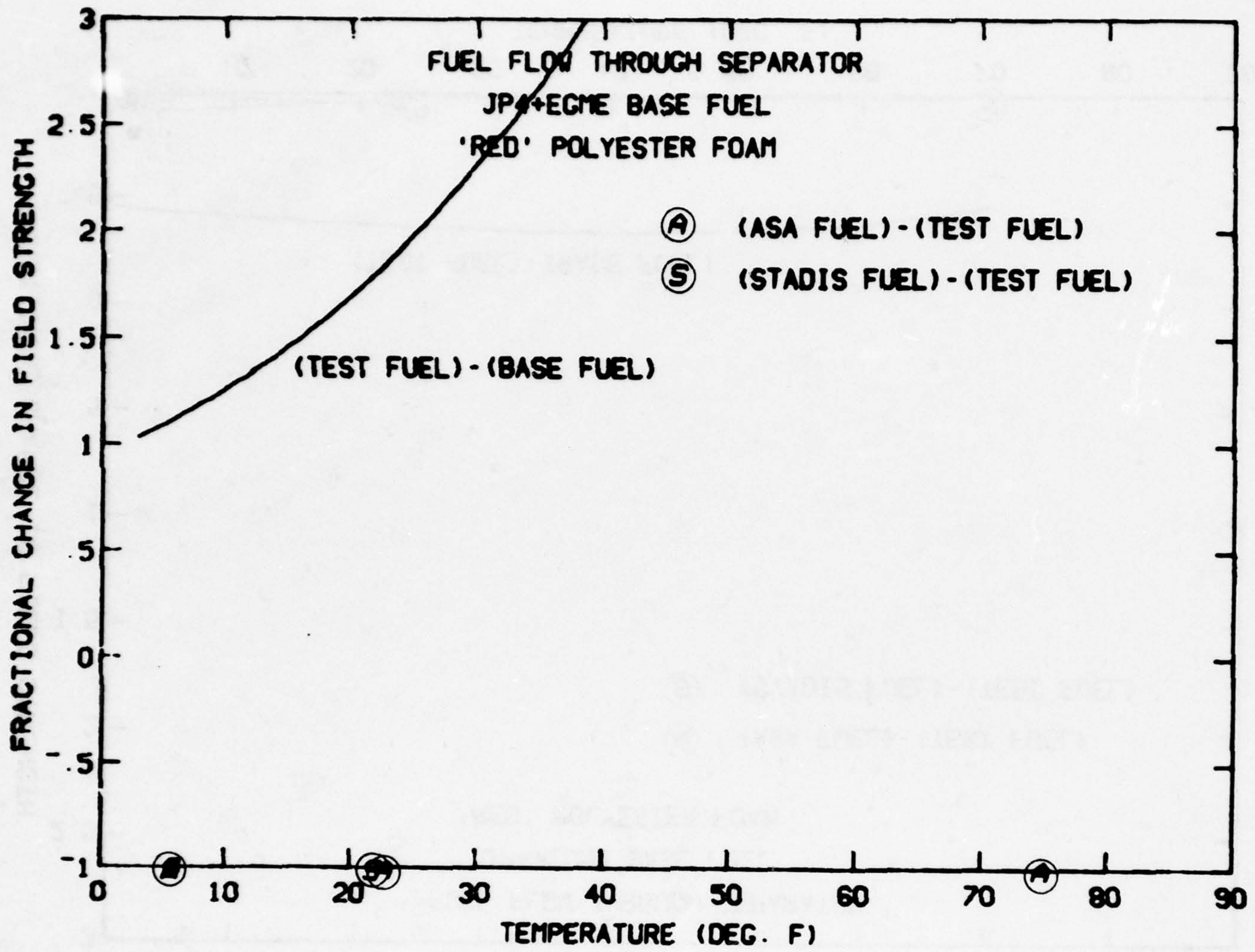


FIGURE 42. EFFECT OF HITEC E515+MDA ON FRACTIONAL CHANGE IN FIELD STRENGTH

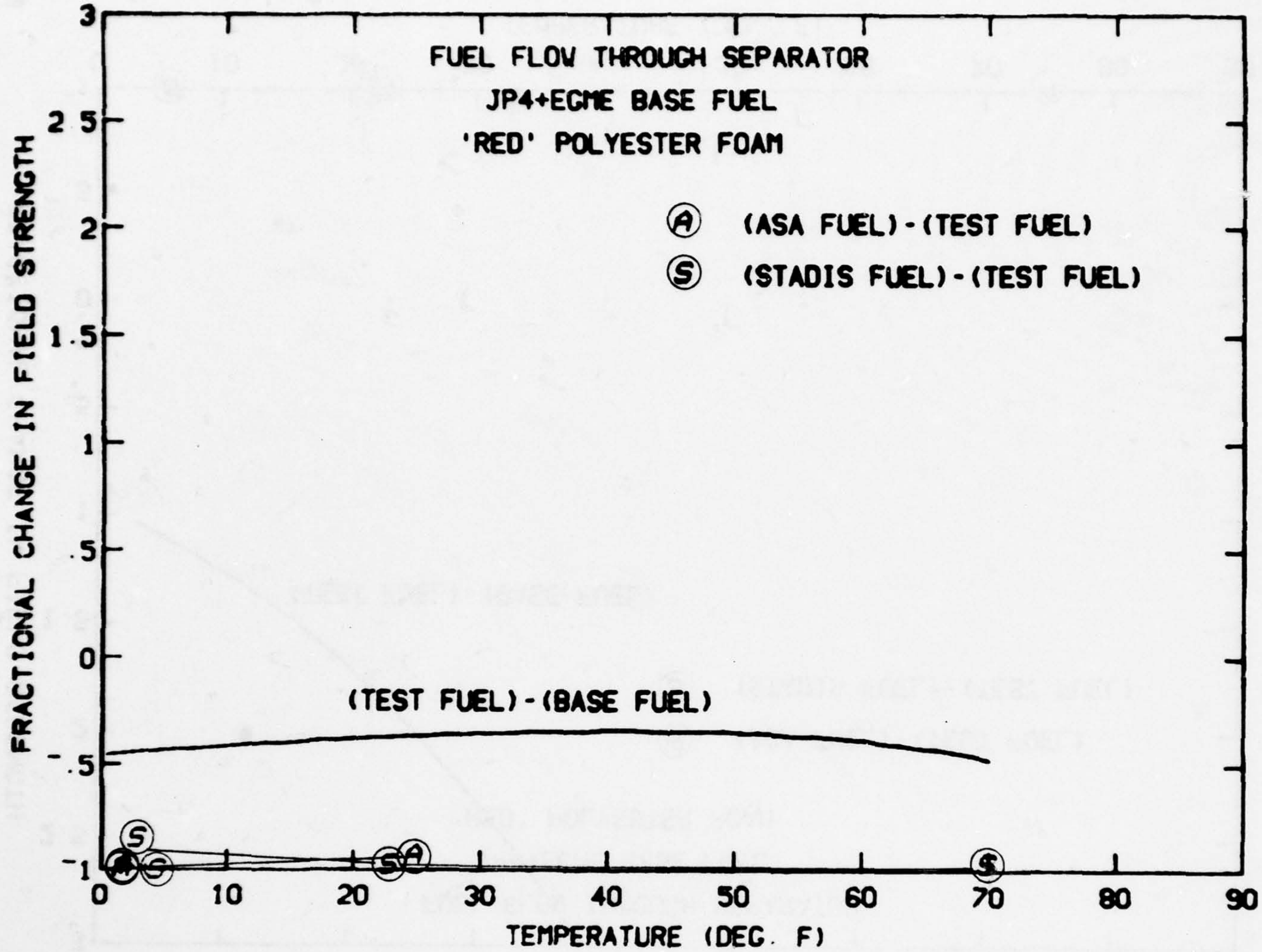


FIGURE 43. EFFECT OF TOLAD 246+MDA ON FRACTIONAL CHANGE IN FIELD STRENGTH

nominal 100 CU at about 5° and 20°F with either ASA-3 or Stadis 450 and at 70°F with Stadis 450 resulted in significant reductions in charge accumulation. These results are presented in Figure 44. Field strength data are plotted in Appendix Figure A29; all data are in Appendix Table A29.

15. Petrolite Tolad 246 + Ethyl 733 + MDA

With fuel flow through the SSET separator, this additive combination had no significant effect on base fuel charge accumulation between about 8°F and 63°F. At lower temperature (8°- 0°F) the additive tended to be anti-static relative to base fuel. At higher temperatures, 63° - 70°F, this additive tended to be pro-static; however, at these temperatures, the effect may not be significant. At any rate, increasing fuel conductivity to nominal 100 CU at about 5° and 25°F with Stadis 450 or ASA-3 and at 70°F with ASA-3 resulted in significant reductions in charge accumulations. These results are presented in Figure 45. Field strength data are plotted in Appendix Figure A30; all data are in Appendix Table A30.

16. Summary of Separator Charging Results

With additized JP-4 fuel flow through the SSET separator, the observed additive combination pro-static effects all appeared related to the corrosion inhibitor. DuPont DCI-4A was significantly pro-static relative to base fuel below about 45°F as was found with fuel flow through the SSET coalescer. Hitec E-515 was also significantly prostatic relative to base fuel above about 15°F with this flow configuration. Additive combinations Hitec E-515 + Ethyl 733, Hitec E-515 + MDA, Tolad 246 + Ethyl 733, and Tolad 246 +

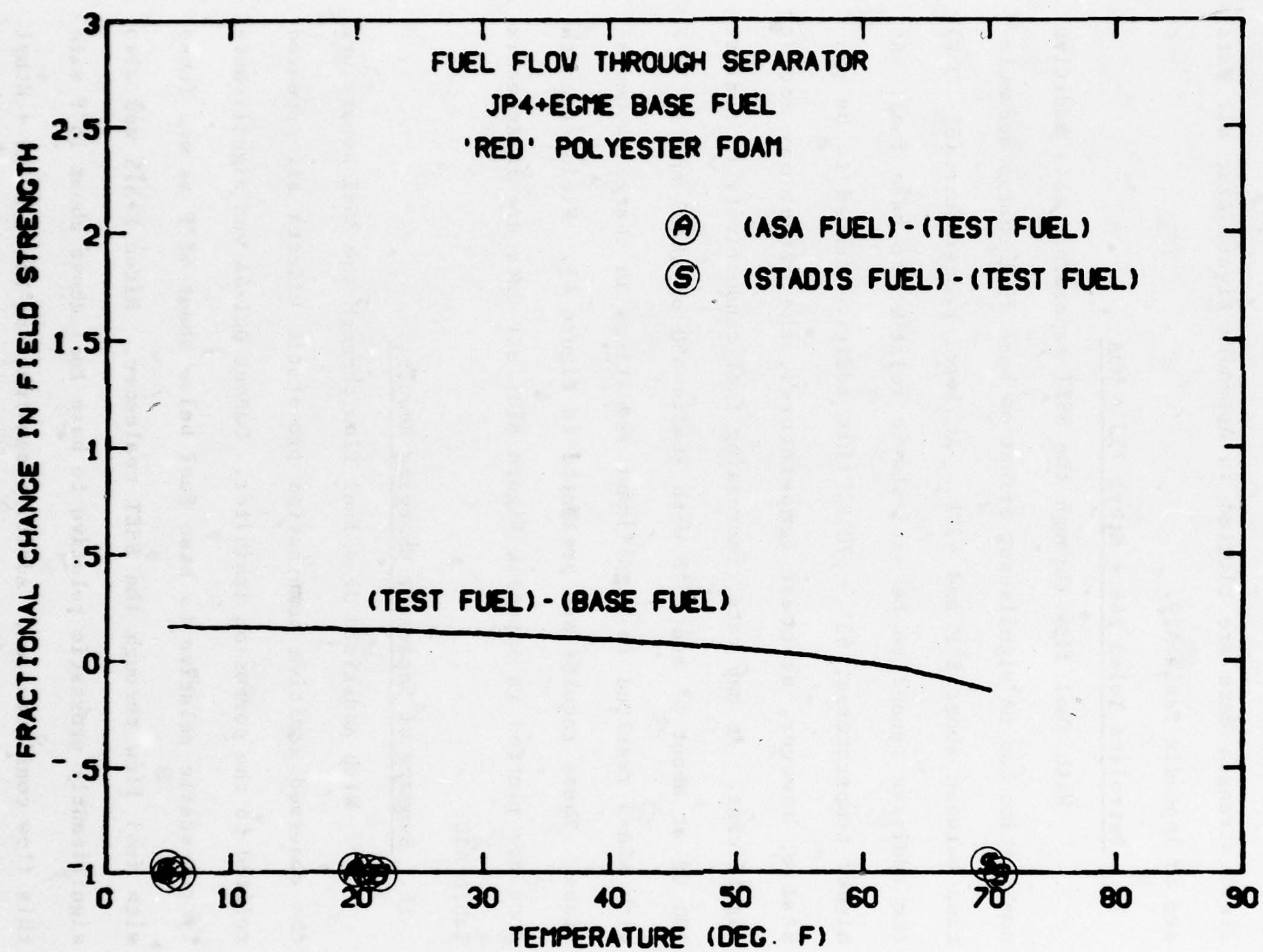


FIGURE 44. EFFECT OF ETHYL 733+MDA ON FRACTIONAL CHANGE IN FIELD STRENGTH

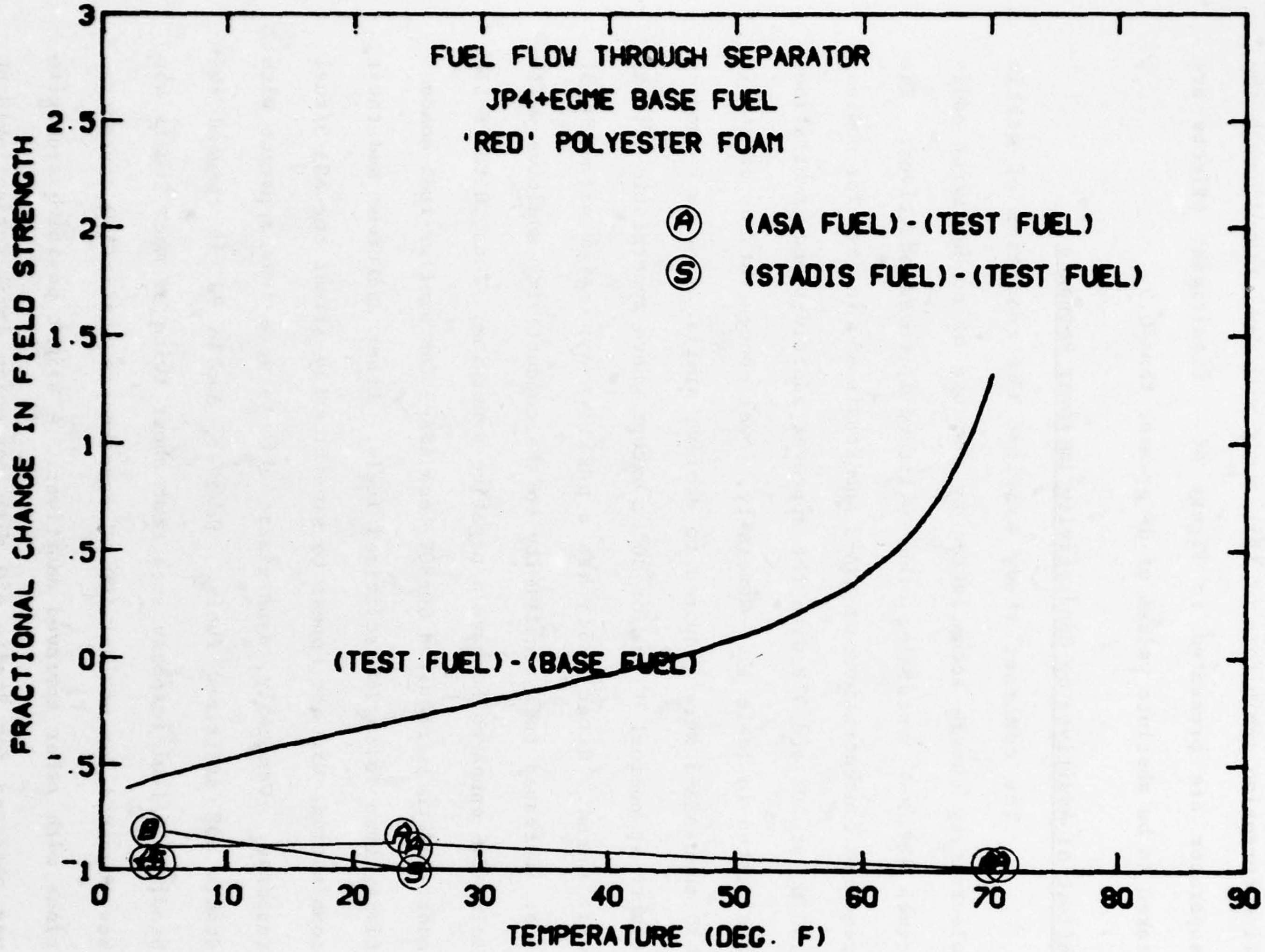


FIGURE 45. EFFECT OF TOLAD 246+ETHYL 733+MDA ON FRACTIONAL CHANGE IN FIELD STRENGTH

Ethyl 733, and Tolad 246 + Ethyl 733 + MDA also appeared to have some pro-static tendencies. The fractional change results for the five corrosion inhibitors of this study with fuel flow through the separator are presented in Figure 46. Significant effects are taken to be absolute values of dF greater than 0.5.

Effect of Additives on Conductivity Improver Response

The contract study examined the reduction of static electricity charge accumulation by the use of conductivity additives in JP-4 containing other military approved additives. The required concentrations of ASA-3 and Stadis 450 in JP-4 for nominal 100 CU at 20° and 0°F with the approved additives and combinations are listed in Table 15. Generally, lower concentrations of Stadis 450 than ASA-3 were required to achieve similar JP-4 fuel conductivity at nominal 0° and/or 20°F, except where synergistic effects were noted. Hitec E-515 has a positive synergism with ASA-3, i.e. increased fuel sensitivity to the conductivity additive while Tolad 246 appeared to have a negative synergism. Thus, Hitec E-515 additized fuels required 60-80% less ASA-3 for similar fuel conductivity than Tolad 246 additized fuels. Other additives and their combinations did not appear to significantly affect the ASA-3/fuel response. Generally, synergistic effects were less apparent with Stadis 450 additized fuels. However, Apollo PRI-19 reduced the Stadis 450/fuel response such that about twice as much Stadis 450 was required for nominal 100 CU compared to Stadis 450 concentrations with other approved additives. A slight positive synergism was observed for Stadis 450 with corrosion inhibitor/antioxidant

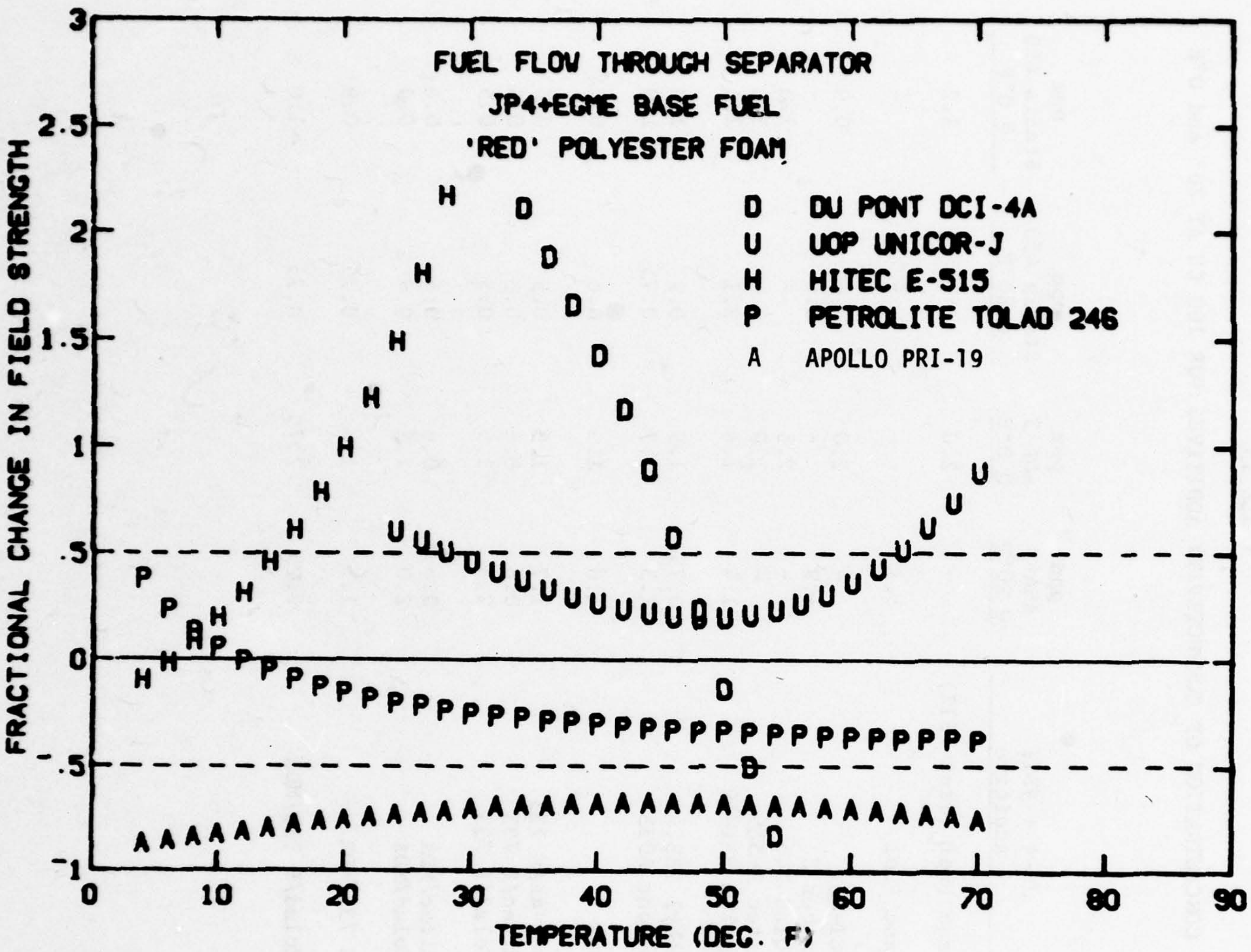


FIGURE 46. EFFECT OF CORROSION INHIBITORS ON FRACTIONAL CHANGE IN FIELD STRENGTH

TABLE 15

CONCENTRATION OF CONDUCTIVITY ADDITIVES FOR 100 CU AT 20° and 0°F

JP-4 + FSII + Additive	ppm ASA-3 @ 20°F	ppm ASA-3 @ 0°F	ppm Stadis 450 @ 20°F	ppm Stadis 450 @ 0°F
Base Fuel (less FSII)	-	2.0	-	1.2
Base Fuel	1.1	-	-	-
DCI-4A	-	2.0	-	0.9
Unicor J	1.9	-	0.6	-
Tolad 246	-	2.5	-	1.0
Hitec E-515	-	1.0	-	1.0
Apollo PRI-19	1.4	1.4	2.1	2.1
Ethyl 733	0.75	1.5	0.9	1.0
DuPont A033	1.3	1.7	0.75	1.0
MDA	1.0	1.3	0.6	0.74
DCI-4A/E 733	1.7	1.9	0.5	0.6
Hitec/E 733	0.6	0.6	0.5	0.5
Tolad/E 733	2.5	2.5	0.5	0.5
Hitec/MDA	0.6	0.6	0.4	0.4
Tolad/MDA	2.0	2.8	0.8	0.9
E 733/MDA	1.5	1.6	0.75	0.9
Tolad/E 733/MDA	2.25	2.75	0.75	1.0

and corrosion inhibitor/MDA combinations. These results are for a single JP-4 fuel. The synergistic effect of Hitec E-515 has been documented in other fuels but, in general, these results should be verified on other fuels.

Effect of Fuel Water Content

There was no apparent correlation between fuel charging and water content. This may have been due to poor precision in the water measurement; experimental deviations as much as ±10 ppm at 30 ppm average total water were noted in some cases. Tables A1 through A30 also contain water content data in addition to other electrostatic charging data. The water content data for the various JP-4/additive studies are summarized in Table 16. Because the water content results are similar for all fuels, it was not possible with these tests to find a correlation between fuel water content and its charging properties.

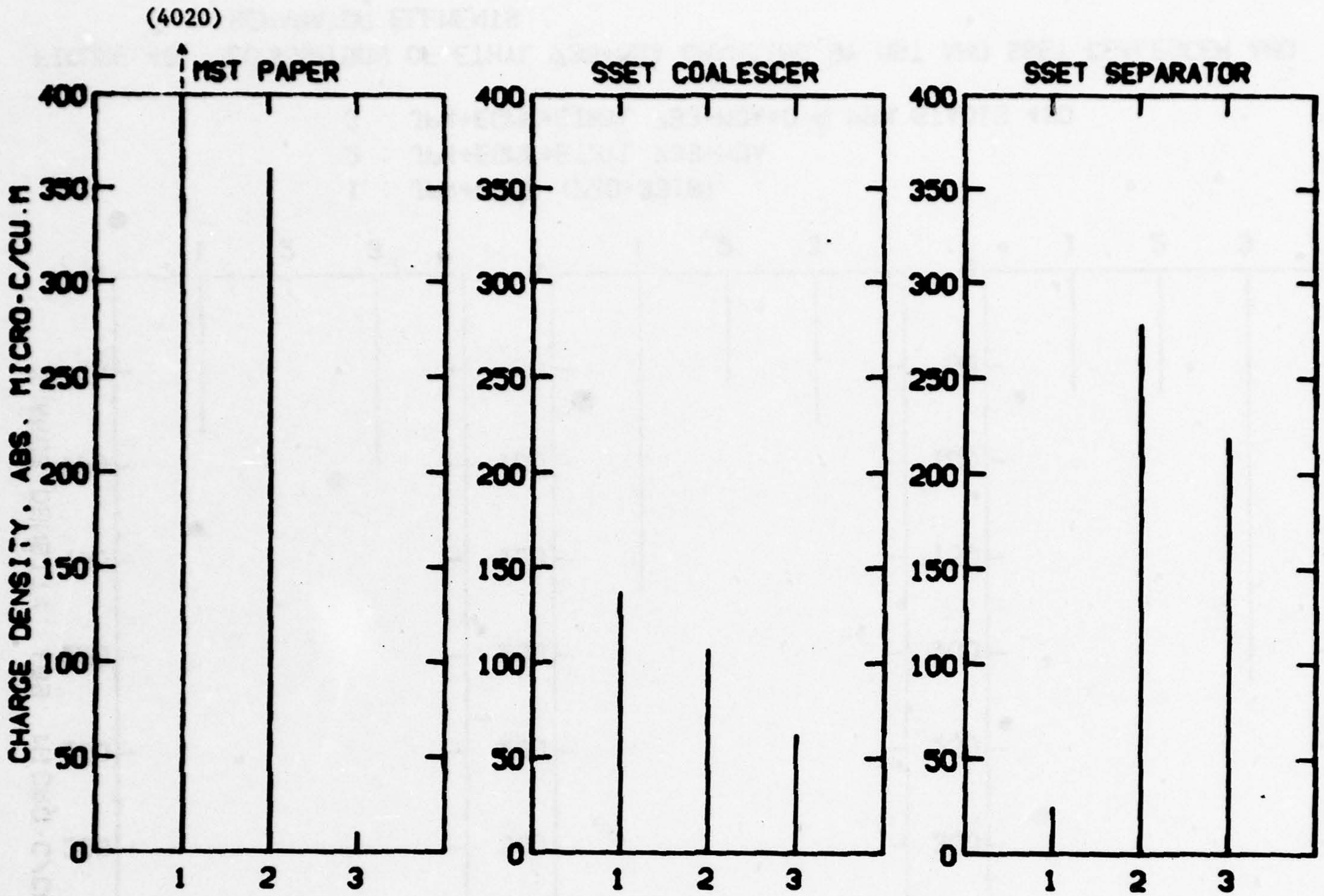
MST-SSET Charging Correlation Results

The Mini-Static Test (MST), developed by Exxon R&D, has been used by Mobil and others to compare charge generation tendencies of hydrocarbon liquids. In this device, streaming currents from a metal filter paper holder are measured as fuel is forced through the filter paper by air pressure. Three SSET fuels were examined by both techniques at 70°F. MST charging was compared to SSET charge densities from both the coalescer and separator vessels. Figures 47, 48, and 49 (and Tables 17, 18, and 19) for the additive combinations Hitec E-515 + MDA, Ethyl 733 + MDA, and

TABLE 16

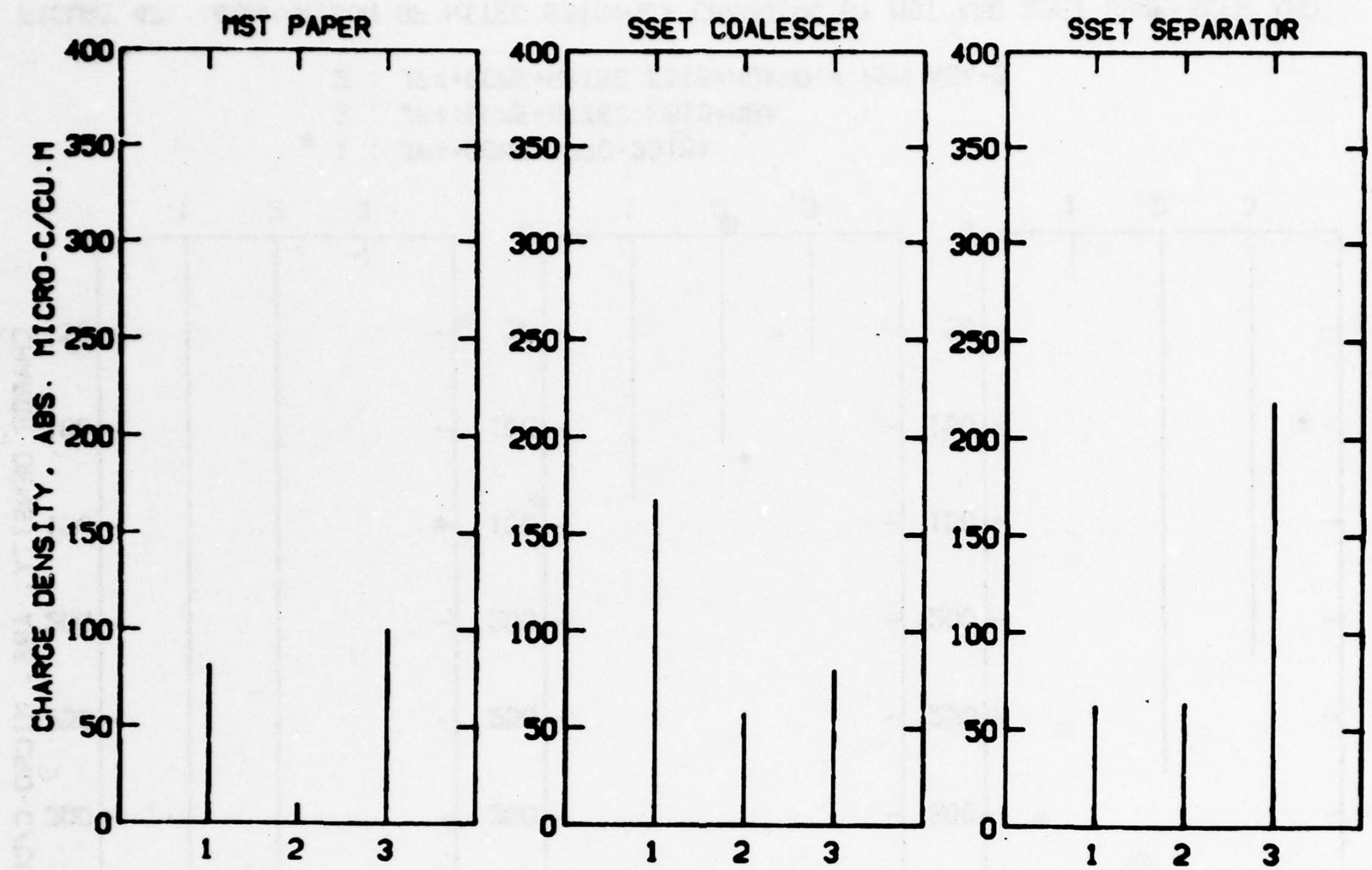
TOTAL WATER CONTENT OF SSET FUELS

Additive	ppm Water in Base Fuel @ 70°	35°	0°	ppm Water in Additized Fuel 70°	35°	0°	ppm Water in Fuel w/ASA-3 @ 25°	w/Stadis 450 @ 25°
DCI-4A	34	30	-	32	27	24	-	-
Unicor J	46	55	-	-	38	-	26	31
Tolad 246	40	24	16	32	31	18	-	-
Hitec E-515	31	20	18	23	24	22	-	-
Apollo PRI-19	29	30	20	35	29	22	25	21
Ethyl 733	30	21	20	32	23	16	29	33
DuPont A033	34	35	21	27	23	20	21	18
MDA	34	27	20	33	33	18	30	28
DCI-4A	42	38	39	42	33	29	33	24
Hitec E-515/E 733	47	44	-	-	40	18	41	16
Tolad 246/E 733	51	35	21	41	30	15	17	16
Hitec E-515/MDA	42	37	28	50	40	24	32	32
Tolad 246/MDA	35	28	18	38	27	20	31	27
Ethyl 733/MDA	-	51	20	35	28	24	21	26
Tolad 246/E 733/MDA	55	35	26	60	49	21	32	32



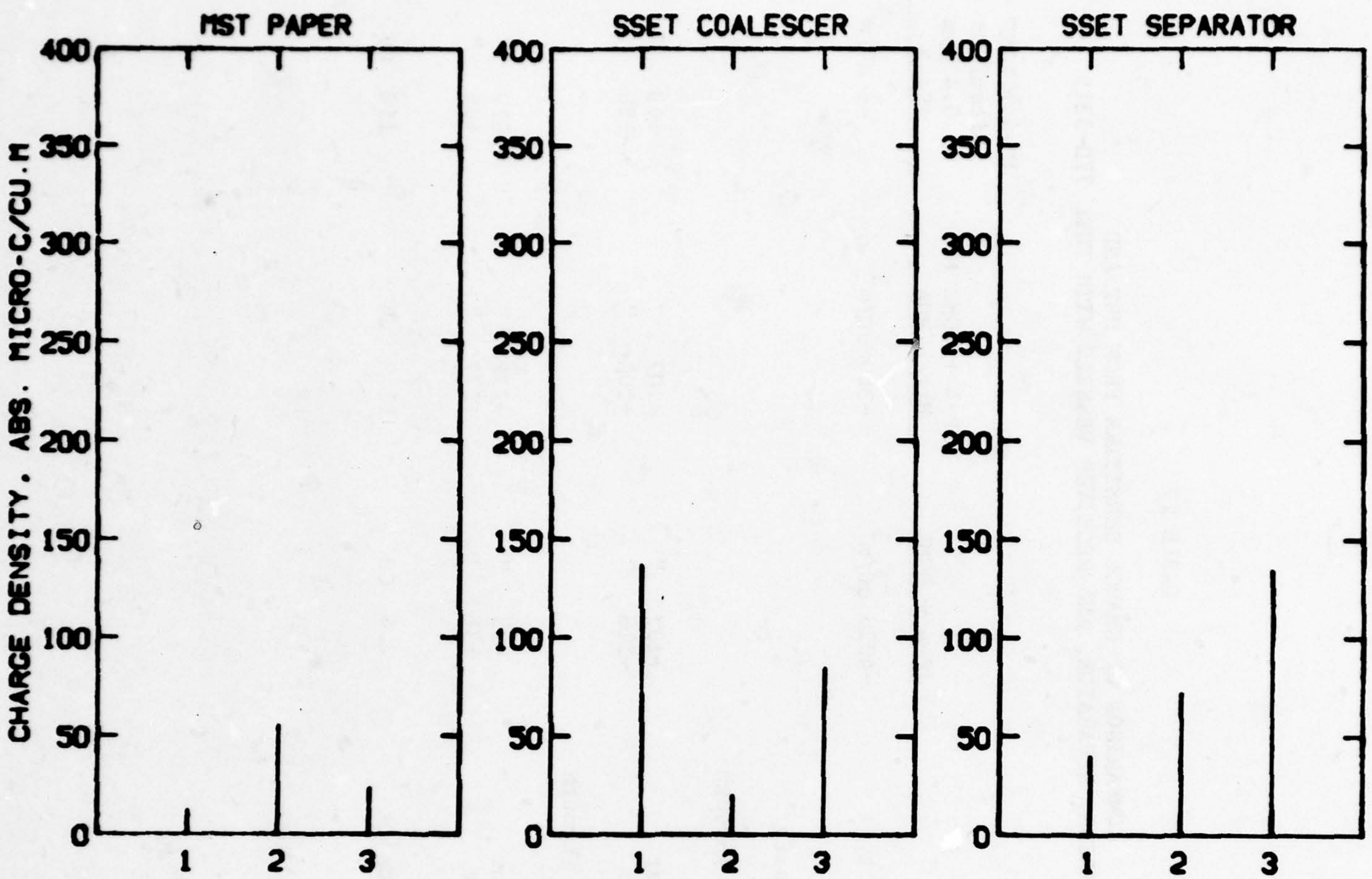
1 : JP4+EGME (77D-3315)
2 : JP4+EGME+HITEC E515+MDA
3 : JP4+EGME+HITEC E515+MDA+0.4 PPM ASA-3

FIGURE 47. COMPARISON OF HITEC E515+MDA CHARGING BY MST AND SSET COALESCER AND SEPARATOR ELEMENTS



1 : JP4+EGME (77D-3316)
2 : JP4+EGME+ETHYL 733+MDA
3 : JP4+EGME+ETHYL 733+MDA+0.6 PPM STADIS 450

FIGURE 48. COMPARISON OF ETHYL 733+MDA CHARGING BY MST AND SSET COALESCER AND SEPARATOR ELEMENTS



1 : JP4+EGME (77D-3314)
2 : JP4+EGME+TOLAD 246+MDA
3 : JP4+EGME+TOLAD 246+MDA+0.5 PPM STADIS 450

FIGURE 49. COMPARISON OF TOLAD 246+MDA CHARGING BY MST AND SSET COALESCER AND SEPARATOR ELEMENTS

TABLE 17

COMPARISON OF CHARGE DENSITIES FROM MST AND SSET COALESCER, SEPARATOR, AND RECEIVER VESSELS WITH FUEL 77D-3315

	JP-4 + EGME	JP-4 + EGME + Hitec/MDA	JP-4 + EGME + Hitec/MDA + 0.4 ppm ASA-3
MST Charge Density	-4020 $\mu C/m^3$	-360 $\mu C/m^3$	-6 $\mu C/m^3$
SSET Charge Density			
1. Fuel Flow Through Coalescer			
Coalescer	+137 "	-107 "	+63 "
Receiver	-118 "	+100 "	-186 "
2. Fuel Flow Through Separator			
Separator	-25 "	-278 "	-219 "
Receiver	+31 "	+277 "	+99 "
Fuel Conductivity	2.4 CU	11.9 CU	158 CU

TABLE 18

COMPARISON OF CHARGE DENSITIES FROM MST AND SSET COALESCER, SEPARATOR, AND RECEIVER VESSELS WITH FUEL 77D-3316

	JP-4 + EGME	JP-4 + EGME + Ethyl 733/MDA	JP-4 + EGME + Ethyl 733/MDA + 0.6 ppm Stadis 450
MST Charge Density	-82 μC/m³	-8 μC/m³	-100 μC/m³
SSET Charge Density			
1. Fuel Flow Through Coalescer			
Coalescer	+168 "	+58 "	+80 "
Receiver	-172 "	-74 "	-275 "
2. Fuel Flow Through Separator			
Separator	-63 "	-64 "	-219 "
Receiver	+60 "	+44 "	+26 "
Fuel Conductivity	2.5 CU	1.2 CU	122 CU

TABLE 19

COMPARISON OF CHARGE DENSITIES FROM MST AND SSET COALESCER, SEPARATOR, AND RECEIVER VESSELS WITH FUEL 77D-3314

	JP-4 + EGME	JP-4 + EGME + Tolad/MDA	JP-4 + EGME + Tolad/MDA + 0.5 ppm Stadis 450
MST Charge Density	-12.6 $\mu C/m^3$	-55.8 $\mu C/m^3$	+24.6 $\mu C/m^3$
SSET Charge Density			
1. Fuel Flow Through Coalescer			
Coalescer	+137 "	+20 "	+85 "
Receiver	-137 "	-70 "	-141 "
2. Fuel Flow Through Separator			
Separator	-40 "	-73 "	-135 "
Receiver	+37 "	+19 "	+70 "
Fuel Conductivity	1.2 CU	2.0 CU	162 CU

Petrolite Tolad 246 + MDA, respectively, presents MST and SSET charge density results at 70°F. None of the MST results show trends similar to either SSET coalescer or separator charging. This lack of correlation is probably due to differences between MST and SSET filter media and their responses to the fuel-additive system. Also, because the MST uses relatively small quantities of fuel, its response is very sensitive to trace fuel impurities and fuel handling practices.

SECTION III
CONCLUSIONS

The following conclusions are made on the basis of these SSET results:

- Conductivity improver additives, Shell ASA-3 or DuPont Stadis 450, at conductivity levels of nominal 100 CU or higher, effectively reduce JP-4 charge accumulations generated by coalescer and separator F/S elements (or by piping and inlet nozzle restrictions) regardless of the presence of certain military approved additives (FSII, corrosion inhibitors, antioxidants, or metal deactivator) or their combinations.
- At conductivity levels less than about 30 CU, Stadis 450 increased charge accumulation (i.e. was pro-static) in SSET coalescer generated, negatively charged fuel and ASA-3 increased charge accumulation in SSET separator generated, positively charged fuel.
- Without conductivity additives, DuPont DCI-4A has significant pro-static characteristics in both negatively and positively charged fuel; Hitec E-515 and its combinations with Ethyl 733 or MDA and Petrolite Tolad 246 + Ethyl 733 with and without MDA are significantly pro-static with positively charged fuels. The use of these additives by the USAF may

have contributed to the reported static charge ignited aircraft fires. Other additives or combinations examined either have little significant effect on charging or are anti-static.

- With the bladder lined foam-filled SSET receiver vessel, electrostatic charges on incoming fuel transfer rapidly to the foam surface. Red foam appears to accept fuel charges more readily than blue foam but the charges are more rapidly relaxed.
- Unusually high concentrations of conductivity additives may be required to obtain minimum fuel conductivity of 100 CU because synergistic effects with some military approved additives (i.e. corrosion inhibitors, anti-oxidants, or metal deactivators) reduces the fuel response to conductivity additives.
- The MST did not predict the charging performance of fuels in the SSET.

SECTION IV
RECOMMENDATIONS

On the basis of these conclusions, the following recommendations are made:

- Because conductivity improver additives significantly reduced charging regardless of other additive effects, consideration should be given to the early introduction of conductivity improver additives Shell ASA-3 or DuPont Stadis 450 into USAF JP-4 fuel system at minimum 100 CU at the aircraft at the temperature of use.
- Electrostatic effects from charged reticulated foam surfaces during introduction of charged fuel into bladder-lined, foam-filled receivers were noted but not investigated. These effects should be the subject of future studies.
- Because some additive-fuel combinations require unusual high concentrations of conductivity improver additives for static hazard protection of 100 CU fuel at low temperatures, it is recommended that fuel-water separability of fuels with conductivities of 300-450 CU at temperatures of about 70°F be the subject of future investigations.

APPENDIX

Field Strength Plots and Data Summaries for Additive and Additive Combination Studies

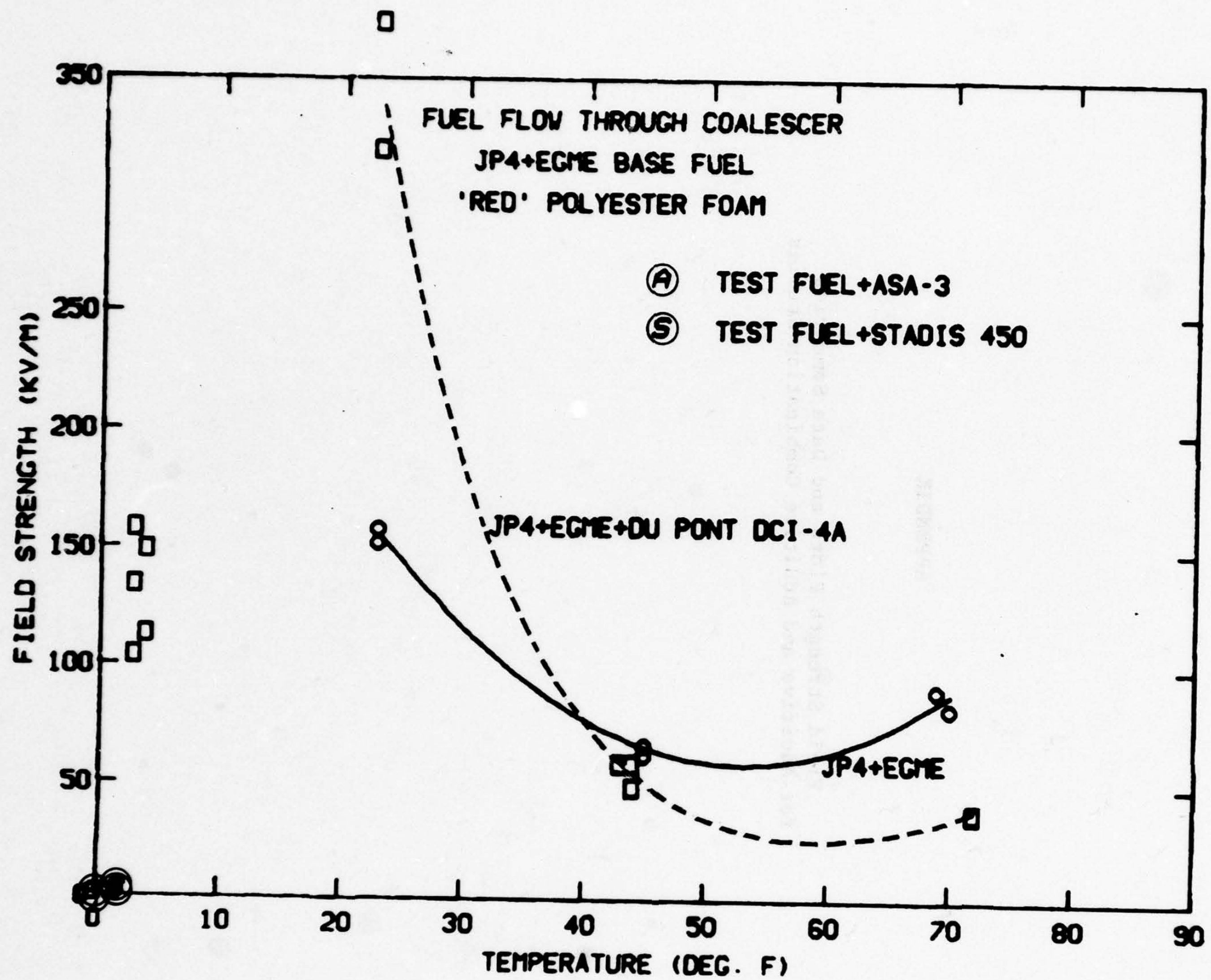


FIGURE A1. EFFECT OF DU PONT DCI-4A ON FIELD STRENGTH

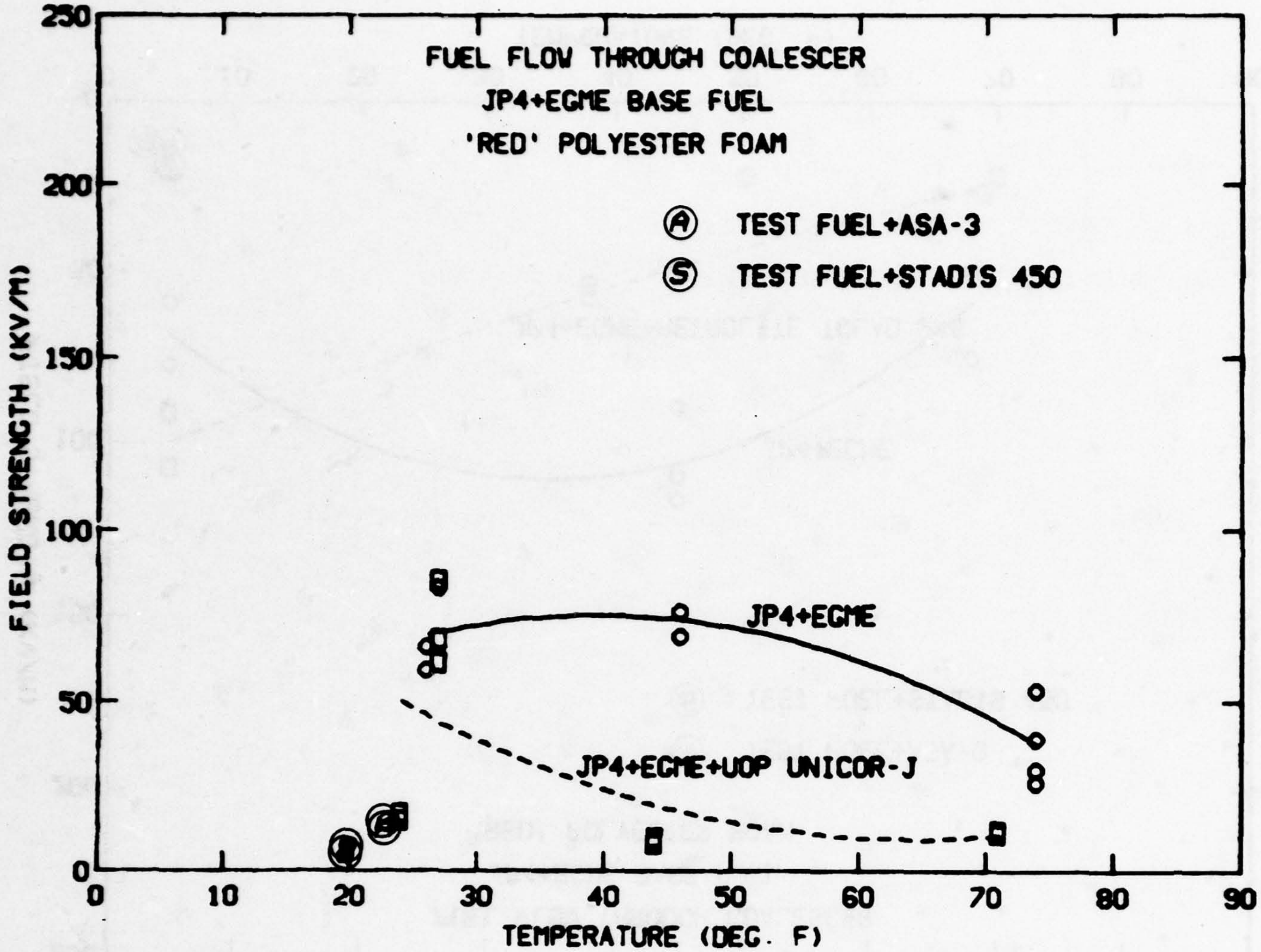


FIGURE A2. EFFECT OF UOP UNICOR-J ON FIELD STRENGTH

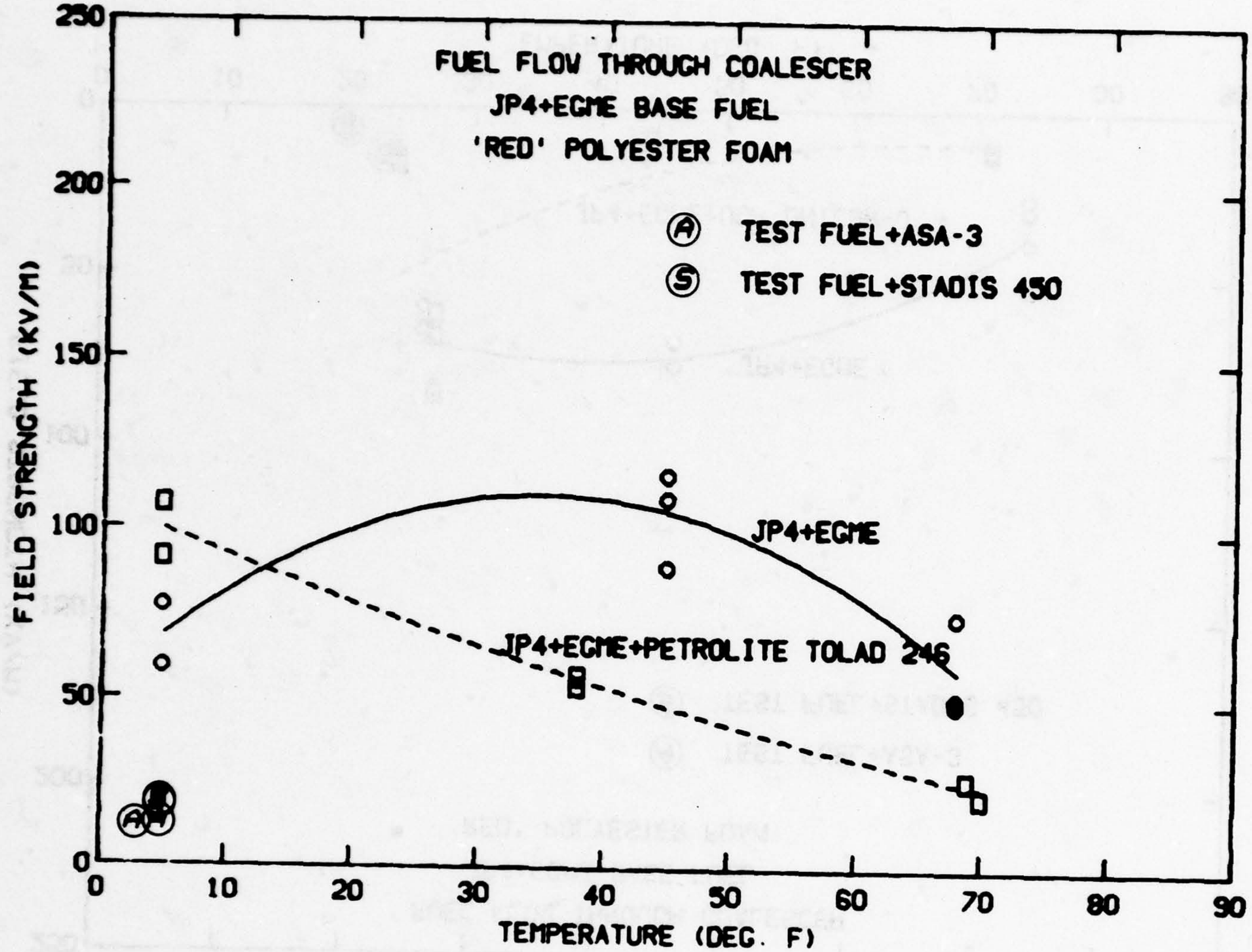


FIGURE A3. EFFECT OF PETROLITE TOLAD 246 ON FIELD STRENGTH

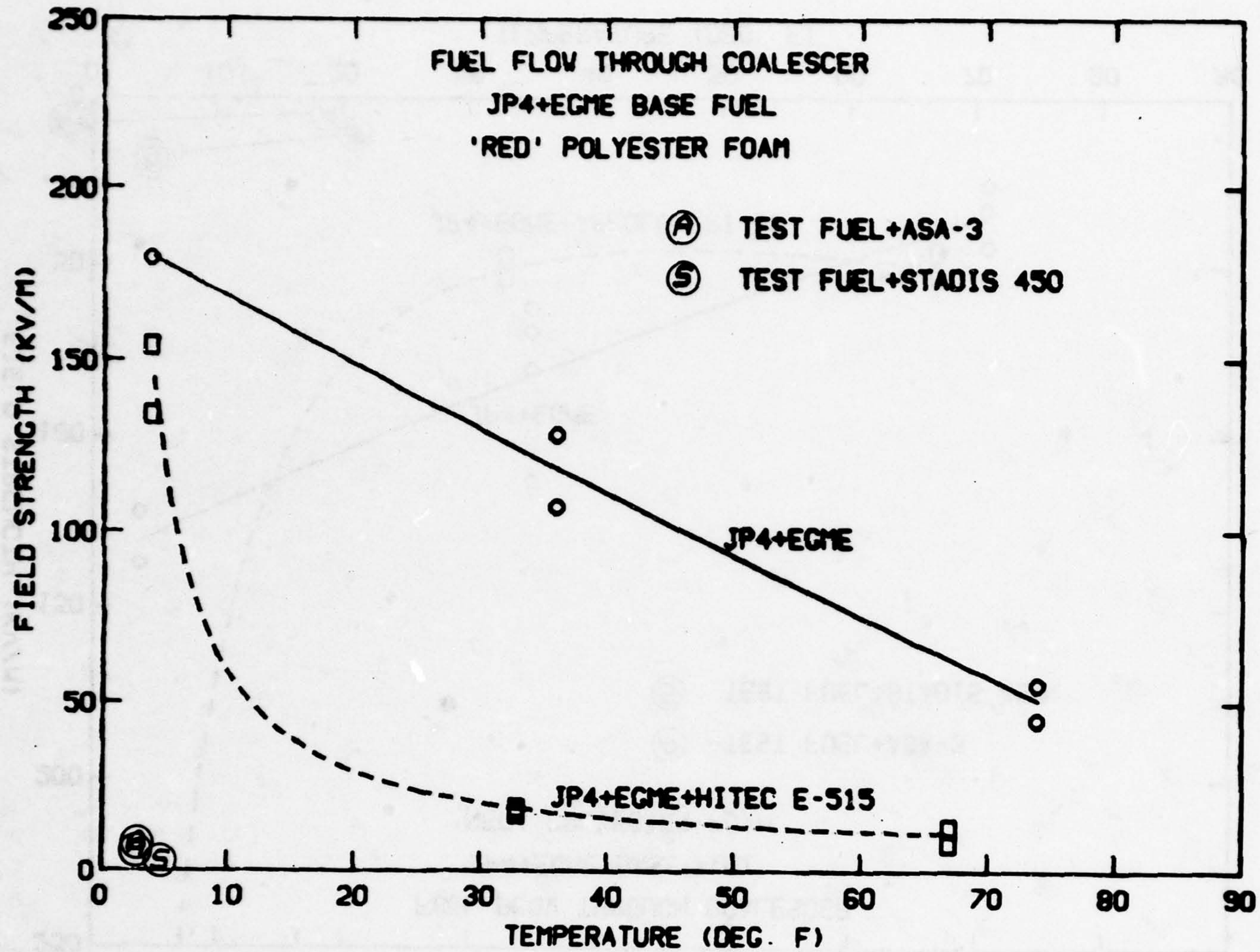


FIGURE A4. EFFECT OF HITEC E-515 ON FIELD STRENGTH

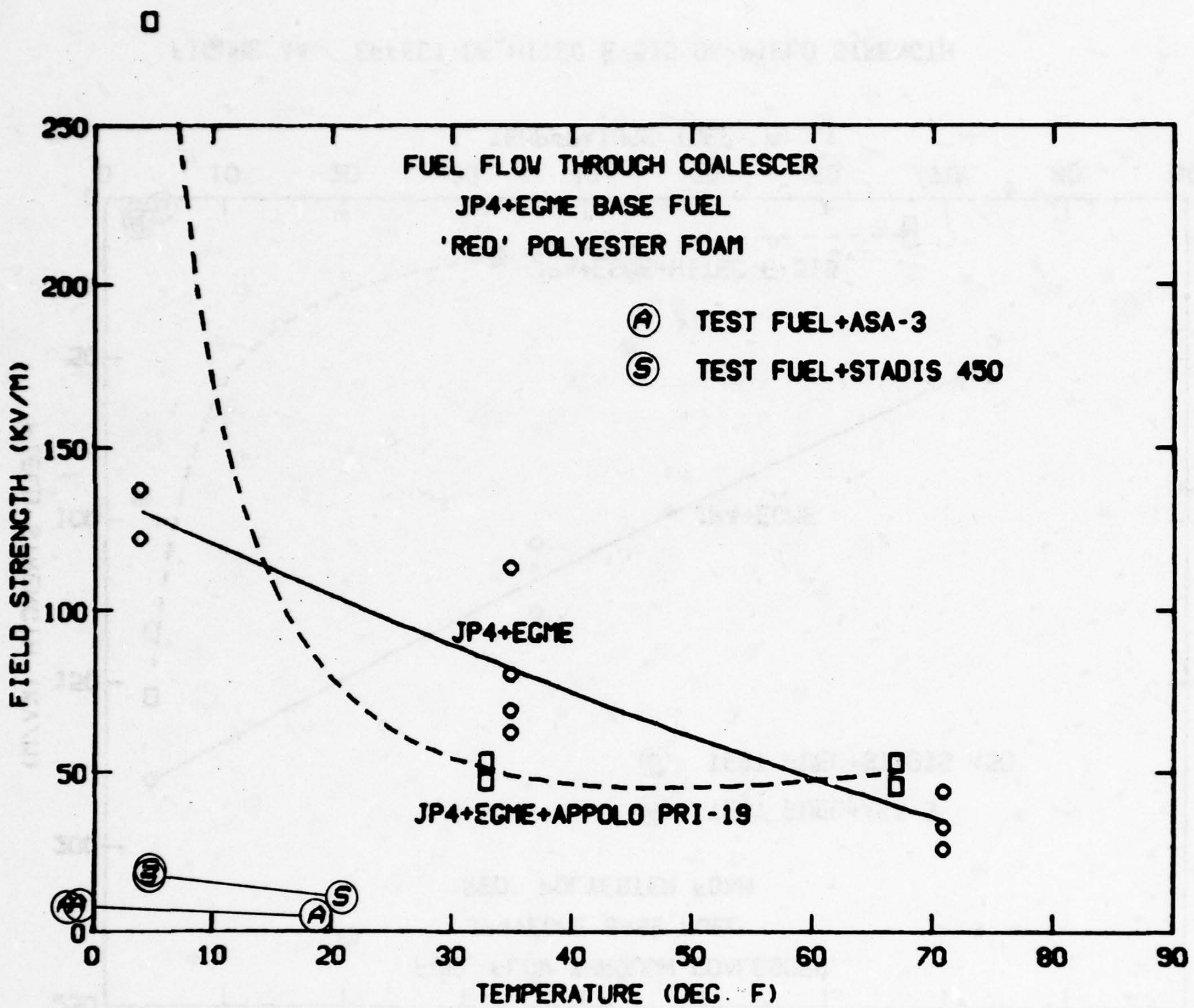


FIGURE A5. EFFECT OF APOLLO PRI-19 ON FIELD STRENGTH.

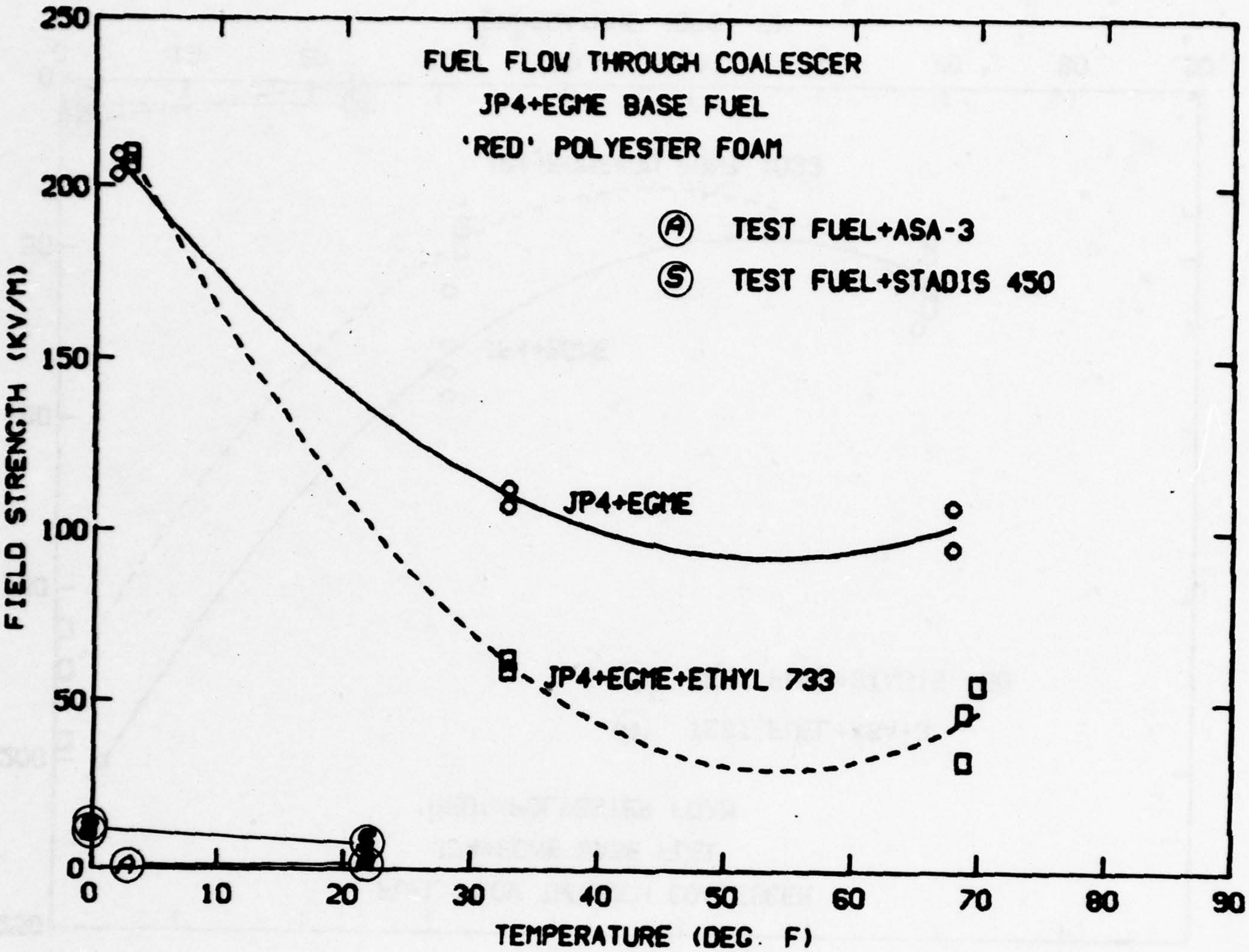


FIGURE A6. EFFECT OF ETHYL 733 ON FIELD STRENGTH

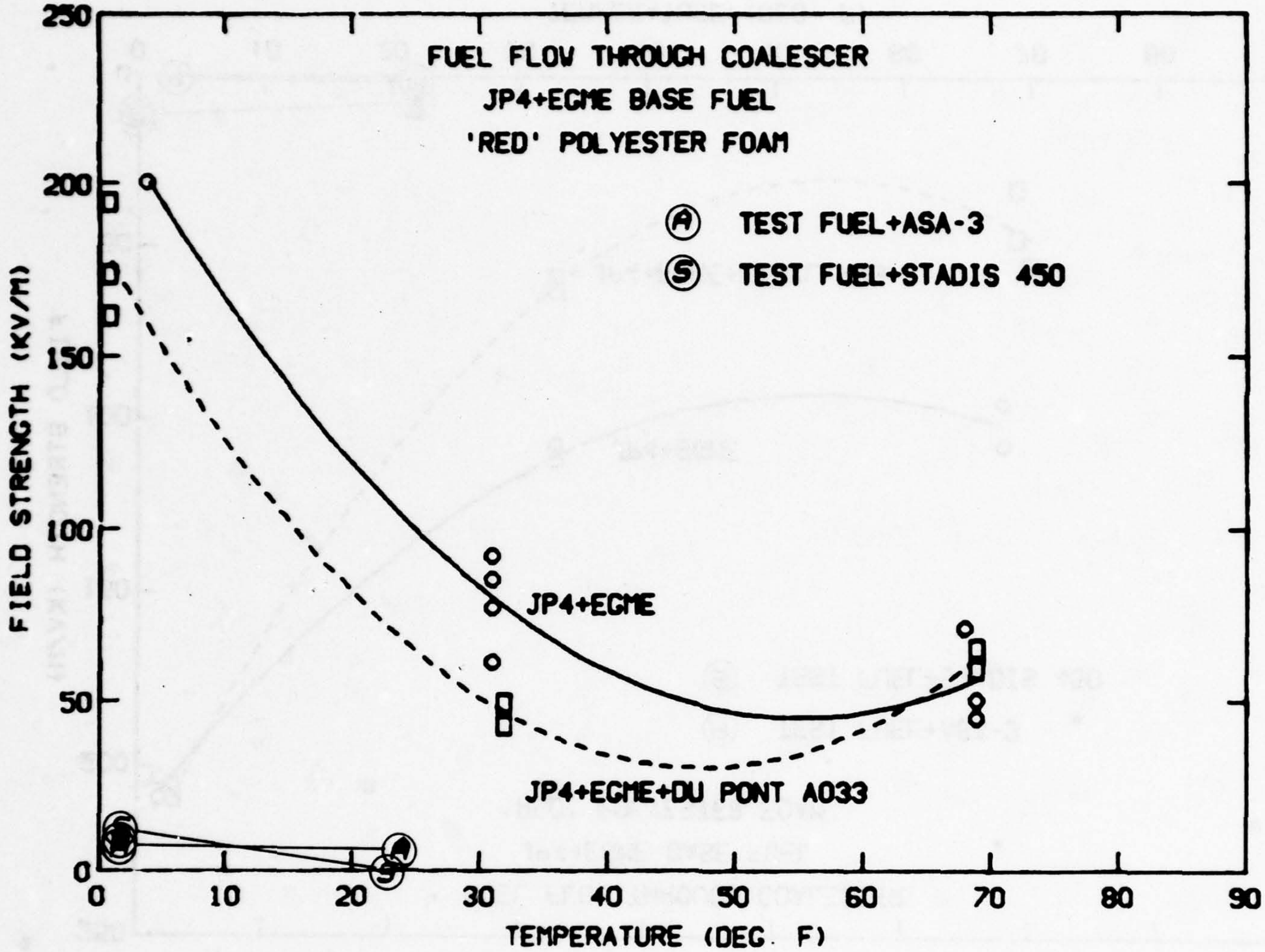


FIGURE A7. EFFECT OF DU PONT A033 ON FIELD STRENGTH

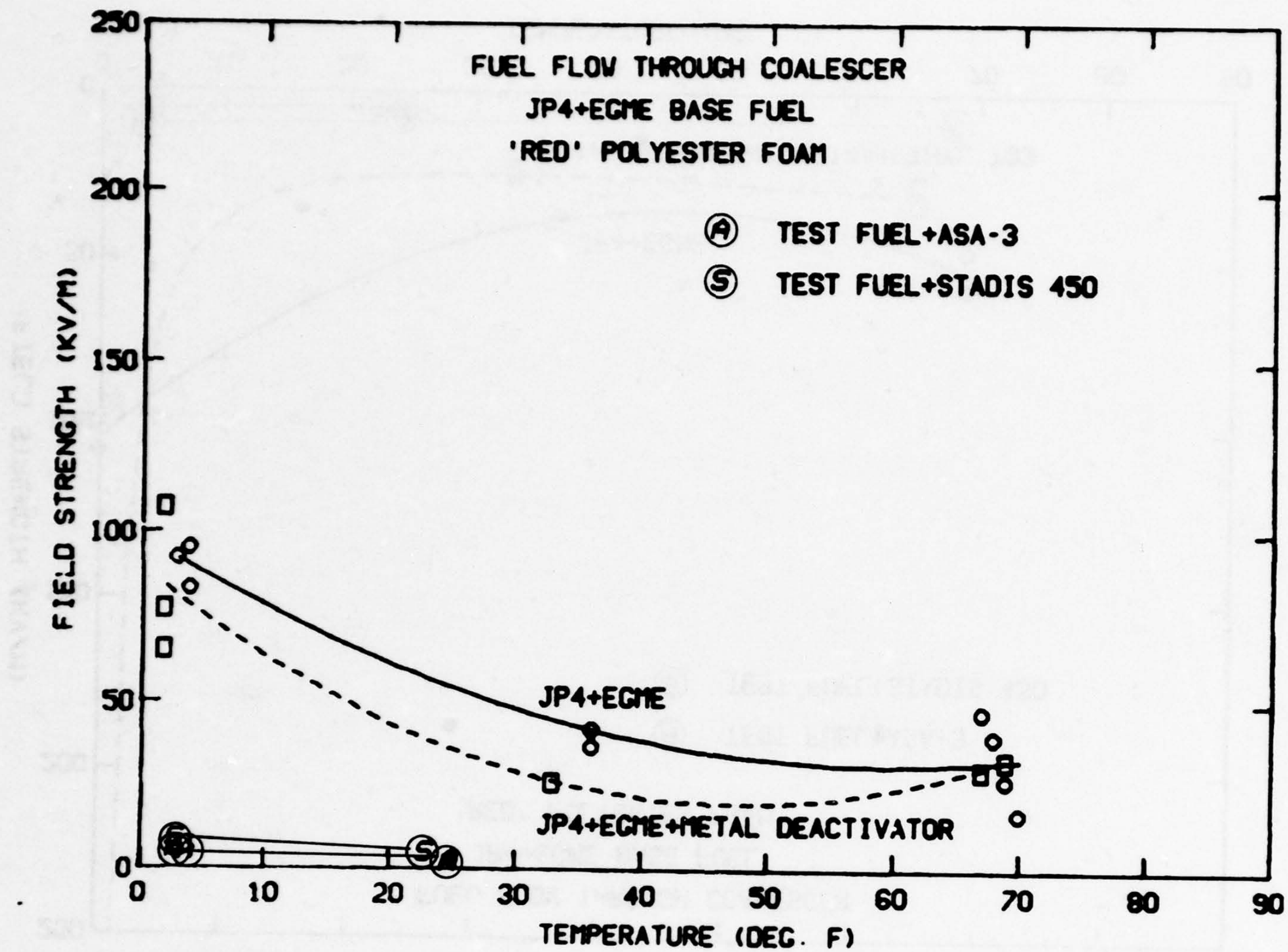


FIGURE A8. EFFECT OF METAL DEACTIVATOR ON FIELD STRENGTH

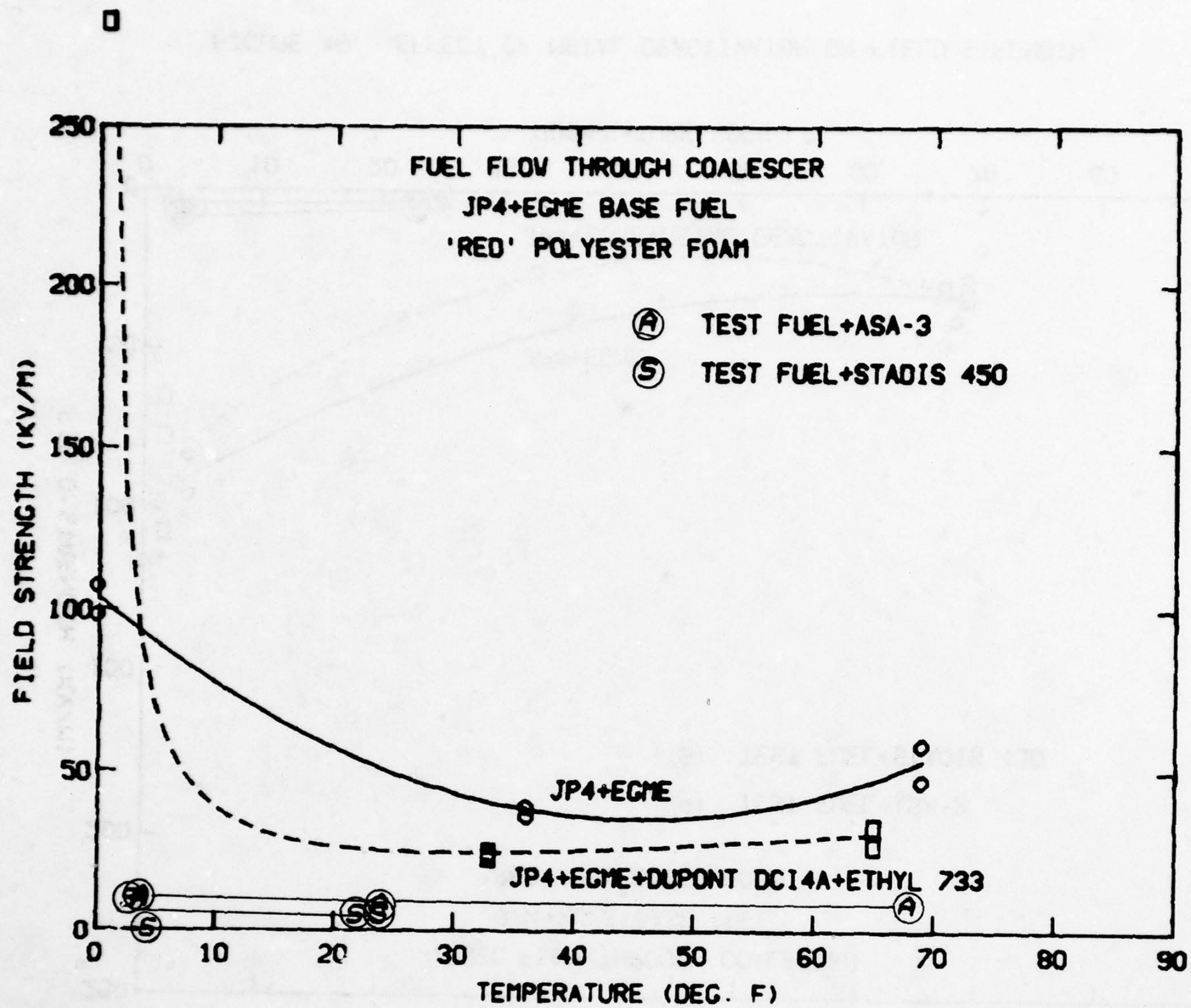


FIGURE A9. EFFECT OF DUPONT DCI4A+ETHYL 733 ON FIELD STRENGTH

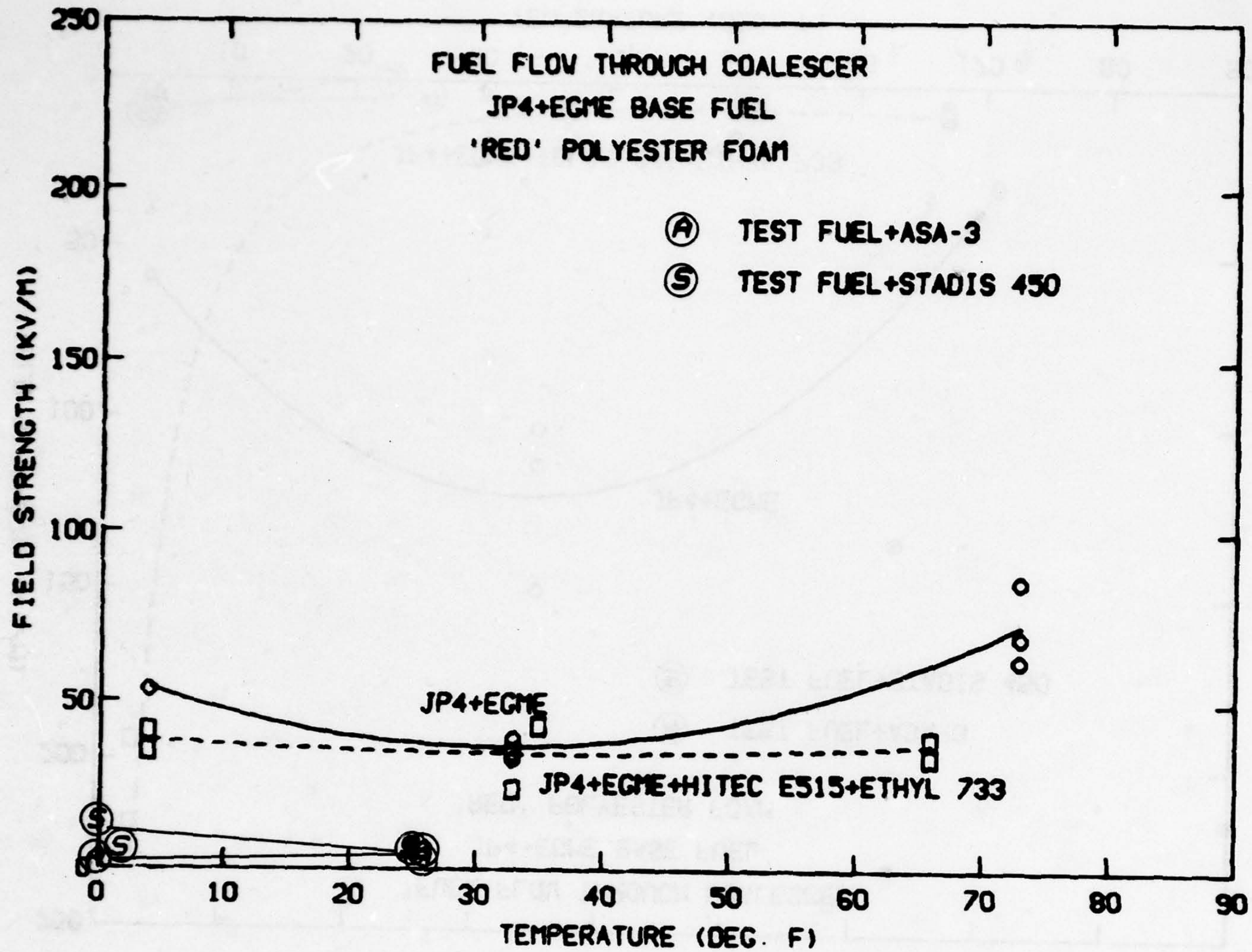


FIGURE A10. EFFECT OF HITEC E515+ETHYL 733 ON FIELD STRENGTH

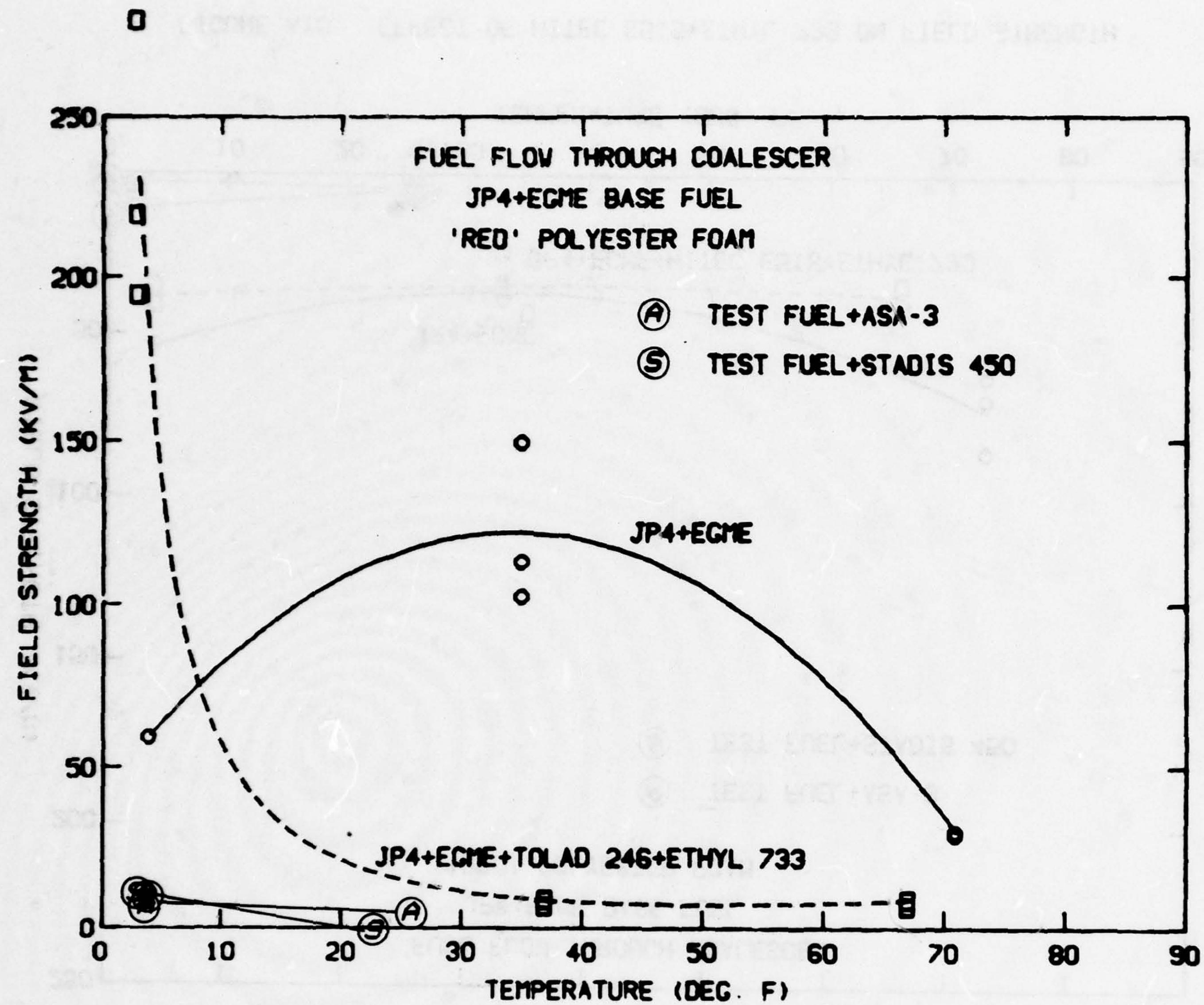


FIGURE A11. EFFECT OF TOLAD 246+ETHYL 733 ON FIELD STRENGTH

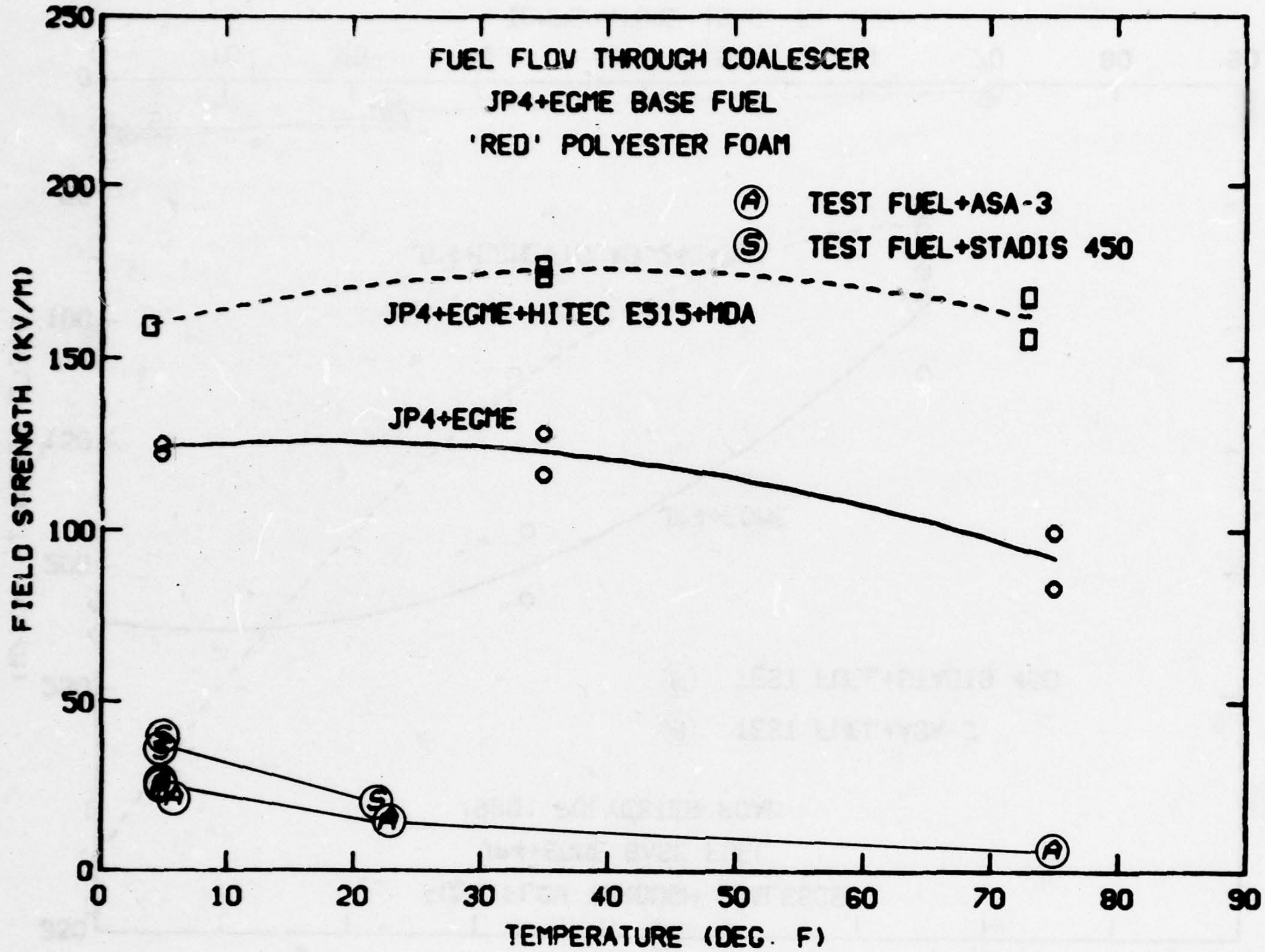


FIGURE A12. EFFECT OF HITEC E515+MDA ON FIELD STRENGTH

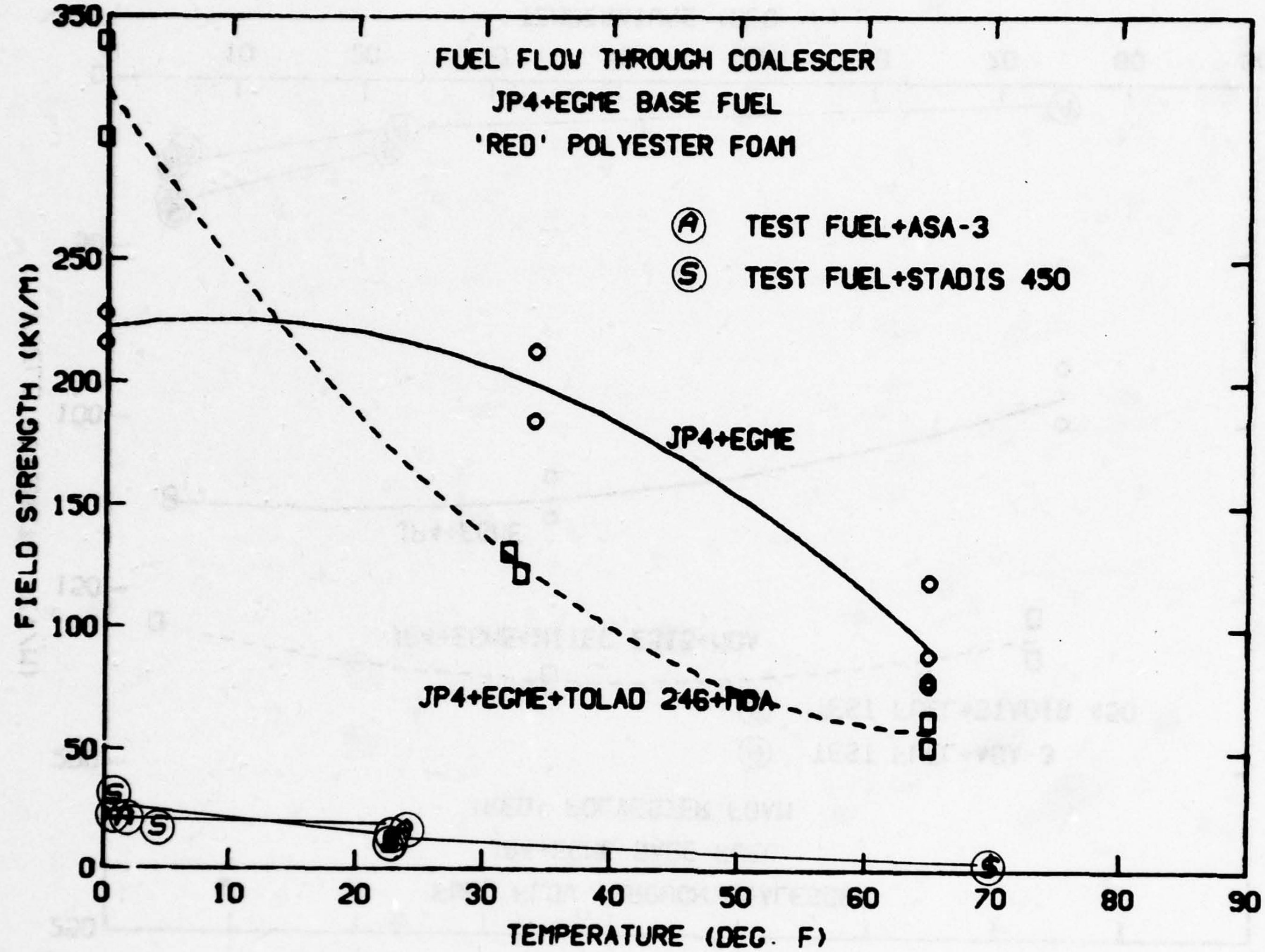


FIGURE A13 EFFECT OF TOLAD 246+MDA ON FIELD STRENGTH

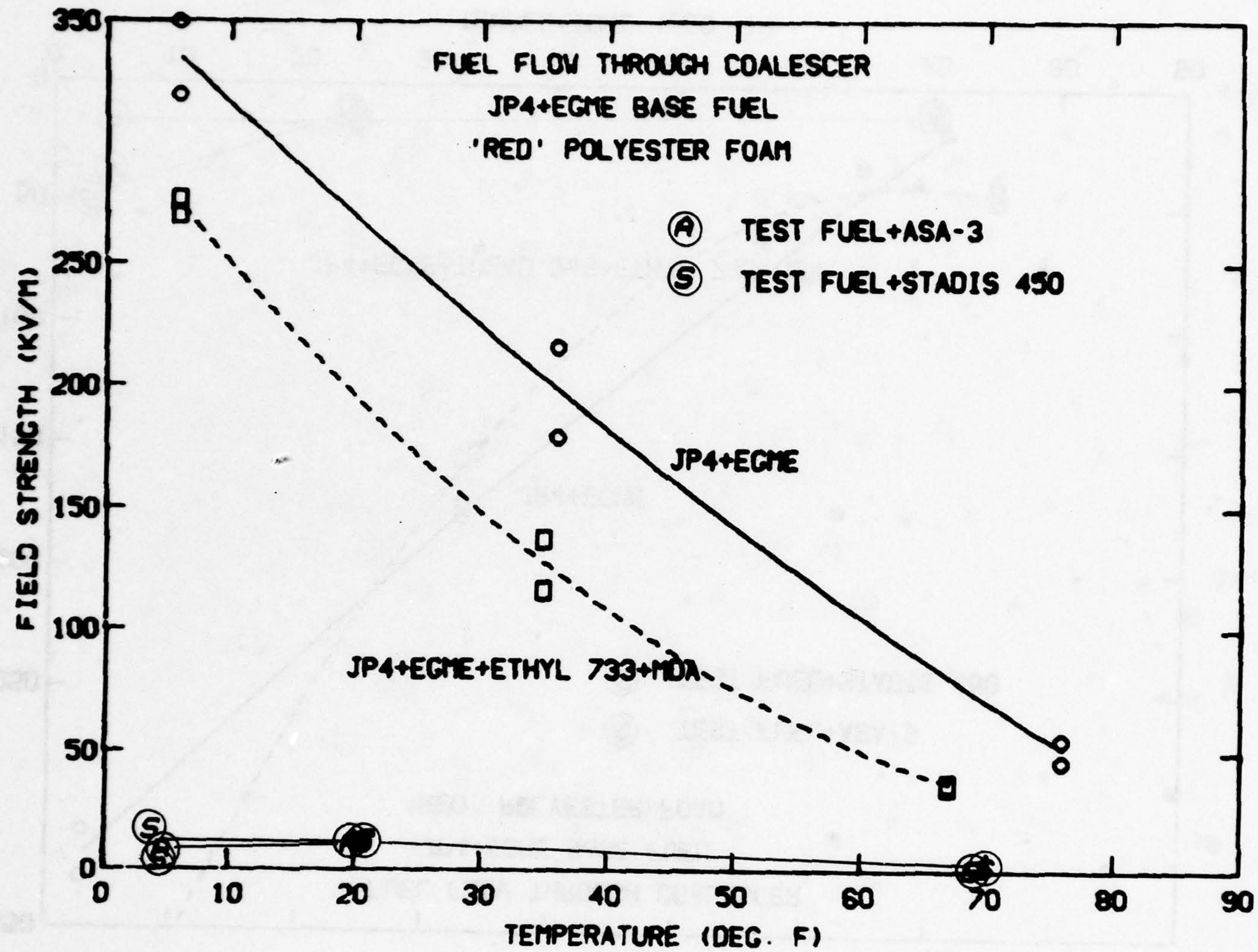


FIGURE A14. EFFECT OF ETHYL 733+MDA ON FIELD STRENGTH

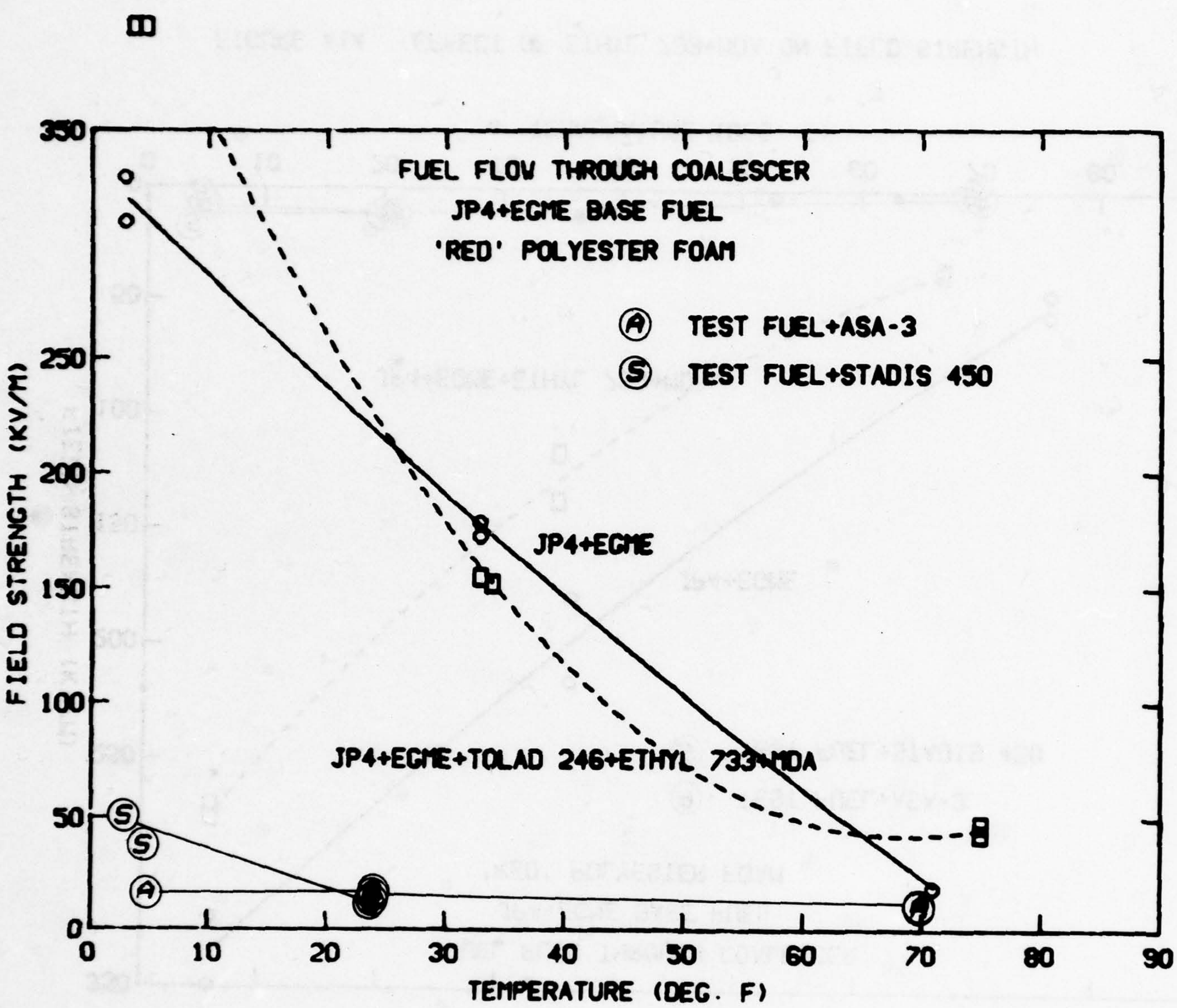


FIGURE A15. EFFECT OF TOLAD 246+ETHYL 733+MDA ON FIELD STRENGTH

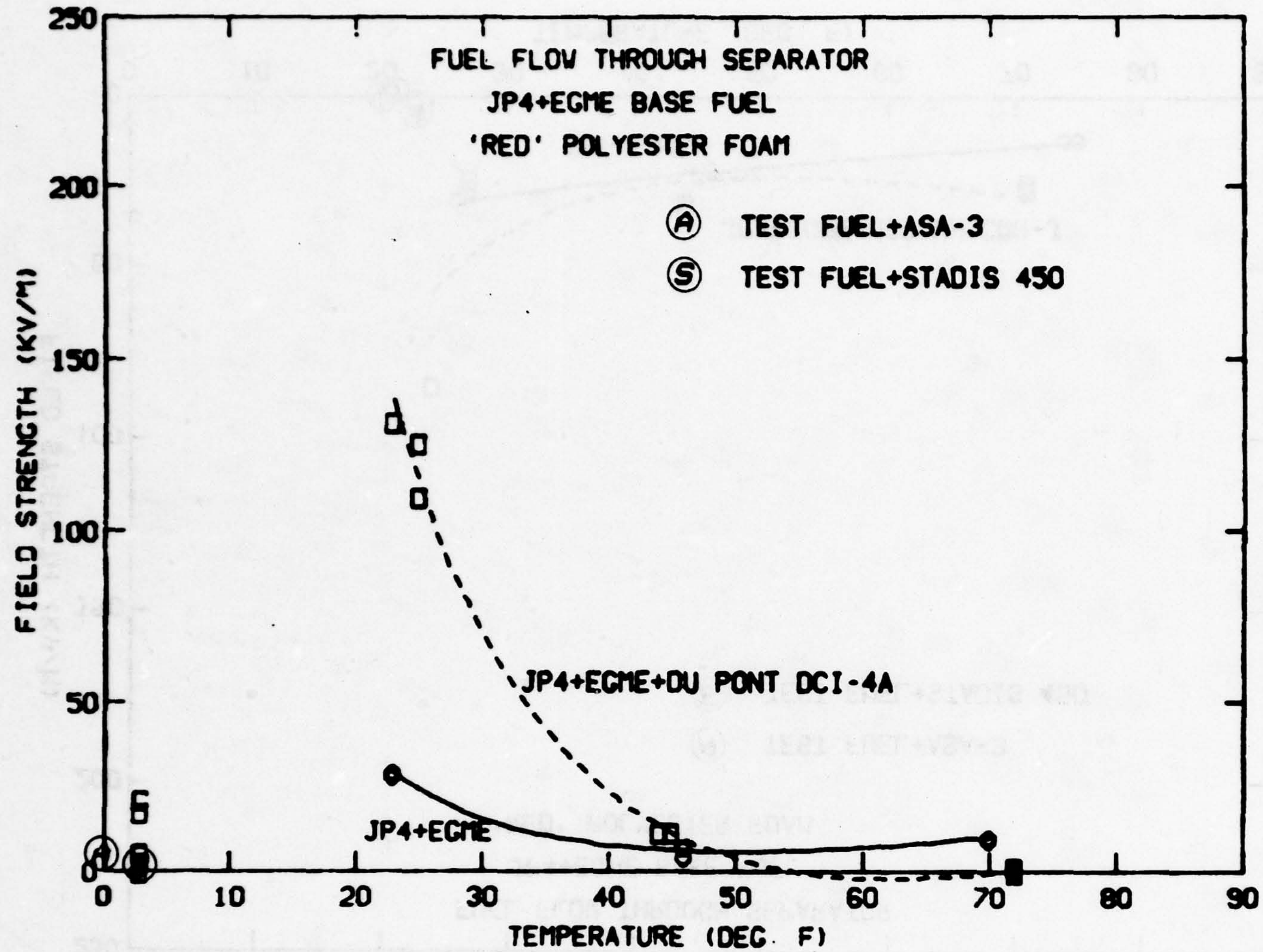


FIGURE A16. EFFECT OF DU PONT DCI-4A ON FIELD STRENGTH

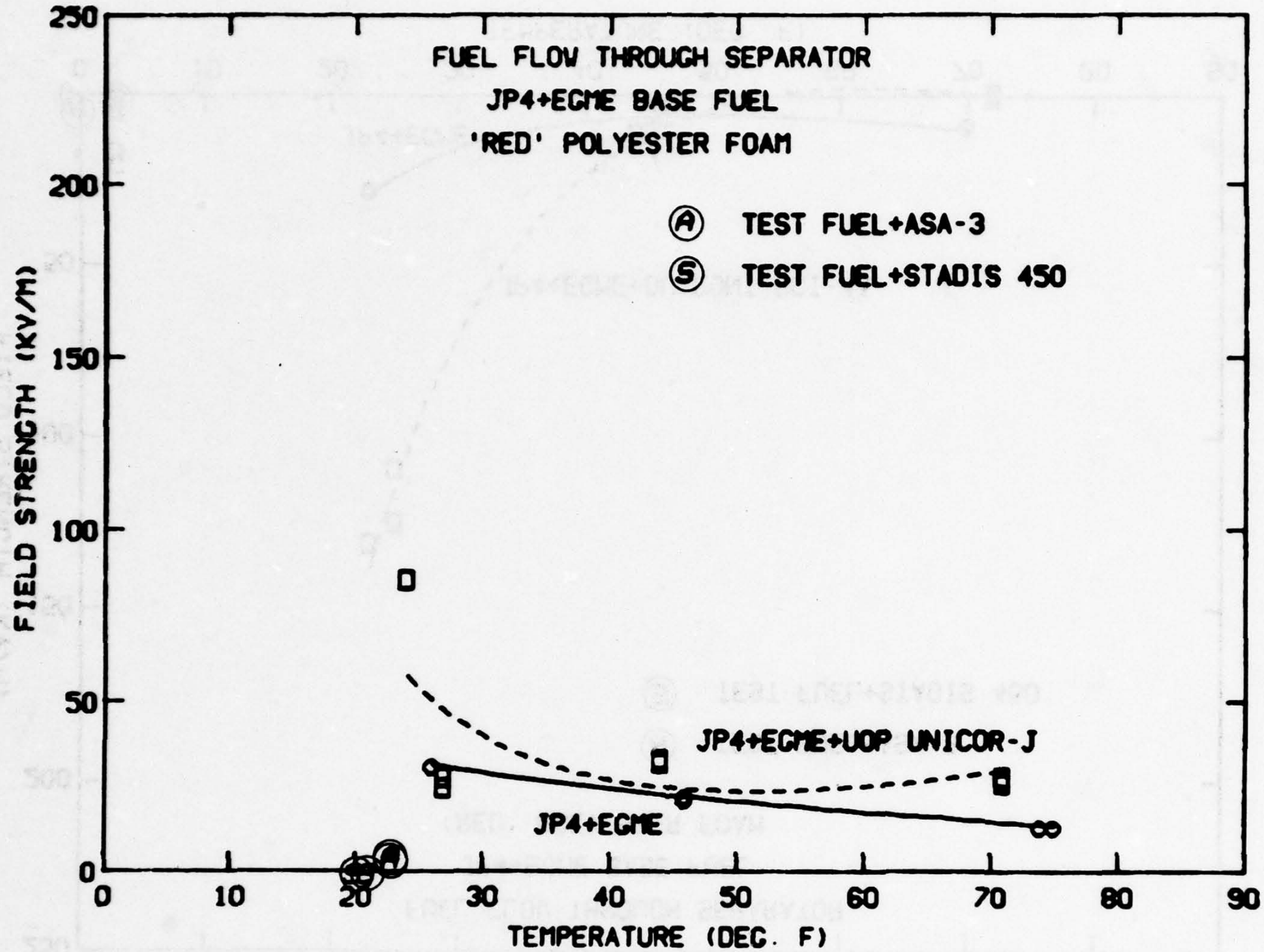


FIGURE A17. EFFECT OF UOP UNICOR-J ON FIELD STRENGTH

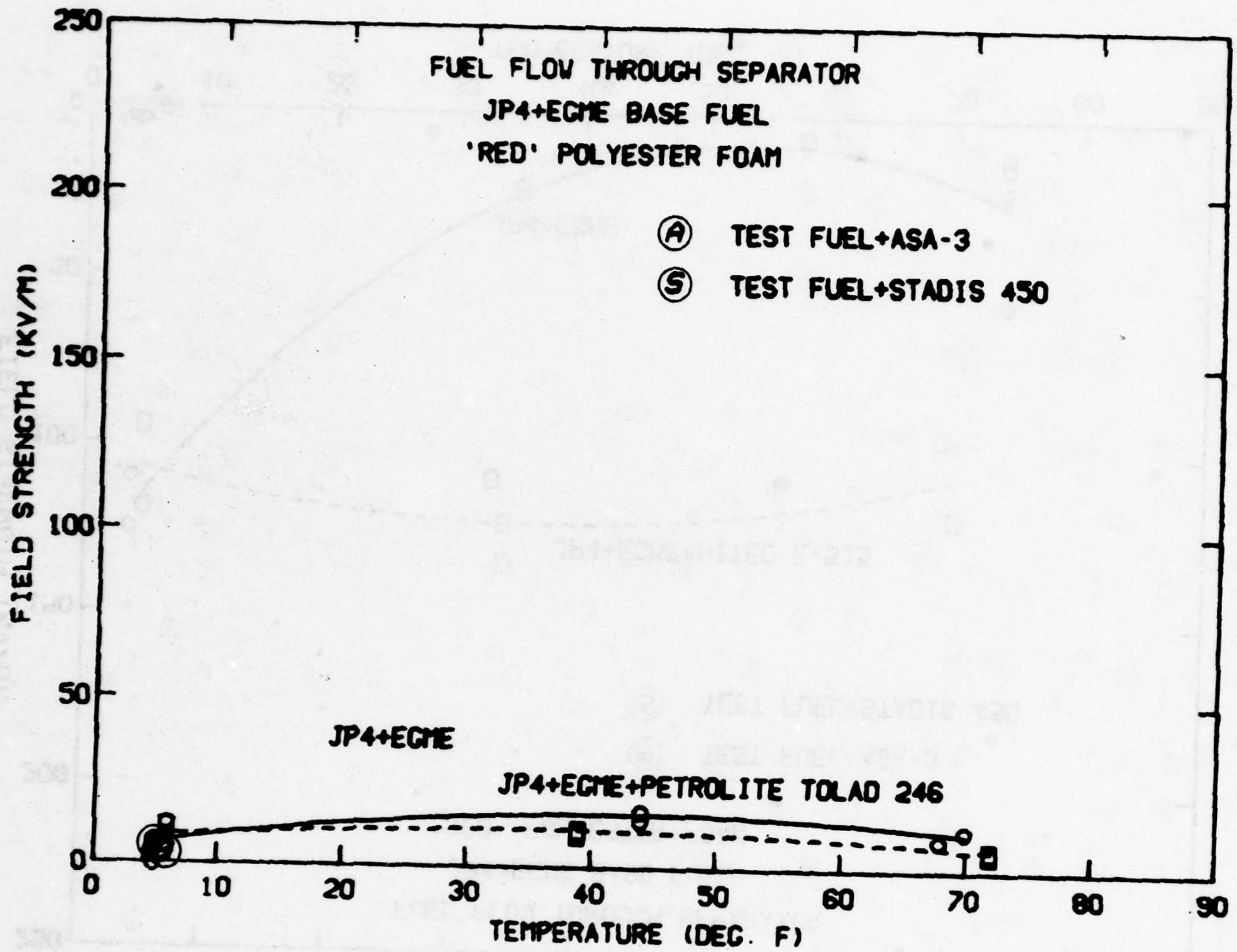


FIGURE A18. EFFECT OF PETROLITE TOLAD 246 ON FIELD STRENGTH

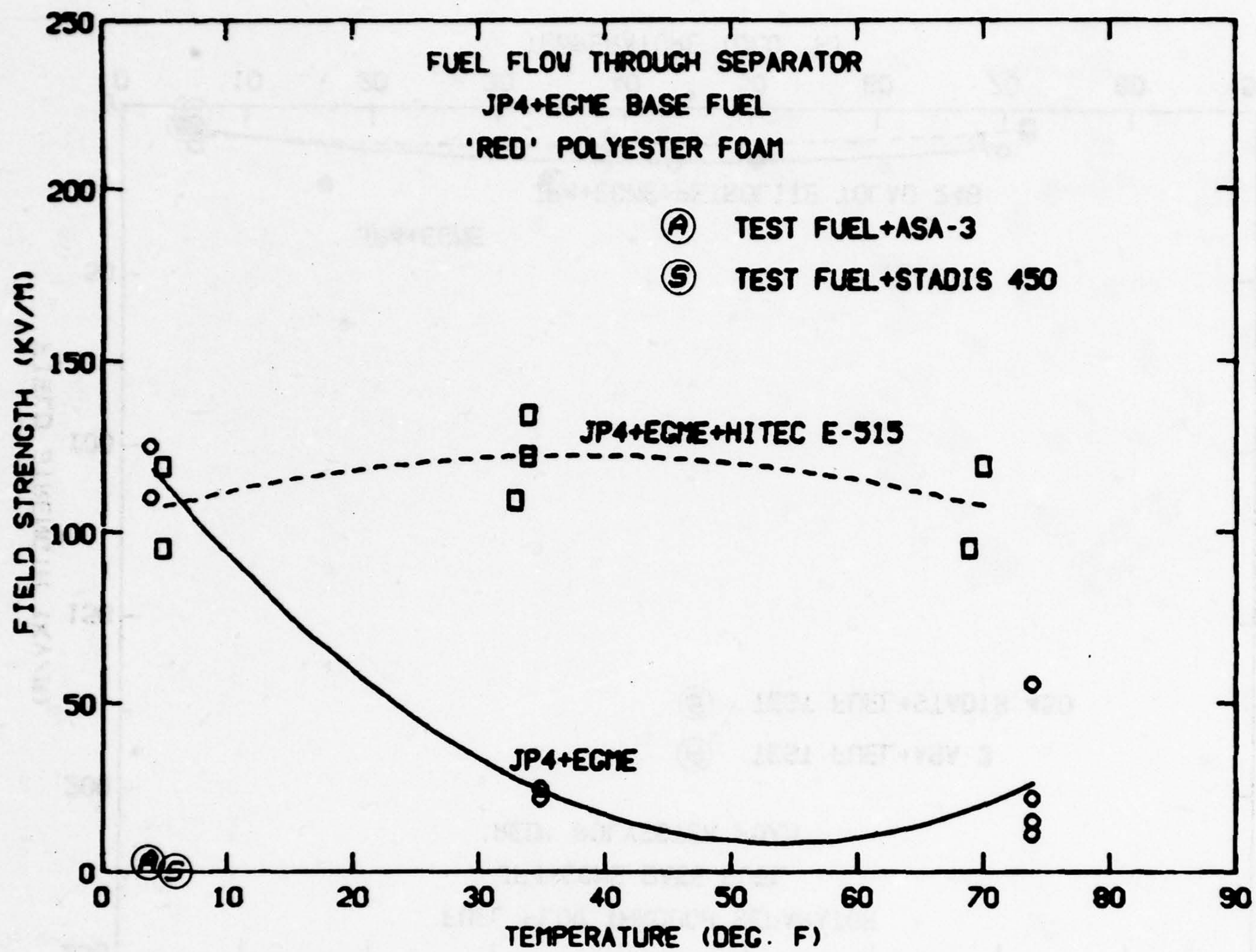


FIGURE A19. EFFECT OF HITEC E-515 ON FIELD STRENGTH

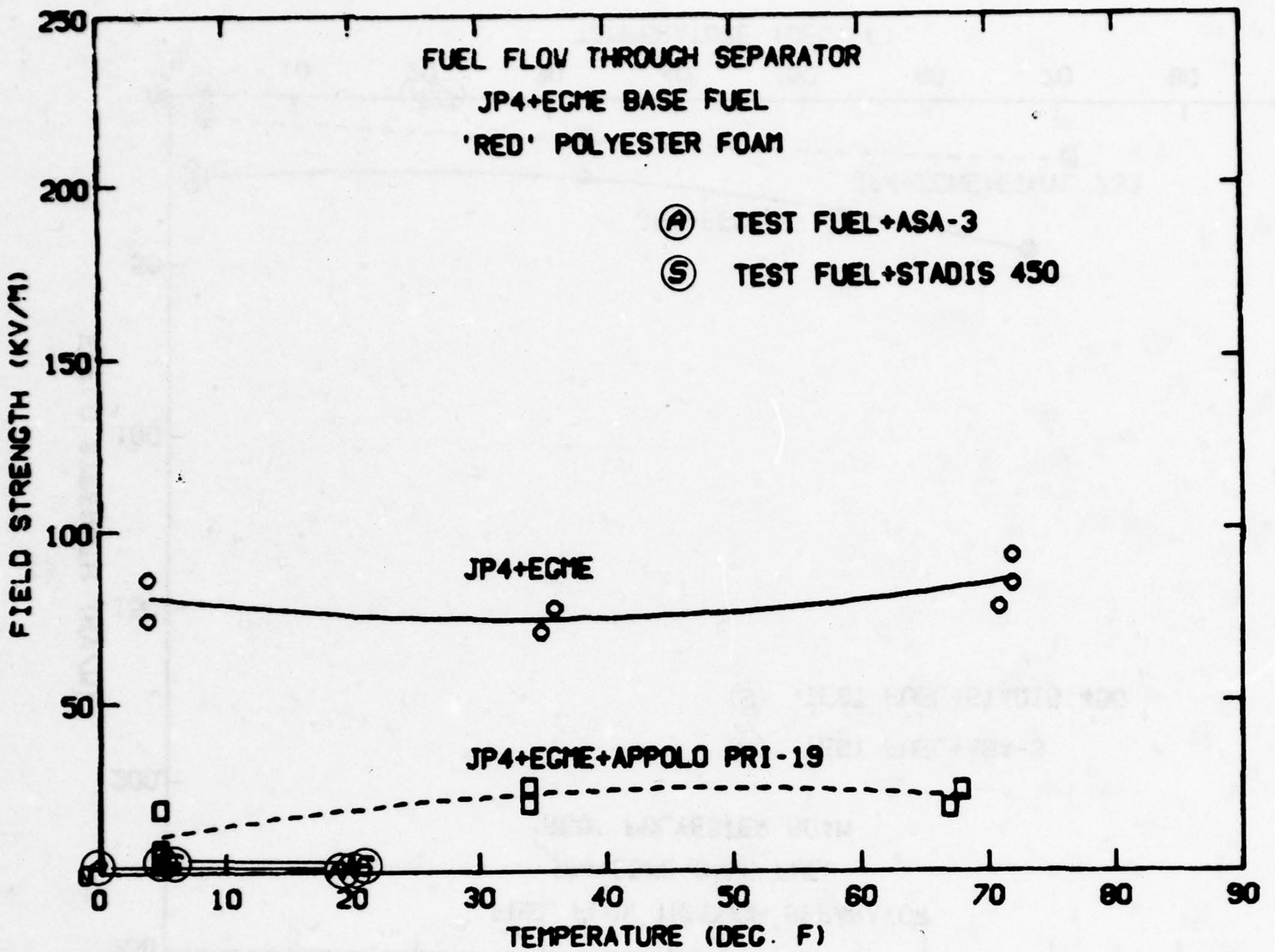


FIGURE A20. EFFECT OF APOLLO PRI-19 ON FIELD STRENGTH

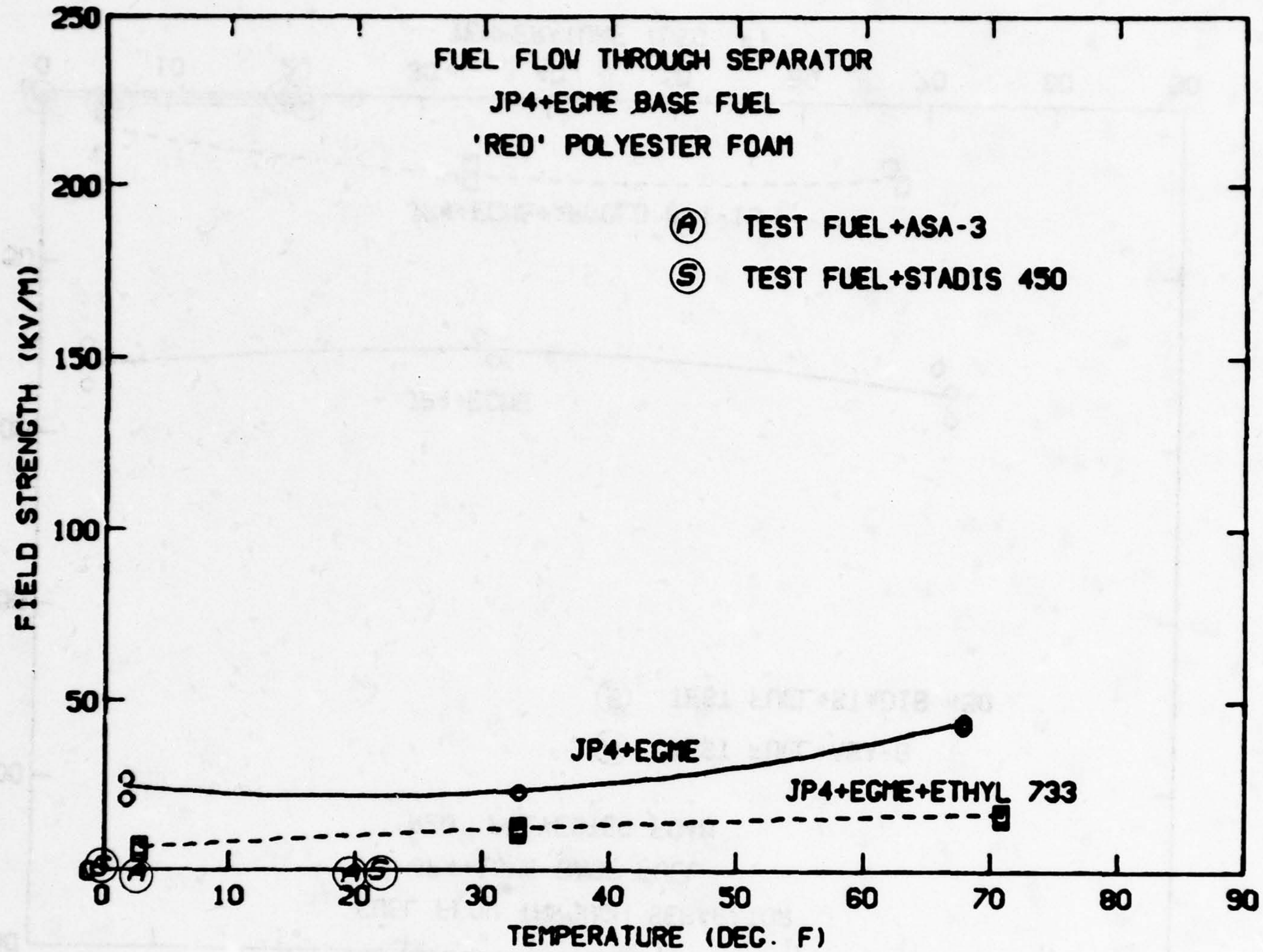


FIGURE A21. EFFECT OF ETHYL 733 ON FIELD STRENGTH

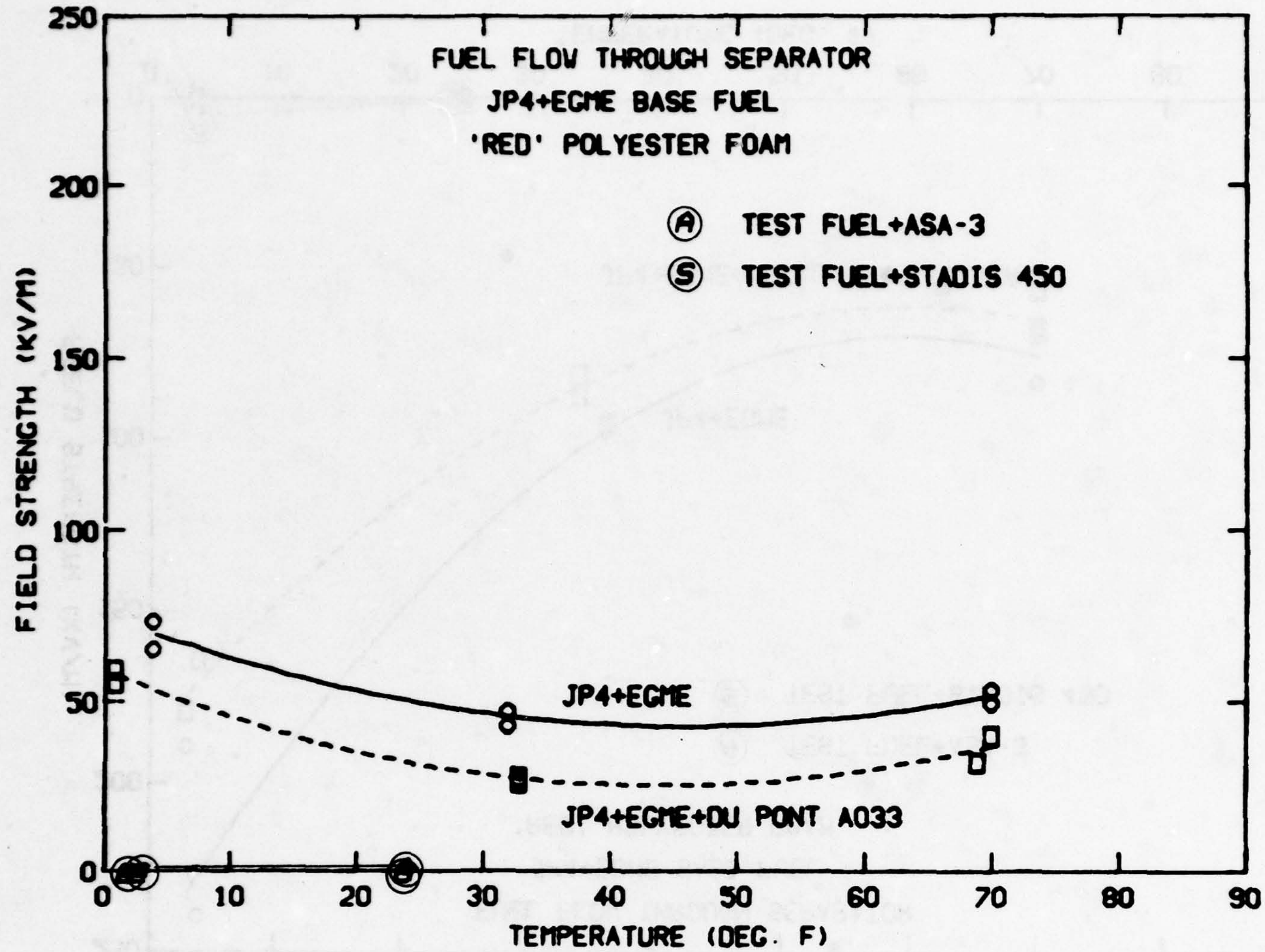


FIGURE A22. EFFECT OF DU PONT A033 ON FIELD STRENGTH

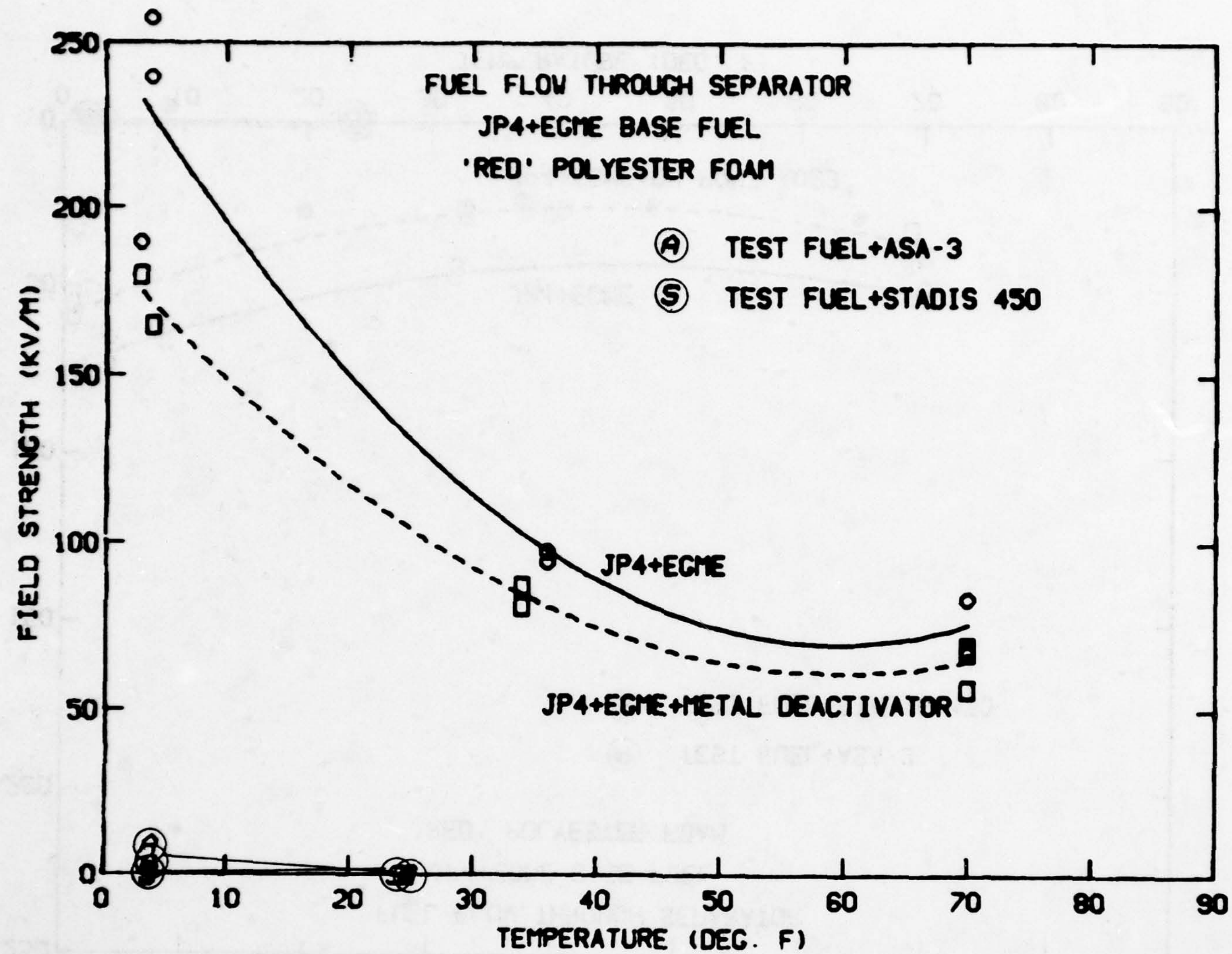


FIGURE A23. EFFECT OF METAL DEACTIVATOR ON FIELD STRENGTH

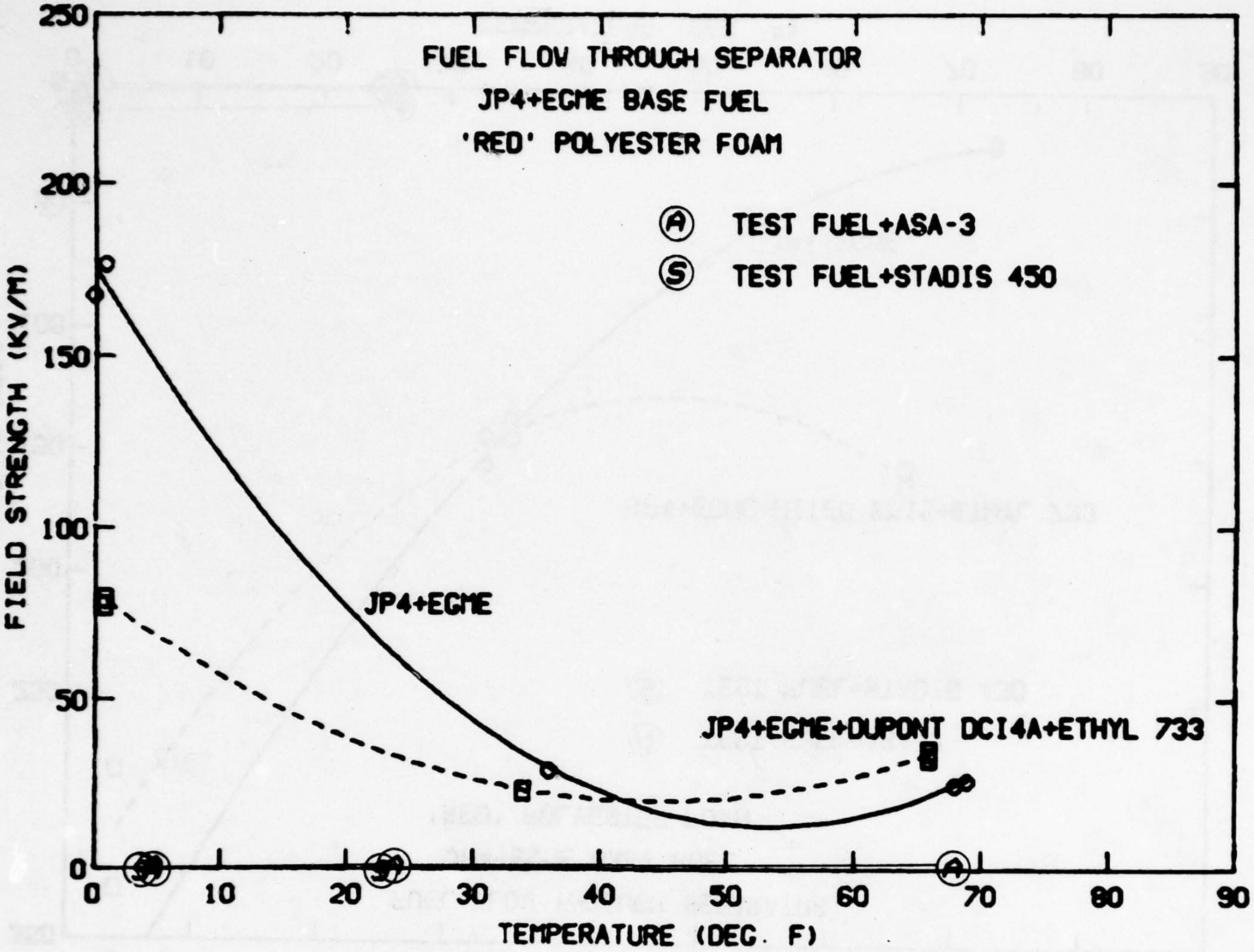


FIGURE A24. EFFECT OF DUPONT DCI4A+ETHYL 733 ON FIELD STRENGTH

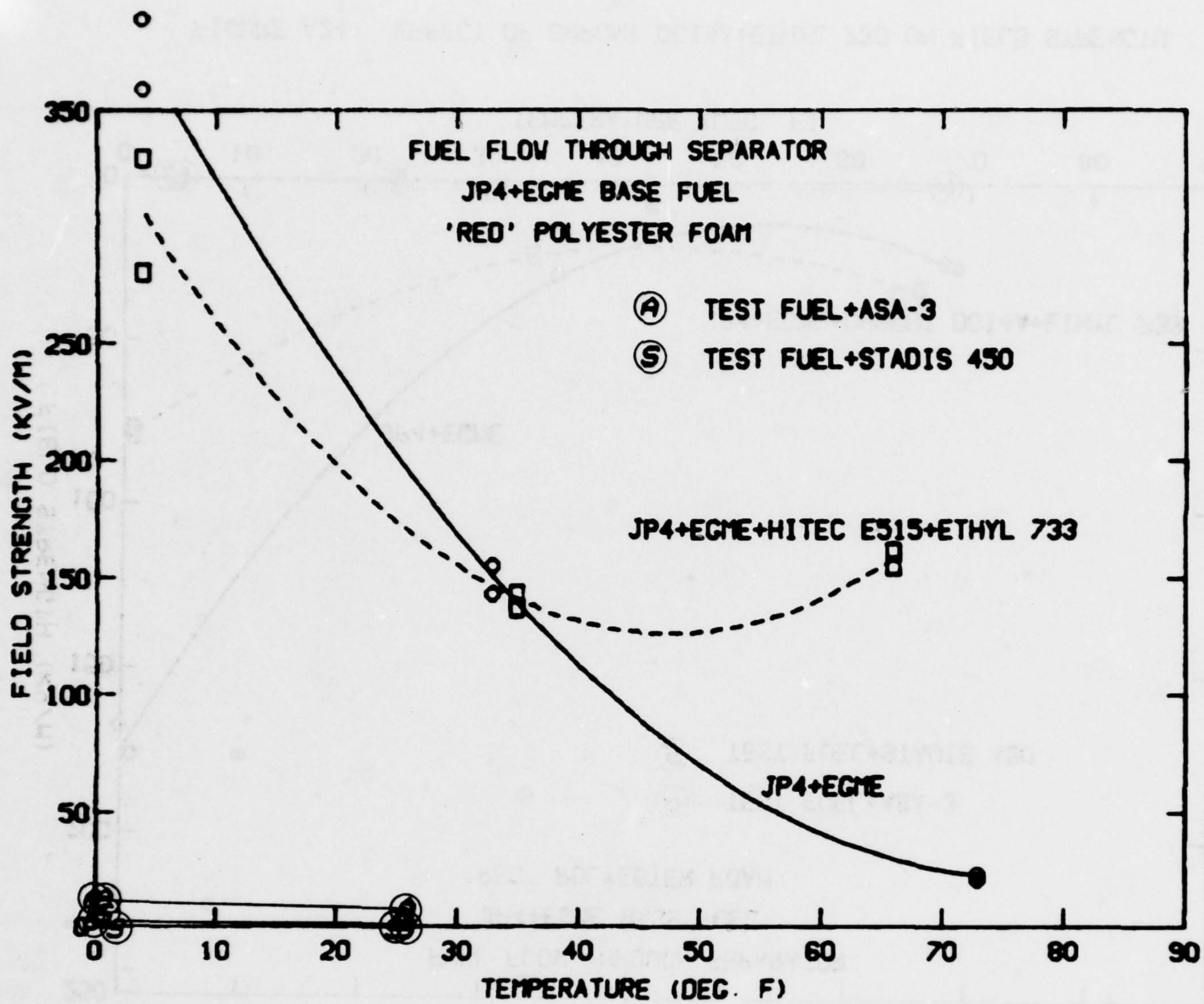


FIGURE A25. EFFECT OF HITEC E515+ETHYL 733 ON FIELD STRENGTH

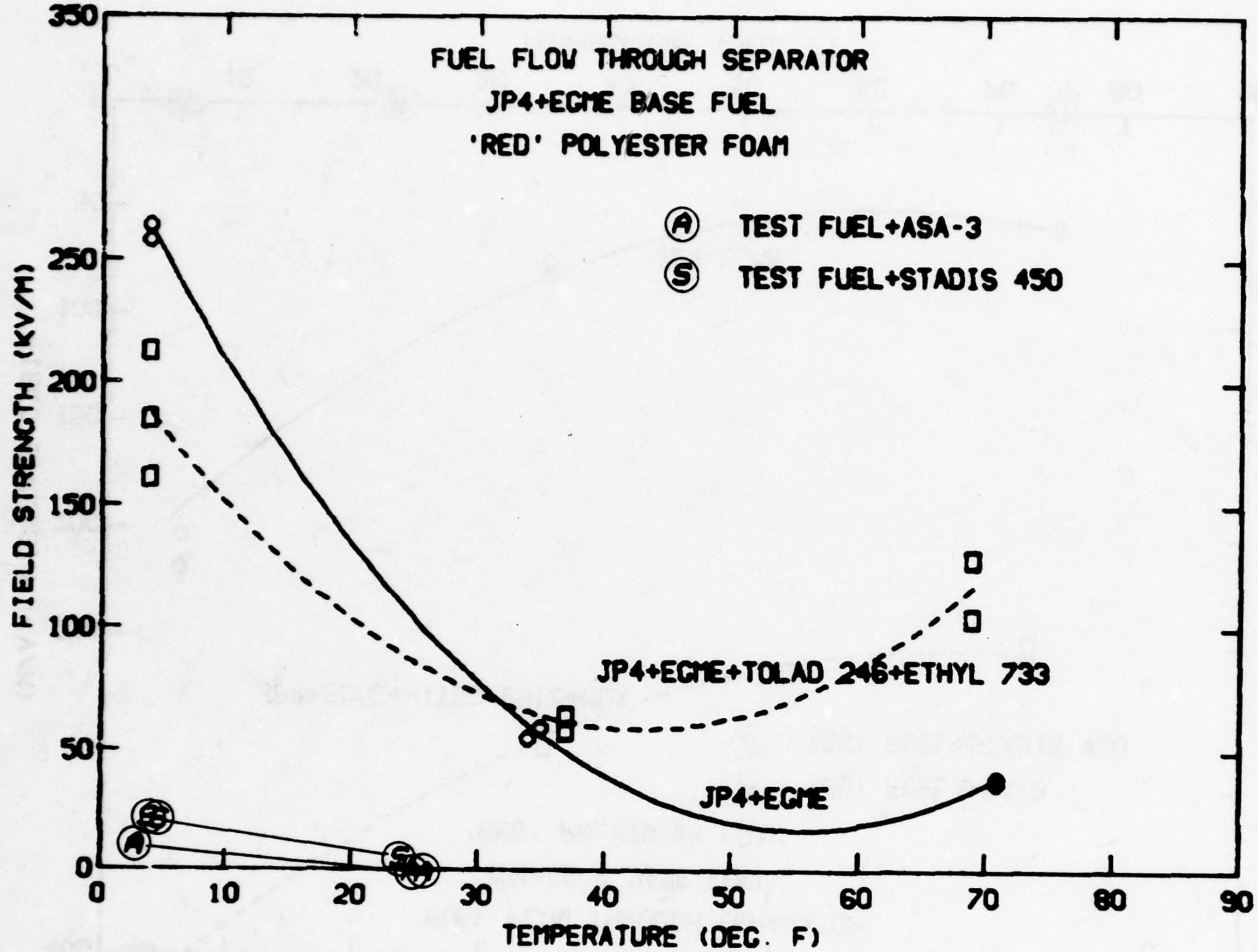


FIGURE A26. EFFECT OF TOLAD 246+ETHYL 733 ON FIELD STRENGTH

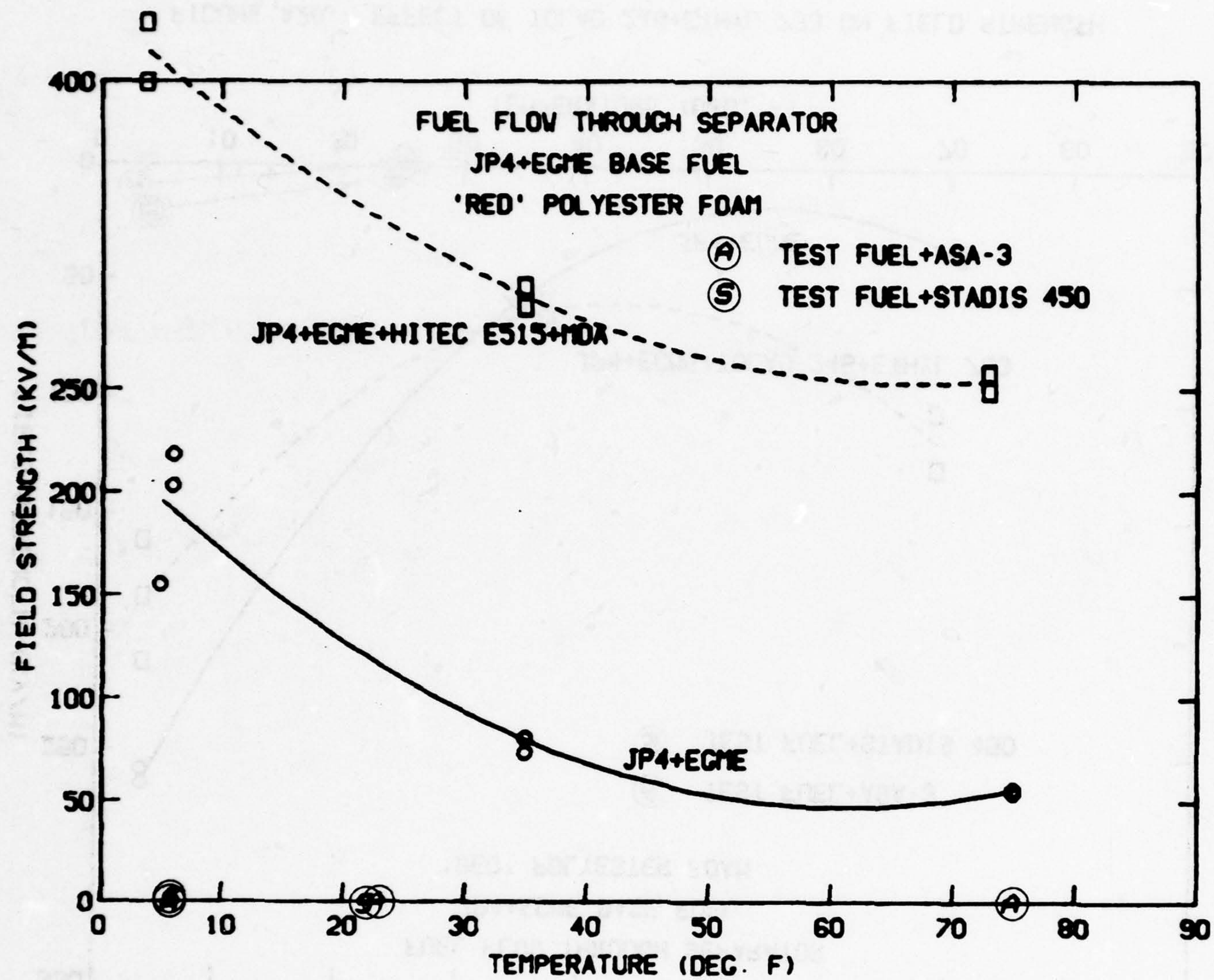


FIGURE A27. EFFECT OF HITEC E515+MDA ON FIELD STRENGTH

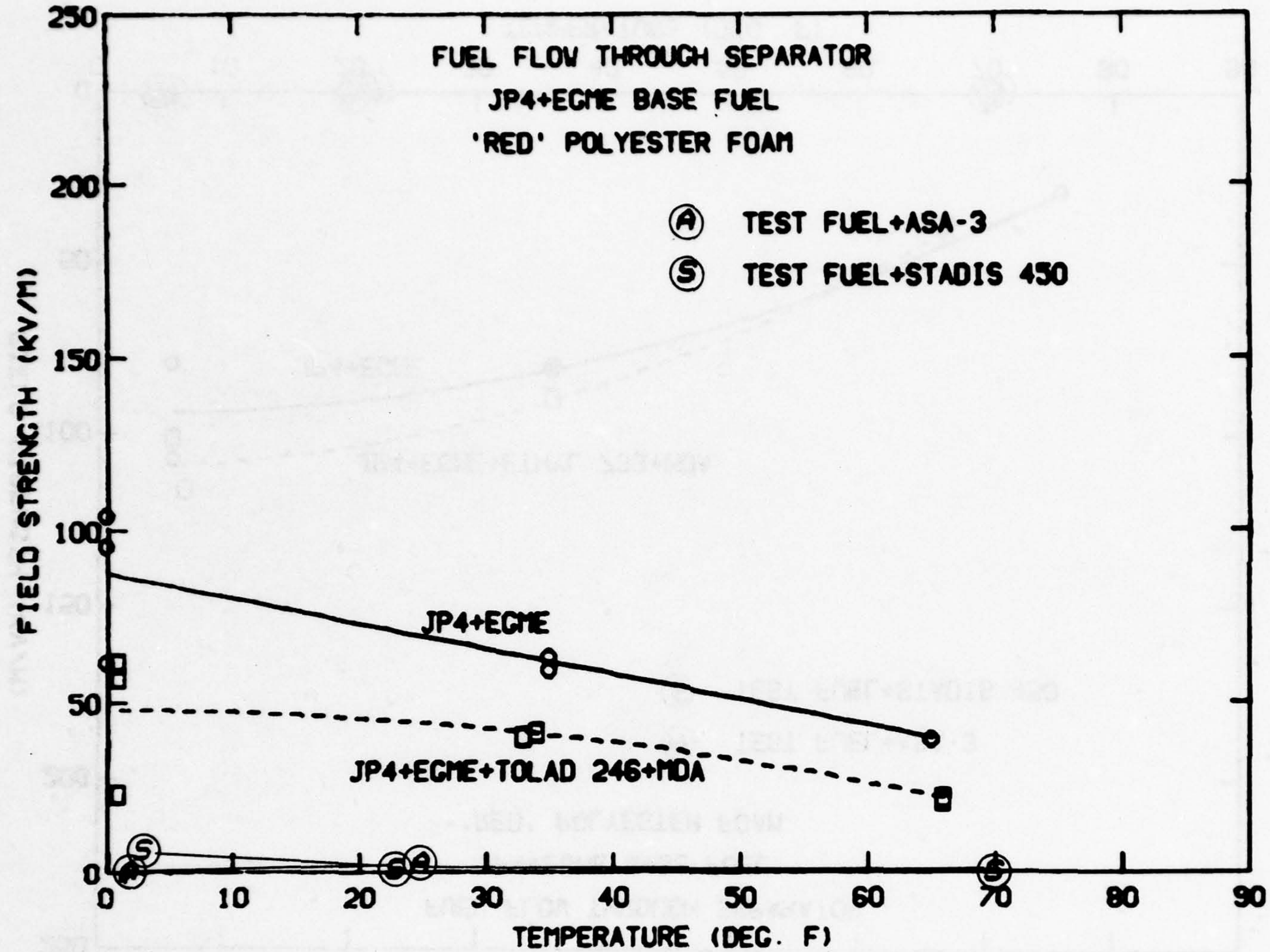


FIGURE A28. EFFECT OF TOLAD 246+MDA ON FIELD STRENGTH

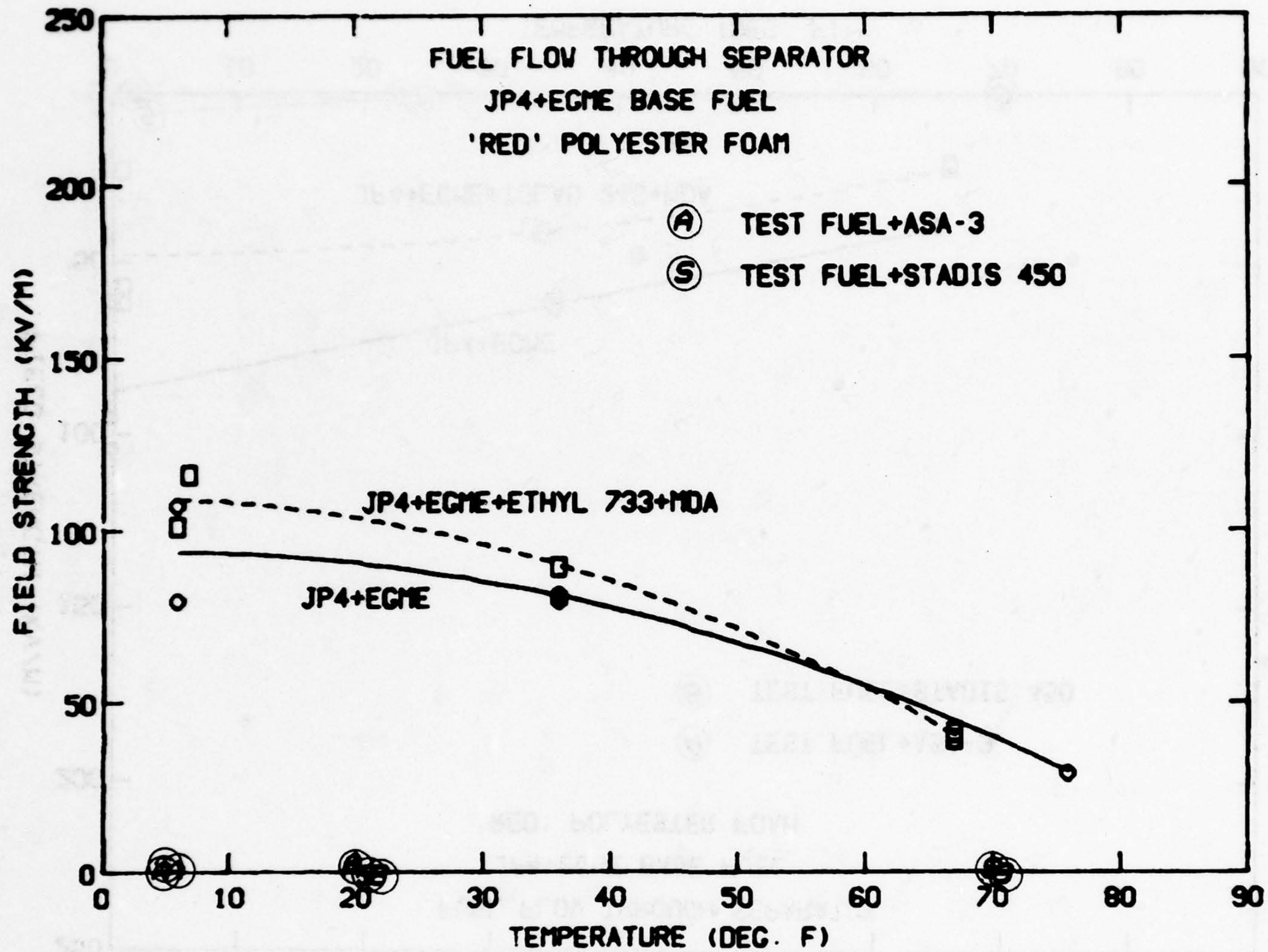


FIGURE A29 EFFECT OF ETHYL 733+MDA ON FIELD STRENGTH

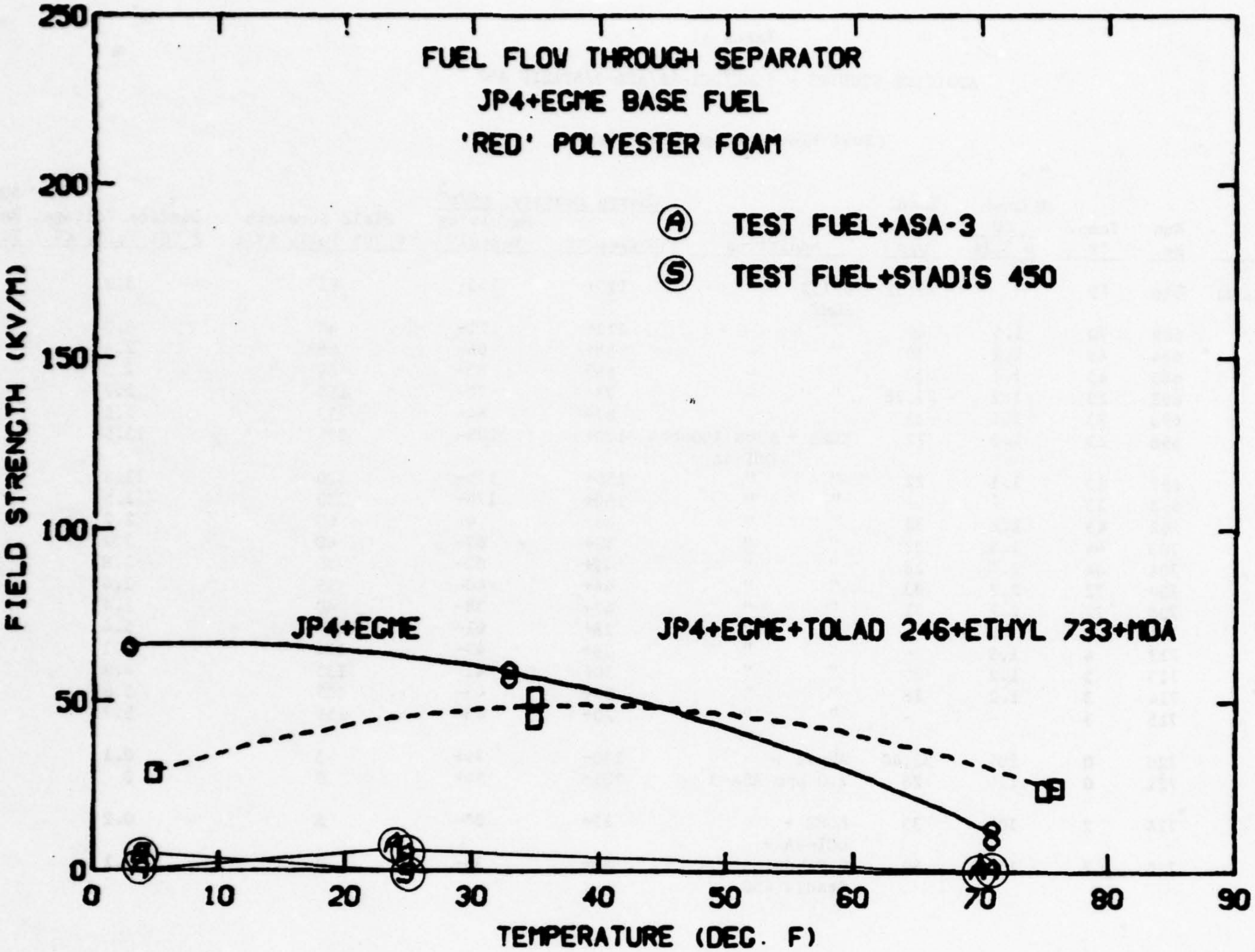


FIGURE A30. EFFECT OF TOLAD 246+ETHYL 733+MDA ON FIELD STRENGTH

TABLE A1

ADDITIVE STUDIES - EGME/DCI-4A/ASA-3/STADIS 450

(Fuel Flow Through Coalescer)

Fuel	Run No.	Temp. °F	Cond. CU D 3114	Total Water ppm	Additives	Charge Density, $\mu C/m^3$ Coalescer	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full, KV/m	Surface Voltage @ 90% Full, KV	50% Charge Relaxation Time, Sec.
JP-4 77D-3301	688	69	-	30,32	0.15% EGME -	170+	153-	92	3.3	5
	689	70	1.5	40	" -	122+	111-	84	3.0	6
	684	45	1.2	30	" -	68+	66-	68	2.4	13
	685	45	1.1	30	" -	66+	63-	64	2.3	10
	692	23	1.2	23,28	" -	73+	70-	159	5.7	19
	693	23	1.1	35	" -	87+	84-	153	5.5	25
	696	23	1.0	22	EGME + 8 lbs/1000bbl DCI-4A	182+	209-	375	13.5	16
	697	23	1.1	22	" "	156+	179-	320	11.5	14
	698	23	-	-	" "	150+	174-	320	11.5	13
	702	43	1.8	38	" "	68+	4+	60	2.2	7
	703	44	1.5	32	" "	52+	67-	60	2.2	7
	704	44	1.4	28	" "	47+	63-	50	1.8	6
	707	72	2.3	33	" "	44+	40-	39	1.4	6
	708	72	2.2	31	" "	42+	58-	40	1.4	6
	711	4	1.2	-	" "	28+	61-	150	5.4	52
	712	4	1.3	-	" "	28+	49-	114	4.1	-
	713	3	1.2	20	" "	20+	41-	135	4.9	51
	714	3	1.2	28	" "	20+	43-	105	3.8	52
	715	3	-	-	" "	20+	43-	159	5.7	32
	720	0	105	32,40	Above + 2.0 ppm ASA-3	190-	39+	3	0.1	0
	721	0	110	28		205-	54+	0	0	0
	724	2	105	33	EGME + DCI-4A + 0.9 ppm Stadis 450	25+	28-	5	0.2	1
	725	2	110	30		28+	36-	3	0.1	2

TABLE A2

ADDITIVE STUDIES - EGME/UNICOR J/ASA-3/STADIS 450

(Fuel Flow Through Coalescer)

Fuel	Run No.	Temp, °F	Conductivity, CU D 3114	Conductivity, CU D 2624	Water, ppm Total	Water, ppm Free	Additive	Charge Density, $\mu C/m^3$ Coalescer	Charge Density, $\mu C/m^3$ Separator	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full, KV/m	Surface Voltage @ 90% Full, KV	50% Charge Relaxation Time, Sec
JP-4, 77D-3300	77-645	74	3.0	-	46,64	-	0.15% EGME	150+	-	155-	54	1.9	5
	-646	74	2.9	-	46	-	"	136+	-	139-	40	1.4	4
	-647	74	2.2	-	40	-	"	125+	-	129-	31	1.1	3
	-648	74	2.0	-	48	-	"	120+	-	119-	27	1.0	3
	-651	46	3.0	-	-	-	"	107+	-	103-	77	2.8	10
	-652	46	1.8	-	-	-	"	101+	-	100-	70	2.5	7
	-655	-	1.5	-	70,42	-	"	64+	-	32-	84	3.0	18
	-656	26	1.5	-	48	-	"	51+	-	58-	67	2.4	16
	-657	26	1.3	-	60	-	"	47+	-	51-	60	2.2	19
	-665	71	3.5	-	-	-	Above +	16+	-	31-	13	0.5	5
	-666	71	3.5	-	-	-	8 lbs/1000bbl Unicor J	14+	-	32-	12	0.4	8
	-669	44	2.2	-	54,28	-	"	12+	-	22-	11	0.4	6
	-670	44	2.1	-	46	-	"	12+	-	23-	9	0.3	6
	-660	27	1.5	-	60	-	"	27+	-	58-	86	3.0	25
	-661	27	1.5	-	-	-	"	16+	-	47-	69	2.5	24
	-662	27	-	-	-	-	"	18+	-	45-	62	2.2	22
	-673	24	1.8	-	26,18	-	"	8+	-	16-	18	0.6	14
	-674	24	1.8	-	42,20	-	"	8+	-	11-	16	0.6	13
	-676	23	100	115	22,32	-	Above +	16-	-	142-	16	0.6	1
	-677	23	100	115	24	-	1.9 ppm ASA-3	20-	-	130-	14	0.5	1
	-680	20	105	110	-	-	EGME + Unicor J +	119+	-	119-	8	0.3	1
	-681	20	94	110	-	-	1.5 ppm Stadis 450	134+	-	135-	6	0.2	1

TABLE A3

ADDITIVE STUDIES - EGME/TOLAD 246/ASA-3/STADIS 450

(Fuel Flow Through Coalescer)

Fuel	Run No.	Temp. °F	Cond. CU D 3114	Total Water ppm	Additives	Charge Density, $\mu C/m^3$ Coalescer	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full, KV/m	Surface Voltage @ 90% Full, KV	50% Charge Relaxation Time, Sec.
JP-4 77D-3302	728	68	2.2	36	0.15% EGME	144+	2-	76	2.7	9
	729	68	1.9	37	"	91+	11-	52	1.9	9
	730	68	1.6	46	"	87+	6-	50	1.8	9
	733	45	-	-	"	87+	-	117	4.2	42
	734	45	1.2	-	"	79+	-	110	3.9	40
	735	45	1.0	24	"	63+	63-	90	3.2	42
	738	5	0.6	18	"	20+	25-	60	2.2	116
	739	5	0.6	14	"	17+	21-	78	2.8	146
	751	69	2.0	-	Above +	48+	51-	28	1.0	6
	752	70	-	32	8 lbs/1000 bbl	40+	47-	23	1.2	9
	747	38	1.2	-	Tolad 246	29+	36-	55	2.0	18
	748	38	1.8	-	"	24+	34-	58	2.1	26
	743	5	0.6	-	"	28+	40-	108	3.9	124
	744	5	-	18	"	20+	30-	92	3.3	95
	767	3	123	32	Above + 2.0 ppm	58+	114-	14	0.5	1
	768	5	117	30	ASA-3	59+	125-	14	0.5	1
	755	5	100	-	EGME + Tolad 246	170+	178-	20	0.7	3
	756	5	105	-	+ 0.9 ppm	182+	192-	21	0.8	3
					Stadis 450					

TABLE A4

ADDITIVE STUDIES - EGME/HITEC E-515/ASA-3/STADIS 450

(Fuel Flow Through Coalescer)

Fuel	Run No.	Temp., °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, $\mu C/m^3$ Coalescer	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full KV	50% Charge Relaxation Time, Sec.
77D 3305	78- 5	74	2.3	26	0.15% EGME	47+	83-	46	1.7	8
	6	74	1.8	32	"	32+	79-	56	1.7	10
	11	36	1.7	18	"	21+	62-	129	4.6	73
	12	36	1.2	22	"	22+	58-	108	3.9	32
	15	3	0.8	16	"	10+	24-	150	5.4	78
	16	4	0.8	20	"	8+	36-	180	6.5	101
	28	67	4.2	20	Above + 16 lbs/1000 bbl	16+	96-	14	0.5	2
	29	67	5.8	26	Hitec E-515	40+	58-	9	0.3	4
	23	33	4.8	22	"	24+	65-	18	0.6	9
	24	33	4.6	26	"	32+	55-	20	0.7	11
	19	4	3.2	-	"	16+	79-	135	4.9	15
	20	4	2.9	22	"	119+	79-	155	5.6	18
	32	5	115	24	EGME + Hitec E-515 +	79+	108-	4	0.1	1
	33	5	120	26	1 ppm Stadis 450	95+	119-	4	0.1	1
	36	3	110	26	EGME + Hitec E-515 +	2-	18-	10	0.4	<1
	37	3	115	24	1 ppm ASA-3	5-	22-	8	0.3	1

TABLE A5

ADDITIVE STUDIES - EGME/APPOLO PRI-19/ASA-3/STADIS 450

(Fuel Flow Through Coalescer)

Fuel	Run No.	Temp., °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, $\mu C/m^3$ Coalescer	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full KV	50% Charge Relaxation Time, Sec.
77D 3306	78-40	71	2.4	28	0.15% EGME	190+	113-	45	1.6	9
	41	71	2.4	30	"	166+	97-	34	1.2	6
	42	71	2.5	30	"	146+	83-	27	1.0	5
	46	35	1.8	28	"	87+	79-	114	4.1	33
	47	35	1.5	26	"	79+	70-	81	2.9	26
	48	35	1.6	34	"	83+	72-	63	2.3	38
	49	35	1.6	30	"	83+	77-	70	2.5	44
	52	4	1.3	16	"	52+	47-	123	4.4	127
	53	4	1.2	24	"	46+	39-	138	5.0	102
	65	67	8.8	35	Above + 8 lbs/1000 bbl	124+	130-	47	1.7	6
	66	67	8.2	-	Appolo PRI-19	109+	130-	54	1.9	3
	61	33	4.6	30	"	111+	127-	48	1.7	6
	62	33	4.5	28	"	96+	107-	54	1.9	7
	56	5	1.7	14	"	104+	166-	370	13.3	35
	57	5	1.7	30	"	88+	155-	360	13.0	31
	69	21	100	18	Above + 2.1 ppm	89+	165-	12	0.4	2
	70	21	105	24	Stadis 450	93+	168-	12	0.4	2
	81	5	110	16	"	69+	172-	21	0.8	2
	82	5	110	22	"	73+	17-	19	0.7	2
	73	19	110	22	EGME + Appolo PRI-19	24+	93-	6	0.2	3
	74	19	105	28	+ 1.4 ppm ASA-3	22+	95-	6	0.2	2
	77	-2	105	22	"	20+	89-	10	0.4	2
	78	-1	94	20	"	13+	88-	10	0.4	2

TABLE A6

ADDITIVE STUDIES - EGME/ETHYL 733/ASA-3/STADIS 450

(Fuel Flow Through Coalescer)

Fuel	Run No.	Temp. °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, $\mu C/m^3$ Coalescer	Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full, KV	50% Charge Relaxation Time, Sec.
77D-3307	78- 85	68	1.8	28	0.15% EGME	213+	134-	108	3.9	10
	86	68	1.8	32	"	194+	126-	96	3.5	8
	89	33	1.2	20	"	126+	111-	108	3.9	8
	90	33	1.3	22	"	119+	103-	113	4.1	9
	93	2	0.8	22	"	79+	70-	210	7.6	92
	94	2	0.6	19	"	71+	68-	204	7.3	70
	105	69	3.8	30	Above + 8.4 lbs./1000 bbl	162+	122-	34	1.2	3
	106	69	3.9	34	Ethyl 733	134+	108-	48	1.7	5
	107	70	3.9	32	"	129+	100-	56	2.0	5
	101	33	1.8	26	"	126+	111-	63	2.3	4
	102	33	1.6	20	"	95+	87-	60	2.2	5
	97	3	0.6	15	"	92+	98-	210	7.6	64
	98	3	0.6	16	"	79+	88-	207	7.5	55
	110	22	105	28	EGME + Ethyl 733 + 0.75 ppm	35+	87-	4	0.1	1
	111	22	100	29	ASA-3	25+	87-	3	0.1	<1
	122	3	105	20	EGME + Ethyl 733 + 1.5 ppm	8-	97-	2	0.1	1
	123	3	110	20	ASA-3	9-	90-	2	0.1	1
	114	22	110	36	EGME + Ethyl 733 + 0.9 ppm	190+	234-	10	0.4	1
	115	22	105	30	Stadis 450	167+	221-	9	0.3	1
	118	0	105	22	EGME + Ethyl 733 + 1.0 ppm	155+	190-	14	0.5	1
	119	0	105	22	Stadis 450	147+	194-	12	0.4	1

TABLE A7

ADDITIVE STUDIES - EGME/DUPONT A033/ASA-3/STADIS 450

(Fuel Flow Through Coalescer)

Fuel	Run No.	Temp. °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, $\mu C/m^3$ Coalescer	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full, KV	50% Charge Relaxation Time, Sec.
77D-3308	78-128	68	3.2	36	0.15% EGME	170+	126-	72	2.6	7
	129	69	2.1	34	"	158+	101-	51	1.8	6
	130	69	2.0	32	"	150+	95-	46	1.7	7
	133	31	1.4	32	"	109+	103-	62	2.2	4
	134	31	1.4	36	"	90+	87-	78	2.8	7
	135	31	1.2	36	"	96+	91-	86	3.1	9
	136	31	1.3	34	"	76+	75-	93	3.3	15
	139	4	0.6	22	"	62+	61-	201	7.2	73
	140	4	0.6	20	"	58+	58-	201	7.2	71
	152	69	3.2	28	Above + 8.4 lbs./1000 bbl	126+	115-	60	2.2	6
	153	69	2.9	26	DuPont A033	104+	99-	66	2.4	9
	148	32	1.5	22	"	65+	63-	44	1.6	11
	149	32	2.0	24	"	56+	56-	50	1.8	7
	144	1	0.6	20	"	38+	51-	174	6.3	74
	145	1	0.6	20	"	33+	50-	162	5.8	70
	156	24	105	22	EGME + DuPont A033 +	8-	130-	8	0.3	1
	157	24	100	20	1.4 ppm ASA-3	24-	119-	7	0.3	1
	168	2	105	18	EGME + DuPont A033 +	33-	100-	10	0.4	1
	169	2	100	22	1.7 ppm ASA-3	36-	100-	8	0.3	1
	160	23	105	16	EGME + DuPont A033 +	122+	174-	8	0.3	1
	161	23	111	20	0.75 ppm Stadis 450	105+	166-	8	0.3	1
	164	2	105	18	EGME + DuPont A033 +	107+	153-	14	0.5	1
	165	2	105	14	1.0 ppm Stadis 450	92+	152-	10	0.4	1

TABLE A8

ADDITIVE STUDIES - EGME/MDA/ASA-3/STADIS 450

(Fuel Flow Through Coalescer)

Fuel	Run No.	Temp. °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, $\mu C/m^3$ Coalescer	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full, KV	50% Charge Relaxation Time, Sec.
77D-3310	78-205	67	2.1	40	0.15% EGME	118+	104-	48	1.7	10
	206	68	1.8	28	"	96+	85-	41	1.5	9
	207	69	1.7	32	"	95+	78-	28	1.0	10
	208	70	1.8	36	"	93+	79-	18	0.6	6
	211	36	1.8	24	"	92+	83-	43	1.5	7
	212	36	1.6	30	"	97+	68-	38	1.4	8
	215	4	-	-	"	43+	47-	84	3.0	52
	216	4	0.8	20	"	43+	43-	96	3.5	45
	219	3	-	-	"	37+	45-	93	3.3	54
	232	67	1.8	-	Above + 2 lbs./1000 bbl	79+	88-	31	1.1	5
	233	69	1.5	30	MDA	60+	87-	34	1.2	7
	228	33	1.4	32	"	40+	54-	27	1.0	10
	229	33	1.5	34	"	32+	48-	27	1.0	13
	223	2	0.9	16	"	28+	42-	108	3.9	49
	224	2	1.0	18	"	21+	43-	78	2.8	32
	225	2	0.8	20	"	19+	40-	66	2.4	32
	237	25	105	28	EGME + MDA + 1.0 ppm	79-	92-	4	0.1	1
	238	25	111	32	ASA-3	49-	77-	3	0.1	1
	249	3	111	18	EGME + MDA + 1.3 ppm	66+	120-	6	0.2	1
	250	4	129	-	ASA-3	67+	119-	6	0.2	1
	241	23	105	-	EGME + MDA + 0.6 ppm	53+	142-	6	0.2	1
	242	23	110	28	Stadis 450	42+	137-	6	0.2	1
	245	3	120	18	EGME + MDA + 0.74 ppm	53+	136-	10	0.4	1
	246	3	129	-	Stadis 450	48+	139-	8	0.3	1

TABLE A9

ADDITIVE STUDIES - EGME/DCI-4A/ETHYL 733/ASA-3/STADIS 450

(Fuel Flow Through Coalescer)

Fuel	Run No.	Temp., °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, $\mu C/m^3$ Coalescer	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full KV	50% Charge Relaxation Time, Sec.
77D 3313	78-383	69	2.7	40	0.15% EGME	143+	140-	59	2.1	5
	384	69	1.3	44	"	121+	115-	48	1.7	4
	387	36	1.5	-	"	111+	113-	40	1.4	2
	388	36	0.9	-	"	100+	100-	37	1.3	3
	391	0	0.8	-	"	43+	54-	108	3.9	48
	392	0	0.8	-	"	37+	49-	99	3.6	39
	403	65	1.8	40	Above + 8.4 lbs./1000bbl	36+	79-	28	1.0	4
	404	65	2.2	45	Ethyl 733 + 8.0 lbs./	28+	72-	34	1.2	5
	399	33	1.8	33	1000 bbl DCI-4A	57+	97-	24	0.9	2
	400	33	1.5	33	"	40+	83-	26	0.9	3
	395	1	1.0	25	"	93+	158-	310	11.2	30
	396	1	1.0	32	"	88+	150-	310	11.2	25
	407	68	88	40	EGME + Ethyl 733 + DCI-	27-	222-	10	0.4	1
	408	68	117	36	4A + 0.8 ppm ASA-3	22-	241-	10	0.4	1
	411	24	111	-	EGME + Ethyl 733 + DCI-	32-	198-	10	0.4	1
	412	24	117	-	4A + 1.7 ppm ASA-3	43-	190-	10	0.4	2
	423	4	105	12	EGME + Ethyl 733 + DCI-	37-	145-	12	0.4	1
	424	4	117	20	4A + 1.9 ppm ASA-3	38-	146-	11	0.4	1
	415	22	129	20	EGME + Ethyl 733 + DCI-	61+	162-	6	0.2	1
	416	24	130	24	4A + 0.5 ppm Stadis 450	54+	138-	6	0.2	1
	419	3	100	12	EGME + Ethyl 733 + DCI-	40+	146-	11	0.4	1
	420	3	100	22	4A + 0.6 ppm Stadis 450	45+	135-	10	0.4	1

TABLE A10

ADDITIVE STUDIES - EGME/HITEC E-515/ETHYL 733/ASA-3/STADIS 450

(Fuel Flow Through Coalescer)

Fuel	Run No.	Temp., °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, $\mu C/m^3$ Coalescer	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full KV	50% Charge Relaxation Time, Sec.
77D-3312	78-336	73	2.7	40	0.15% EGME	225+	201-	86	3.0	6
	337	73	1.2	56	"	200+	176-	70	2.5	4
	338	73	1.2	46	"	194+	174-	63	2.3	4
	341	33	1.3	48	"	82+	83-	34	1.2	8
	342	33	1.0	40	"	87+	85-	40	1.4	7
	345	4	0.6	-	"	43+	51-	54	1.9	21
	346	4	0.8	-	"	48+	55-	54	1.9	21
	358	66	716	-	Above + 8.4 lbs./1000 bbl	44+	59-	35	1.3	1
	359	66	7.0	-	Ethyl 733 + 16 lbs./1000	36+	62-	40	1.4	1
	353	33	5.5	38	bbl Hitec E-515	27+	55-	25	0.9	1
	354	33	4.7	42	"	8+	30-	36	1.3	2
	355	35	4.8	-	"	11+	21-	44	1.6	2
	349	4	2.9	22	"	21+	80-	36	1.3	6
	350	4	2.5	26	"	6+	63-	42	1.5	8
	363	25	117	-	EGME + Ethyl 733 + Hitec	55+	158-	8	0.3	1
	364	25	123	-	E-515 + 0.5 ppm Stadis	40+	151-	7	0.3	2
	375	0	100	-	450	9-	119-	15	0.5	1
	376	0	94	34	"	16+	132-	15	0.5	1
	379	2	130	24	EGME + Ethyl 733 + Hitec	35+	137-	7	0.3	1
	380	2	140	37	E-515 + 0.6 ppm Stadis 450	25+	130-	8	0.3	1
	367	26	129	44	EGME + Ethyl 733 + Hitec	11+	110-	5	0.2	2
	368	26	129	38	E-515 + 0.6 ppm ASA-3	4+	106-	7	0.3	2
	371	0	110	-	"	8-	66-	4	0.1	1
	372	0	111	30	"	9-	67-	4	0.1	1

TABLE A11

ADDITIVE STUDIES - EGME/TOLAD 246/ETHYL 733/ASA-3/STADIS 450

(Fuel Flow Through Coalescer)

Fuel	Run No.	Temp., °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, $\mu C/m^3$ Coalescer	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full KV	50% Charge Relaxation Time, Sec.
77D-3311	78-286	71	2.3	38	0.15% EGME	150+	116-	30	1.1	4
	287	71	2.4	64	"	150+	123-	31	1.1	3
	290	35	2.0	36	"	97+	103-	150	5.4	37
	291	35	1.5	35	"	92+	91-	114	4.1	32
	292	35	1.8	35	"	85+	85-	103	3.7	27
	295	4	1.0	20	"	42+	44-	60	2.2	27
	296	4	1.2	22	"	38+	43-	60	2.2	25
	309	67	3.5	44	Above + 8.4 lbs./1000 bbl	18+	68-	10	0.4	5
	310	67	3.8	52	Ethyl 733 + 8.0 lbs./1000	8+	63-	8	0.3	7
	305	37	2.6	-	bbl Tolad 246	20+	65-	10	0.4	4
	306	37	1.8	-	"	12+	52-	8	0.3	6
	299	3	1.3	14	"	76+	119-	280	10.0	94
	300	3	1.3	20	"	47+	92-	220	7.9	39
	301	3	1.3	20	"	27+	81-	195	7.0	71
	316	26	121	14	EGME + Ethyl 733 +	16+	167-	6	0.2	1
	317	26	164	20	Tolad 246 + 2.5 ppm	19+	152-	6	0.2	1
	334	4	100	-	ASA-3	27+	171-	12	0.4	1
	335	4	123	-	"	22+	175-	8	0.3	2
	320	23	141	18	EGME + Ethyl 733 +	69+	85-	0	0	0
	321	23	146	14	Tolad 246 + 0.5 ppm Stadis	66+	79-	0	0	0
	324	3	82	-	450	77+	112-	12	0.4	1
	325	4	94	-	"	72+	105-	10	0.4	2
	330	6	180	20	EGME + Ethyl 733 + Tolad	44+	58-	1	0.04	1
	331	6	176	-	246 + 0.75 ppm Stadis 450	40+	55-	2	0.07	1

TABLE A12

ADDITIVE STUDIES - EGME/HITEC E-515/MDA/ASA-3/STADIS 450

(Fuel Flow Through Coalescer)

Fuel	Run No.	Temp., °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, μC/m³ Coalescer	Charge Density, μC/m³ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full KV	50% Charge Relaxation Time, Sec.
77D-3315	78-475	75	3.5	-	0.15% EGME	158+	134-	100	3.6	12
	476	75	1.9	-	"	115+	101-	84	3.0	12
	479	35	1.0	-	"	77+	77-	174	6.3	56
	480	35	1.0	-	"	47+	50-	129	4.6	50
	481	35	1.0	-	"	40+	45-	117	4.2	56
	484	5	0.6	-	"	21+	36-	126	4.5	90
	485	5	0.6	-	"	24+	32-	123	4.4	102
	497	73	12.9	-	Above + 16 lbs./1000 bbl	99-	88+	156	5.6	3
	498	73	11.0	-	Hitec E-515 + 2 lbs./1000	114-	111+	168	6.0	4
	493	35	4.6	-	bbl MDA	64+	48-	174	6.3	4
	494	35	4.7	38	"	74+	70-	177	6.4	3
	489	4	1.5	-	"	53+	10-	160	5.8	5
	490	4	1.8	22	"	58+	24-	140	5.0	4
	501	75	152	52	EGME + Hitec E-515 + MDA	64+	201-	8	0.3	2
	502	75	158	46	+ 0.4 ppm ASA-3	62+	170-	8	0.3	1
	505	23	117	0	EGME + Hitec E-515 + MDA	85+	164-	17	0.6	2
	506	23	123	32	+ 0.6 ppm ASA-3	70+	161-	16	0.6	2
	517	5	117	22	"	103+	171-	26	0.9	1
	518	5	123	-	"	88+	178-	27	1.0	2
	521	5	141	24	EGME + Hitec E-515 + MDA	102+	181-	28	1.0	2
	522	6	146	-	+ 0.8 ppm ASA-3	94+	191-	23	0.8	1
	509	22	123	30	EGME + Hitec E-515 + MDA	122+	122-	22	0.8	1
	510	22	129	34	+ 0.4 ppm Stadis 450	111+	198-	21	0.8	2
	513	5	-	-	"	134+	209-	41	1.5	2
	514	5	105	-	"	136+	217-	37	1.3	2
	523	6	164	-	EGME + Hitec E-515 + MDA	163+	213-	24	0.9	1
	524	7	170	-	+ 0.6 ppm Stadis 450	149+	220-	18	0.6	2

TABLE A13

ADDITIVE STUDIES - EGME/TOLAD 246/MDA/ASA-3/STADIS 450

(Fuel Flow Through Coalescer)

Fuel	Run No.	Temp., °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, $\mu C/m^3$ Coalescer	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full KV	50% Charge Relaxation Time, Sec.
77D 3314	78-427	65	1.1	38	0.15% EGME	152+	156-	120	4.3	12
	428	65	1.2	33	"	122+	117-	90	3.2	10
	429	65	1.2	38	"	119+	111-	78	2.8	8
	430	65	1.3	34	"	120+	115-	80	2.9	10
	433	34	1.2	-	"	108+	108-	213	7.7	52
	434	34	1.0	28	"	112+	112-	185	6.7	37
	437	0	1.0	-	"	51+	52-	216	7.8	165
	438	0	0.9	18	"	53+	58-	228	8.2	145
	451	65	2.5	36	Above + 8 lbs./1000 bbl	22+	77-	53	1.9	8
	452	65	1.7	39	Tolad 246 + 2 lbs./1000	17+	62-	64	2.3	11
	447	32	1.2	24	bbl MDA	32+	73-	132	4.8	36
	448	33	0.9	30	"	24+	58-	123	4.4	42
	442	0	0.9	18	"	40+	103-	340	12.2	116
	443	0	1.1	22	"	36+	79-	300	10.8	102
	455	70	164	42	EGME + Tolad 246 + MDA +	85+	141-	4	0.14	2
	456	70	158	38	0.5 ppm Stadis 450	85+	140-	4	0.14	2
	459	23	111	25	EGME + Tolad 246 + MDA +	96+	182-	14	0.5	2
	460	23	117	30	0.8 ppm Stadis 450	92+	174-	12	0.4	2
	471	1	117	20	EGME + Tolad 246 + MDA +	95+	193-	32	1.2	1
	472	1	117	18	0.9 ppm Stadis 450	88+	184-	27	1.0	1
	463	24	117	30	EGME + Tolad 246 + MDA +	8+	158-	18	0.6	1
	464	24	129	32	2.0 ppm ASA-3	6+	167-	18	0.6	2
	467	1	94	18	EGME + Tolad 246 + MDA +	16+	149-	23	0.8	1
	468	2	100	22	2.25 ppm ASA-3	0	144-	23	0.8	1

TABLE A14

ADDITIVE STUDIES - EGME/ETHYL 733/MDA/ASA-3/STADIS 450

(Fuel Flow Through Coalescer)

Fuel	Run No.	Temp., °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, μC/m³ Coalescer	Charge Density, μC/m³ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full KV	50% Charge Relaxation Time, Sec.
77D	78-527	76	-	-	0.15% EGME	184+	195-	56	2.0	4
	528	76	2.7	-	"	152+	149-	47	1.7	4
	531	36	1.2	53	"	152+	160-	216	7.8	31
	532	36	1.0	48	"	142+	145-	180	6.5	26
	535	6	0.6	24	"	101+	107-	320	11.5	84
	536	6	0.6	16	"	106+	113-	350	12.6	101
	547	67	1.5	36	Above +8.4 lbs/1000 bbl	68+	81-	37	1.3	7
	548	67	1.1	34	Ethyl 733 + 2 lbs/1000 bbl MDA	48+	67-	38	1.4	8
	543	35	0.7	26	"	91+	100-	138	4.9	44
	544	35	0.6	30	"	64+	74-	117	4.2	45
	539	6	0.6	28	"	95+	105-	276	9.9	106
	540	6	1.0	22	"	85+	96-	270	9.7	113
	551	69	111	38	EGME + Ethyl 733 + MDA	81+	258-	2	0.1	< 1
	552	70	123	45	+ 0.5 ppm Stadis 450	79+	292-	3	0.1	< 1
	555	21	117	26	EGME + Ethyl 733 + MDA	158+	285-	13	0.5	2
	556	21	123	26	+0.75 ppm Stadis 450	152+	285-	14	0.5	1
	567	4	111	25	EGME + Ethyl 733 + MDA	172+	303-	18	0.6	2
	568	4	111	28	+ 0.5 ppm Stadis 450	144+	292-	16	0.6	2
	559	20	94	24	EGME + Ethyl 733 + MDA	22+	271-	14	0.5	2
	560	20	105	18	+ 1.5 ppm ASA-3	14+	256-	12	0.4	1
	563	5	111	18	EGME + Ethyl 733 + MDA	8+	182-	10	0.4	< 1
	564	5	117	22	+ 1.6 ppm ASA-3	4+	187-	10	0.4	1

TABLE A15

ADDITIVE STUDIES - EGME/TOLAD 246/ETHYL 733/MDA/ASA-3/STADIS 450

(Fuel Flow Through Coalescer)

Fuel	Run No.	Temp., °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, $\mu C/m^3$ Coalescer	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full KV	50% Charge Relaxation Time, Sec.
77D - 3317	78-571	71	2.6	52	0.15% EGME	208+	229-	20	0.7	2
	572	71	2.6	58	"	190+	190-	20	0.7	2
	575	33	1.6	38	"	178+	175-	180	6.5	15
	576	33	1.7	33	"	175+	170-	174	6.3	13
	579	3	-	-	"	107+	115-	330	11.9	87
	580	3	0.8	26	"	100+	104-	310	11.2	68
	592	75	2.4	58	Above + 8.4 lbs./1000 bbl	41+	119-	44	1.6	4
	593	75	2.1	62	Ethyl 733 + 8.0 lbs./1000	23+	87-	48	1.7	5
	588	33	1.2	58	bbl Tolad 246 + 2.0 lbs./	63+	111-	156	5.6	18
	589	34	1.4	40	1000 bbl MDA	48+	93-	153	5.5	20
	583	5	0.6	18	"	105+	110-	440	15.8	88
	584	4	0.5	24	"	78+	86-	400	14.4	75
	596	70	105	56	EGME/Ethyl 733/Tolad 246/	79+	260-	14	0.5	2
	597	70	105	50	MDA + 1.5 ppm ASA-3	79+	290-	12	0.4	2
	600	24	100	32	EGME/Ethyl 733/Tolad 246/	107+	122-	20	0.8	2
	601	24	105	-	MDA + 2.25 ppm ASA-3	107+	275-	18	0.6	2
	614	5	123	-	EGME/Ethyl 733/Tolad 246/	16+	201-	18	0.6	2
	615	5	123	-	MDA + 2.75 ppm ASA-3	24+	196-	18	0.6	2
	604	24	110	36	EGME/Ethyl 733/Tolad 246/	194+	240-	14	0.5	2
	605	24	123	28	MDA + 0.75 ppm Stadis 450	152+	205-	12	0.4	2
	608	3	94	25	EGME/Ethyl 733/Tolad 246/	234+	265-	52	1.9	4
	609	3	111	20	MDA + 1.0 ppm Stadis 450	229+	237-	40	1.4	3

TABLE A16

ADDITIVE STUDIES - EGME/DCI-4A/ASA-3/STADIS 450

(Fuel Flow Through Separator)

Fuel	Run No.	Temp. °F	Cond. CU D 3114	Total Water ppm	Additives	Charge Density, $\mu C/m^3$ Separator	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full, KV/m	Surface Voltage @ 90% Full, KV	50% Charge Relaxation Time, Sec.
JP-4 77D-3301	690	70	1.6	32	0.15% EGME –	6-	6+	10	0.4	5
	691	70	1.5	38	" –	6-	7+	11	0.4	6
	686	46	1.2	46	" –	1.5-	3+	5	0.2	5
	687	46	1.0	30	" –	1.5-	5+	8	0.3	5
	694	23	1.2	–	" –	11-	13+	29	1.0	14
	695	23	–	–	" –	12-	13+	30	1.1	16
	699	23	1.3	30	EGME + 8 lbs/1000bbl DCI-4A	8+	40-	132	4.8	11
	700	25	1.2	20	" "	8+	40-	126	4.5	13
	701	25	1.2	32	" "	4+	32-	110	4	14
	705	44	1.4	29	" "	12-	11-	12	0.4	2
	706	45	1.2	–	" "	15-	8-	12	0.4	2
	709	72	2.4	28	" "	15-	3-	2	0.01	
	710	72	2.1	29	" "	19-	8+	0	0	0
	716	3	–	–	" "	13-	16-	18	0.6	5
	717	3	–	–	" "	19-	10-	0	0	0
	718	3	–	–	" "	19-	5-	22	0.8	26
	719	3	–	–	" "	20-	5-	6	0.2	0
	722	0	105	–	EGME + DCI-4A + 2 ppm ASA-3	17-	51-	6	0.2	1
	723	0	110	–		17-	46-	6	0.2	<1
	726	3	105	36	EGME + DCI-4A + 0.9 ppm Stadis 450	51-	36+	3	0.1	2
	727	3	105	30		59-	43+	2	0.1	1

TABLE A17

ADDITIVE STUDIES - EGME/UNICOR J/ASA-3/STADIS 450

(Fuel Flow Through Separator)

Fuel	Run No.	Temp, °F	Conductivity, CU D 3114	Conductivity, CU D 2624	Water, ppm Total	Water, ppm Free	Additive	Charge Density, μC/m³ Coalescer	Charge Density, μC/m³ Separator	Charge Density, μC/m³ Receiving Vessel	Field Strength @ 90% Full, KV/m	Surface Voltage 90% Full, KV	50% Charge Relaxation Time, Sec.
JP-4, 77D-3300	77-649	74	2.3	-	60	-	0.15% Vol.	-	27-	22+	14	0.5	1
	-650	75	2.3	-	62	-	EGME	-	28-	23+	14	0.5	2
	-653	46	2.2	-	-	-	"	-	24-	28+	22	0.8	6
	-654	46	2.2	-	-	<1.0	"	-	24-	24+	23	0.8	6
	-658	26	1.2	-	55	-	"	-	46-	36+	32	1.2	13
	-659	26	1.5	-	48	-	"	-	46-	16+	32	1.2	13
	-667	71	-	-	-	-	0.15% Vol.	-	63-	40+	27	1.0	4
	-668	71	-	-	-	<1.0	EGME +	-	54-	40+	29	1.0	5
	-671	44	2.2	-	40	-	8 lbs/1000bbl	-	62-	51+	34	1.2	5
	-672	44	2.3	-	56	-	Unicor J	-	55-	44+	33	1.2	5
	-663	27	-	-	-	-	"	-	20-	17+	26	0.9	12
	-664	27	-	-	-	<1.0	"	-	22-	19+	29	1.0	18
	-675	24	-	-	-	-	"	-	79-	87+	86	3.0	22
	-678	23	94	115	28,32	-	EGME + Unicor J	-	57-	74-	6	0.2	1
	-679	23	100	115	-	-	+ 1.9 ppm ASA-3	-	50-	71-	5	0.2	1
	-682	20	105	110	38	-	EGME + Unicor J	-	38-	12+	0	0	0
	-683	21	105	110	24	<1.0	+ 0.6 ppm Stadis 450	-	40-	11+	0	0	0

TABLE A18

ADDITIVE STUDIES - EGME/TOLAD 246/ASA-3/STADIS 450

(Fuel Flow Through Separator)

Fuel	Run No.	Temp. °F	Cond. CU D 3114	Total Water ppm	Additives	Charge Density, μC/m³ Separator	Charge Density, μC/m³ Receiving Vessel	Field Strength @ 90% Full, KV/m	Surface Voltage @ 90% Full, KV	50% Charge Relaxation Time, Sec.
JP-4 77D-3302	731	68	1.5	35	0.15% EGME	8-	8+	10	0.4	7
	732	70	1.6	30	"	8-	8+	13	0.5	7
	736	44	1.2	30	"	7-	7+	15	0.5	10
	737	44	1.2	32	"	9-	8+	18	0.6	20
	740	5	0.6	20	"	16-	10+	0	0	0
	741	5	-	-	"	16-	9+	8	0.3	31
	742	6	-	-	"	17-	10+	13	0.5	37
	753	72	2.1	28	Above +	19-	5+	6	0.2	2
	754	72	2.0	32	8 lbs/1000 bbl	17-	6+	7	0.3	8
	749	39	1.2	30	Tolad 246	16-	6+	12	0.4	11
	750	39	1.3	32	"	18-	5+	11	0.4	9
	745	5	0.6	24	"	22-	8+	6	0.2	44
	746	6	0.6	26	"	19-	6+	12	0.4	89
	769	5	117	-	Above + 2 ppm	29-	37-	6	0.2	<1.0
	770	6	117	-	ASA-3	31-	47-	5	0.2	1.0
	757	5	-	-	EGME + Tolad 246	75-	8+	4	0.1	1.0
	758	6	105	27	+ 0.9 ppm Stadis 450	78-	2+	4	0.1	2.0

TABLE A19

ADDITIVE STUDIES - EGME/HITEC E-515/ASA-3/STADIS 450

(Fuel Flow Through Separator)

Fuel	Run No.	Temp., °F	Cond. CU D 3114	Total water ppm	Additive	Charge Density $\mu C/m^3$ Separator	Charge Density $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full KV	50% Charge Relaxation Time, Sec.
77D 3305	78- 7	74	2.6	-	0.15% EGME	119-	55+	56	2.0	7
	8	74	2.4	36	"	79-	2+	23	0.8	4
	9	74	1.8	30	"	68-	3-	16	0.6	2
	10	74	1.8	22	"	66-	6-	12	0.9	1
	13	35	1.3	20	"	40-	3+	23	0.8	20
	14	35	1.2	24	"	45-	3+	26	0.9	23
	17	4	0.8	19	"	52-	22-	111	3.9	61
	18	4	0.9	-	"	63-	35-	126	4.5	60
	30	69	6.4	22	Above + 16 lbs/1000 bbl	147-	122+	96	3.5	8
	31	70	6.4	20	Hitec E-515	155-	143+	120	4.3	5
	25	33	4.1	24	"	109-	82+	110	3.9	8
	26	34	4.2	-	"	122-	90+	123	4.4	8
	27	34	4.4	-	"	137-	95+	135	4.9	10
	21	5	3.6	17	"	213-	103+	96	3.5	7
	22	5	3.5	20	"	198-	79+	120	4.3	9
	34	6	115	20	EGME + Hitec E-515 +	40-	16-	1	0.04	<1
	35	6	-	-	1 ppm Stadis 450	35-	17-	1	0.04	<1
	38	4	120	24	EGME + Hitec E-515 +	24-	3+	5	0.2	1
	39	4	120	-	1 ppm ASA-3	27-	4+	4	0.1	1

TABLE A20

ADDITIVE STUDIES - EGME/APPOLO PRI-19/ASA-3/STADIS 450

(Fuel Flow Through Separator)

Fuel	Run No.	Temp., °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, $\mu C/m^3$ Separator	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full KV	50% Charge Relaxation Time, Sec.
77D 3306	78-43	71	2.4	-	0.15% EGME	6-	47+	78	2.8	3
	44	72	2.6	-	"	8-	68+	93	3.4	2
	45	72	2.2	-	"	12-	62+	85	3.1	2
	50	35	1.4	30	"	13-	19+	71	2.6	16
	51	36	-	-	"	16-	18+	78	2.8	14
	54	4	1.2	20	"	28-	30+	75	2.7	12
	55	4	-	-	"	32-	33+	87	3.1	12
	67	67	8.2	38	Above + 8 lbs/1000 bbl	40-	12+	20	0.7	3
	68	68	8.8	40	Appolo PRI-19	52-	24+	25	0.9	8
	63	34	5.5	28	"	35-	16+	21	0.8	3
	64	34	5.6	-	"	41-	22+	26	0.9	4
	58	5	1.8	28	"	49-	21-	20	0.7	<1
	59	5	1.7	-	"	54-	17-	6	0.2	<1
	60	5	1.7	-	"	48-	17-	8	0.3	<1
	71	21	100	21	Above + 2.1 ppm	65-	28-	3	0.1	1
	72	21	105	-	Stadis 450	76-	30-	3	0.1	2
	83	5	105	-	"	79-	21-	4	0.1	1
	84	6	105	-	"	81-	26-	4	0.1	2
	75	19	110	28	EGME + Appolo	57-	15-	2	0.1	1
	76	20	110	-	PRI-19 + 1.4 ppm	55-	17-	2	0.1	1
	79	0	105	18	ASA-3	73-	2+	3	0.1	1
	80	0	105	-	"	73-	2+	3	0.1	2

TABLE A21

ADDITIVE STUDIES - EGME/ETHYL 733/ASA-3/STADIS 450

(Fuel Flow Through Separator)

Fuel	Run No.	Temp. °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, μC/m³ Separator	Charge Density, μC/m³ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full, KV	50% Charge Relaxation Time, Sec.
77D-3307	78- 87	68	1.8	34	0.15% EGME	0-	58+	45	1.6	14
	88	68	1.9	32	"	5-	55+	44	1.6	6
	91	33	1.3	20	"	5-	18+	24	0.9	8
	92	33	1.2	18	"	6-	18+	24	0.9	7
	95	2	0.6	16	"	15-	13+	22	0.8	16
	96	2	0.8	20	"	17-	14+	28	1.0	19
	108	71	3.8	36	Above + 8.4 lbs./1000 bbl	8-	34+	17	0.6	4
	109	71	3.9	30	Ethyl 733	15-	40+	18	0.6	5
	103	33	1.6	22	"	9-	15+	12	0.4	4
	104	33	1.6	-	"	13-	18+	14	0.5	4
	99	3	0.6	-	"	20-	7+	6	0.2	11
	100	3	-	-	"	21-	6+	8	0.3	10
	112	22	94	32	EGME + Ethyl 733 +	123-	65+	33	1.2	1
	113	22	105	24	0.75 ppm ASA-3	107-	48+	30	1.1	1
	124	3	105	-	EGME + Ethyl 733 +	58-	22-	0	0.0	0
	125	3	105	-	1.5 ppm ASA-3	55-	21-	0	0.0	0
	126	20	175	-	"	36-	36-	0	0.0	0
	127	20	180	-	"	35-	31-	0	0.0	0
	116	22	110	32	EGME + Ethyl 733 +	76-	33-	1	0.04	1
	117	22	105	-	0.9 ppm Stadis 450	68-	32-	1	0.04	<1
	120	0	110	20	EGME + Ethyl 733 +	67-	24-	2	0.1	<1
	121	0	110	20	1.0 ppm Stadis 450	66-	21-	2	0.1	1

TABLE A22

ADDITIVE STUDIES - EGME/DUPONT A033/ASA-3/STADIS 450

(Fuel Flow Through Separator)

Fuel	Run No.	Temp. °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, $\mu C/m^3$ Separator	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full, KV	50% Charge Relaxation Time, Sec.
77D-3308	78-131	70	2.1	36	0.15% EGME	8-	53+	50	1.8	7
	132	70	2.0	38	"	9-	62+	54	1.9	7
	137	32	1.2	42	"	21-	24+	44	1.6	11
	138	32	1.3	34	"	24-	28+	48	1.7	11
	141	4	0.6	20	"	33-	29+	66	2.4	32
	142	4	0.6	22	"	35-	32+	74	2.7	38
	154	69	3.0	25	Above + 8.4 lbs./1000 bbl	26-	33+	33	1.2	5
	155	70	3.0	28	DuPont A033	28-	41+	41	1.5	6
	150	33	1.8	18	"	26-	24+	27	1.0	7
	151	33	1.8	18	"	32-	28+	29	1.0	7
	146	1	0.6	18	"	40-	20+	56	2.0	41
	147	1	0.6	22	"	28-	19+	60	2.2	55
	158	24	105	18	EGME + DuPont A033 +	96-	8-	2	0.1	<1
	159	24	105	20	1.4 ppm ASA-3	92-	9-	1	0.04	<1
	170	2	105	15	EGME + DuPont A033 +	115-	12+	0	0	0
	171	3	100	16	1.7 ppm ASA-3	101-	13+	0	0	0
	162	24	111	18	EGME + DuPont A033 +	71-	4-	0	0	0
	163	24	105	-	0.75 ppm Stadis 450	71-	2-	0	0	0
	166	2	111	15	EGME + DuPont A033 +	62-	8-	2	0.07	<1
	167	3	111	16	1.0 ppm Stadis 450	51-	10-	2	0.07	<1

TABLE A23

ADDITIVE STUDIES - EGME/MDA/ASA-3/STADIS 450

(Fuel Flow Through Separator)

Fuel	Run No.	Temp. °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, $\mu C/m^3$ Separator	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full, KV	50% Charge Relaxation Time, Sec.
77D-3310	78-209	70	1.8	32	0.15% EGME	76-	88+	84	3.0	7
	210	70	1.8	36	"	66-	77+	68	2.4	5
	213	36	1.6	28	"	93-	92+	95	3.4	8
	214	36	1.6	24	"	92-	86+	98	3.5	9
	217	4	-	-	"	115-	109+	258	9.3	62
	218	4	-	-	"	107-	100+	240	8.6	52
	220	3	-	-	"	101-	84+	190	6.8	33
	234	70	1.6	36	Above + 2 lbs./	98-	65+	57	2.0	5
	235	70	1.6	-	1000 bbl MDA	99-	82+	68	2.4	6
	236	70	-	-	"	98-	79+	70	2.5	5
	230	34	1.5	34	"	85-	66+	88	3.2	10
	231	34	1.4	36	"	76-	54+	82	3.0	9
	226	3	0.9	16	"	108-	81+	180	6.4	49
	227	4	-	-	"	103-	73+	165	5.9	42
	239	25	110	30	EGME + MDA +	205-	88+	0	0	<1
	240	25	110	-	1.0 ppm ASA-3	186-	79+	0	0	<1
	251	4	123	-	EGME + MDA +	461-	325+	10	0.4	1
	252	4	129	-	1.3 ppm ASA-3	482-	324+	4	0.1	<1
	243	24	105	32	EGME + MDA +	173-	79+	0.6	0.02	<1
	244	25	110	30	0.6 ppm Stadis 450	171-	79+	0.6	0.02	<1
	247	4	135	-	EGME + MDA +	178-	75+	1.0	0.04	<1
	248	4	129	-	0.74 ppm Stadis 450	190-	81+	0	0	<1

TABLE A24

ADDITIVE STUDIES - EGME/DCI-4A/ETHYL 733/ASA-3/STADIS 450

(Fuel Flow Through Separator)

Fuel	Run No.	Temp., °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, $\mu C/m^3$ Separator	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full KV	50% Charge Relaxation Time, Sec.
77D 3313	78-385	68	1.2	42	0.15% EGME	38-	38+	26	0.9	3
	386	69	1.2	40	"	40-	40+	27	1.0	3
	389	36	1.0	40	"	67-	57+	30	1.1	3
	390	36	0.9	36	"	67-	58+	30	1.1	3
	393	0	0.8	38	"	86-	73+	168	6.0	41
	394	1	0.7	40	"	85-	73+	177	6.4	40
	405	66	2.2	42	Above + 8.4 lbs./1000bbl	110-	65+	34	1.2	5
	406	66	2.2	38	Ethyl 733 + 8.0 lbs./1000	108-	62+	36	1.3	5
	401	34	1.5	29	bbl DCI-4A	121-	73+	24	0.9	3
	402	34	-	-	"	119-	70+	24	0.9	4
	397	1	1.1	28	"	149-	67+	80	2.9	18
	398	1	1.0	30	"	132-	63+	78	2.8	24
	409	68	141	-	EGME + Ethyl 733 + DCI-	292-	47+	2	0.1	<1
	410	68	141	-	4A + 0.8 ppm ASA-3	277-	24+	2	0.1	<1
	413	24	117	30	EGME + Ethyl 733 + DCI-	245-	51+	2	0.1	<1
	414	24	129	36	4A + 1.7 ppm ASA-3	237-	45+	2	0.1	<1
	425	5	117	18	EGME + Ethyl 733 + DCI-	280-	119+	<1	<1	<1
	426	5	117	14	4A + 1.9 ppm ASA-3	277-	114+	2	0.1	<1
	417	23	123	26	EGME + Ethyl 733 + DCI-	179-	74+	<1	<1	<1
	418	23	129	24	4A + 0.5 ppm Stadis 450	186-	87+	<1	<1	<1
	421	4	100	18	EGME + Ethyl 733 + DCI-	273-	116+	<1	<1	<1
	422	4	110	20	4A + 0.6 ppm Stadis 450	210-	113+	1	<1	<1

TABLE A25

ADDITIVE STUDIES - EGME/HITEC E-515/ETHYL 733/ASA-3/STADIS 450

(Fuel Flow Through Separator)

Fuel	Run No.	Temp., °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, $\mu C/m^3$ Separator	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full KV	50% Charge Relaxation Time, Sec.
77D - 3312	78-339	73	1.2	-	0.15% EGME	8-	29+	24	0.9	3
	340	73	1.4	-	"	11-	27+	22	0.8	3
	343	33	1.0	46	"	152-	143+	156	5.6	7
	344	33	1.1	-	"	172-	126+	144	5.2	7
	347	4	0.6	-	"	170-	155+	360	13.0	39
	348	4	0.6	-	"	162-	148+	390	14.0	44
	360	66	7.0	-	Above + 8.4 lbs./1000 bbl	251-	213+	162	5.8	5
	361	66	7.6	-	Ethyl 733 + 16 lbs./1000	239-	201+	156	5.6	5
	356	35	4.7	-	bbl Hitec E-515	229-	190+	138	5.0	3
	357	35	4.6	-	"	216-	178+	144	5.2	3
	351	4	2.9	22	"	296-	228+	330	11.9	3
	352	4	2.8	-	"	252-	183+	280	10.0	5
	365	25	123	32	EGME + Ethyl 733 + Hitec	156-	34+	0	0.0	0
	366	26	123	36	E-515 + 0.5 ppm	171-	51+	0	0.0	0
	377	0	100	36	Stadis 450	258-	135+	4	0.1	1
	378	1	100	36	"	245-	121+	7	0.3	1
	381	2	135	38	EGME + Ethyl 733 + Hitec	96-	8-	0	0.0	1
	382	2	141	-	E-515 + 0.6 ppm Stadis 450	100-	8+	0	0.0	0
	369	26	114	-	EGME + Ethyl 733 + Hitec	212-	105+	8	0.3	1
	370	26	129	-	E-515 + 0.6 ppm ASA-3	198-	96+	10	0.4	1
	373	0	111	-	"	300-	209+	14	0.5	1
	374	1	111	34	"	300-	213+	14	0.5	1

TABLE A26

ADDITIVE STUDIES - EGME/TOLAD 246/ETHYL 733/ASA-3/STADIS 450

(Fuel Flow Through Separator)

Fuel	Run No.	Temp., °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, $\mu C/m^3$ Separator	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full KV	50% Charge Relaxation Time, Sec.
77D - 3311	78-288	71	2.6	56	0.15% EGME	44-	63+	38	1.4	3
	289	71	2.6	60	"	44-	59+	40	1.4	3
	293	35	1.8	35	"	28-	24+	60	2.2	21
	294	34	1.8	-	"	28-	20+	56	2.0	20
	297	4	1.0	20	"	119-	107+	258	9.3	46
	298	4	1.2	18	"	111-	98+	264	9.5	39
	311	69	2.9	40	Above + 8.4 lbs./1000 bbl	182-	108+	105	3.8	7
	312	69	3.1	42	Ethyl 733 + 8.0 lbs./1000	199-	114+	129	4.6	9
	313	71	-	-	bbl Tolad 246	229-	166+	162	5.8	8
	314	75	3.5	-	"	237-	169+	144	5.2	7
	315	75	3.4	-	"	243-	172+	147	5.3	7
	307	37	1.8	28	"	131-	84+	59	2.1	4
	308	37	2.0	32	"	126-	81+	65	2.3	5
	302	4	1.2	-	"	138-	76+	213	7.7	58
	303	4	1.4	-	"	133-	73+	186	6.7	43
	304	4	1.2	15	"	124-	70+	162	5.8	37
	318	26	176	-	EGME + Ethyl 733 + Tolad 246	120-	4-	0	0	0
	319	25	176	-	+ 2.5 ppm ASA-3	115-	13-	0	0	0
	332	3	130	18	"	269-	137+	12	0.4	2
	333	3	130	-	"	273-	126+	11	0.4	3
	322	24	135	-	EGME + Ethyl 733 + Tolad 246	143-	107+	6	0.2	1
	323	24	140	-	+ 0.5 ppm Stadis 450	142-	107+	6	0.2	1
	326	4	94	-	"	288-	237+	23	0.8	1
	327	5	88	30	"	285-	233+	22	0.8	2
	328	6	146	-	EGME + Ethyl 733 + Tolad 246	76-	40+	3	0.1	2
	329	6	164	24	+ 0.75 ppm Stadis 450	77-	43+	3	0.1	2

TABLE A27

ADDITIVE STUDIES - EGME/HITEC E-515/MDA/ASA-3/STADIS 450

(Fuel Flow Through Separator)

Fuel	Run No.	Temp., °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, μC/m³ Separator	Charge Density, μC/m³ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full KV	50% Charge Relaxation Time, Sec.
77D-3315	78-477	75	2.1	-	0.15% EGME	24-	32+	57	2.1	9
	478	75	2.1	42	"	25-	30+	56	2.0	8
	482	35	1.0	36	"	27-	21+	75	2.7	41
	483	35	1.0	38	"	28-	21+	82	3.0	41
	486	5	0.6	30	"	48-	40+	156	5.6	126
	487	6	0.6	28	"	51-	43+	204	7.3	149
	488	6	0.6	25	"	51-	44+	219	7.9	162
	499	73	14.6	48	Above + 16 lbs./1000 bbl	269-	269+	250	9.0	2
	500	72	9.0	52	Hitec E-515 + 2 lbs./1000	286-	284+	258	9.3	4
	495	35	4.8	42	bbl MDA	171-	179+	290	10.4	6
	496	35	5.0	46	"	225-	204+	300	10.8	7
	491	4	1.9	28	"	222-	190+	430	15.5	8
	492	4	1.8	26	"	192-	160+	400	14.4	8
	503	75	164	-	EGME + Hitec E-515 + MDA	229-	111+	2	0.1	<1
	504	75	-	-	+ 0.4 ppm ASA-3	208-	87+	2	0.1	<1
	507	23	135	30	EGME + Hitec E-515 + MDA	150-	46+	2	0.1	<1
	508	23	135	36	+ 0.6 ppm ASA-3	151-	47+	2	0.1	<1
	519	6	123	20	"	180-	47+	<1	<1	<1
	520	6	123	18	"	186-	64+	2	0.1	<1
	511	22	135	33	EGME + Hitec E-515 + MDA	148-	32+	<1	<1	<1
	512	22	135	-	+ 0.4 ppm Stadis 450	149-	34+	<1	<1	<1
	515	6	117	-	"	185-	57+	3	0.1	<1
	516	6	123	-	"	190-	62+	2	0.1	<1

TABLE A28

ADDITIVE STUDIES - EGME/TOLAD 246/MDA/ASA-3/STADIS 450

(Fuel Flow Through Separator)

Fuel	Run No.	Temp., °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, μC/m³ Separator	Charge Density, μC/m³ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full KV	50% Charge Relaxation Time, Sec.
77D 3314	78-431	65	1.2	30	0.15% EGME	40-	36+	40	1.4	7
	432	65	1.3	-	"	40-	38+	40	1.4	7
	435	35	1.0	26	"	32-	27+	60	2.2	27
	436	35	1.0	26	"	32-	27+	64	2.3	24
	439	0	0.8	14	"	29-	22+	62	2.2	84
	440	0	0.8	16	"	29-	24+	105	3.8	110
	441	0	-	-	"	33-	25+	96	1.2	120
	453	66	1.8	36	Above + 8 lbs./1000bbl	69-	19+	22	0.8	10
	454	66	-	-	Tolad 246 + 2 lbs./1000	76-	18+	23	0.8	11
	449	33	0.9	28	bbl MDA	58-	20+	41	1.5	39
	450	34	0.9	32	"	57-	18+	42	1.5	44
	444	1	0.9	17	"	65-	17+	24	0.9	58
	445	1	1.0	-	"	64-	16+	58	2.1	92
	446	1	-	-	"	65-	14+	62	2.2	147
	457	70	164	52	EGME + Tolad 246 + MDA	135-	70+	1	<1	<1
	458	70	164	32	+ 0.5 ppm Stadis 450	134-	70+	1	<1	<1
	461	23	117	32	EGME + Tolad 246 + MDA	105-	24+	2	0.1	<1
	462	23	117	-	+ 0.8 ppm Stadis 450	125-	28+	2	0.1	<1
	473	3	123	-	EGME + Tolad 246 + MDA	126-	12+	8	0.3	1
	474	3	123	-	+ 0.9 ppm Stadis 450	130-	17+	6	0.2	1
	465	25	129	28	EGME + Tolad 246 + MDA	150-	12+	4	0.1	1
	466	25	129	-	+ 2.0 ppm ASA-3	158-	18+	4	0.1	1
	469	2	100	19	EGME + Tolad 246 + MDA	230-	97+	<1	<1	<1
	470	2	105	-	+ 2.25 ppm ASA-3	242-	107+	2	0.1	<1

TABLE A29

ADDITIVE STUDIES - EGME/ETHYL 733/MDA/ASA-3/STADIS 450

(Fuel Flow Through Separator)

Fuel	Run No.	Temp., °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, $\mu C/m^3$ Separator	Charge Density, $\mu C/m^3$ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full KV	50% Charge Relaxation Time, Sec.
77D 3316	78-529	76	2.3	-	0.15% EGME	64-	58+	30	1.1	2
	530	76	2.4	-	"	62-	62+	30	1.1	2
	533	36	1.1	32	"	71-	45+	82	3.0	21
	534	36	0.9	35	"	71-	43+	80	2.9	20
	537	6	0.6	20	"	55-	42+	80	2.9	75
	538	6	0.6	16	"	52-	40+	108	3.9	79
	549	67	1.0	35	Above + 8.4 lbs/1000 bbl	65-	43+	40	1.4	6
	550	67	1.0	38	Ethyl 733 + 2 lbs./1000 bbl MDA	63-	45+	42	1.5	6
	545	36	0.7	32	"	60-	43+	90	3.2	33
	546	36	0.7	30	"	58-	40+	90	3.2	32
	541	6	0.6	28	"	60-	43+	102	3.7	77
	542	7	0.6	22	"	58-	40+	117	4.2	79
	553	70	123	39	EGME/Ethyl 733/MDA	221-	24+	2	0.1	< 1
	554	71	129	50	+0.5 ppm Stadis 450	217-	28+	< 1	< 1	< 1
	557	21	123	30	EGME/Ethyl 733/MDA	237-	51+	< 1	< 1	< 1
	558	22	129	28	+0.75 ppm Stadis 450	238-	55+	< 1	< 1	< 1
	569	5	117	-	EGME/Ethyl 733/MDA	193-	11+	3	0.1	1
	570	5	123	-	+0.9 ppm Stadis 450	200-	12+	3	0.1	1
	561	20	117	24	EGME/Ethyl 733/MDA	273-	51+	4	0.1	1
	562	20	123	27	+1.5 ppm ASA-3	260-	51+	2	0.1	< 1
	565	5	123	20	EGME/Ethyl 733/MDA	217-	49+	2	0.1	< 1
	566	6	123	-	+1.6 ppm ASA-3	216-	55+	2	0.1	< 1

TABLE A30

ADDITIVE STUDIES - EGME/TOLAD 246/ETHYL 733/MDA/ASA-3/STADIS 450

(Fuel Flow Through Separator)

Fuel	Run No.	Temp., °F	Cond. CU D 3114	Total Water ppm	Additive	Charge Density, μC/m³ Separator	Charge Density, μC/m³ Receiving Vessel	Field Strength @ 90% Full KV/m	Surface Voltage @ 90% Full KV	50% Charge Relaxation Time, Sec.
77D-3317	78-573	71	2.6	50	0.15% EGME	45-	42+	10	0.4	2
	574	71	2.6	-	"	51-	48+	14	0.5	2
	577	33	1.6	39	"	45-	40+	57	2.1	11
	578	33	2.0	-	"	52-	45+	60	2.2	10
	581	3	1.0	20	"	35-	24+	67	2.4	45
	582	3	0.9	22	"	34-	24+	66	2.4	49
	594	75	2.2	52	Above + 8.4 lbs./1000 bbl	122-	43+	25	0.9	5
	595	76	2.0	55	Ethyl 733 + 8.0 lbs./1000	121-	55+	26	0.9	6
	590	35	1.2	42	bbl Tolad 246 + 2.0 lbs./	87-	36+	52	1.9	25
	591	35	1.5	38	1000 bbl MDA	75-	30+	46	1.7	24
	585	5	0.5	28	"	85-	8+	30	1.1	40
	586	5	0.6	23	"	87-	24+	30	1.1	56
	587	5	0.6	-	"	84-	40+	30	1.1	55
	598	70	123	-	EGME/Ethyl 733/Tolad 246/	284-	95+	2	0.1	<1
	599	71	117	65	MDA + 1.5 ppm ASA-3	280-	8+	2	0.1	<1
	602	24	123	-	EGME/Ethyl 733/Tolad 246/	237-	35+	9	0.3	2
	603	25	129	27	MDA + 2.25 ppm ASA-3	239-	32+	6	0.2	1
	612	4	117	-	EGME/Ethyl 733/Tolad 246/	243-	59+	2	0.1	1
	613	4	117	-	MDA + 2.75 ppm ASA-3	260-	69+	6	0.2	1
	606	25	123	-	EGME/Ethyl 733/Tolad 246/	164-	49+	<1	<1	<1
	607	25	129	24	MDA + 0.75 ppm Stadis 450	162-	58+	<1	<1	<1
	610	4	117	-	EGME/Ethyl 733/Tolad 246/	160-	33+	6	0.2	1
	611	4	123	-	MDA + 1.0 ppm Stadis 450	160-	45+	6	0.2	2

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