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INVESTIGATION OF THERMAL COKING RATES OF
AIR FORCE JET FUELS

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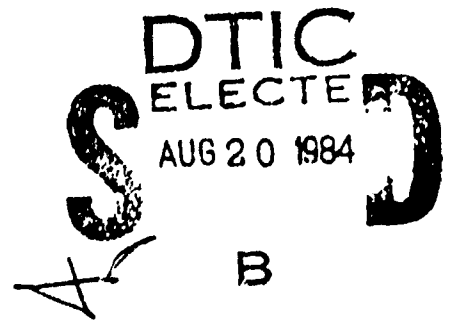FINAL REPORT FOR PERIOD MARCH 1982 – JANUARY 1984

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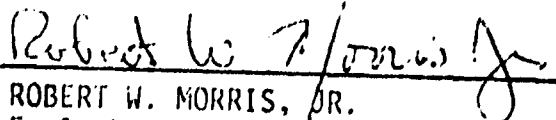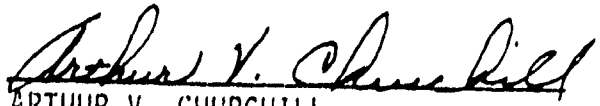84 08 17 063

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Present gas turbine engine fuel systems operate with pressures and temperatures that promote auto-oxidative degradation of jet fuels. As a result, insoluble fuel deposits form which can adhere to engine parts, reducing both life and performance significantly.

This study evaluated the rates of deposit for selected jet fuels as a function of temperature and the effect of several current fuel additives on the rates of thermal deposition. Tests were run on the

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fuels with various concentrations of the additives and various levels of aromatic content. Deposits were collected on stainless steel coupons using an experimental coking apparatus that was developed for this program.

It was found that the breakpoint temperature decreased and the concentration of peroxide increased as the aromatic content of the fuels increased. The rate of formation of deposits increased with decreases in the breakpoint temperature. The presence of different fuel additives had substantial effects on the rate of deposition.

It was concluded that aromatic concentration and breakpoint temperature are good indicators of the relative rate of deposition of a fuel. An increase in the rate of deposition results from an increase in aromatic content or a decrease in breakpoint temperature. Fuel additives that are used for specific effects may produce a secondary effect that is reflected in the rate of deposition.

FOREWORD

This final report on the investigation of thermal coking rates of Air Force jet fuels was prepared by the Government Products Division of Pratt & Whitney Aircraft, West Palm Beach, Florida for the Aero Propulsion Laboratory of Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio, under Contract F33615-82-C-2210, Project 3048, Work Unit 30480597. The Air Force Project Engineer was Robert W. Morris, Jr., AFWAL/POSF.

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SECTION I

INTRODUCTION

Aircraft powered by gas turbine engines rely, for the most part, on jet fuels derived from petroleum based crudes. Due to variations in geographical, chemical and petrochemical process characteristics, jet fuels can vary in both basic physical and chemical nature. These variations, some more exact than others, can impact the performance, reliability and/or maintainability of a gas turbine engine system. To a larger extent, high performance gas turbine aircraft are also susceptible to fuel property variations, particularly with regard to performance, maintenance and most importantly — mission life. Fuel properties from a specifications requirement can vary over a broad range in some instances. For example, the total chemical aromatic content can vary up to 25% by volume for a JP-4 fuel (MIL-T-5624L). Variations of fuel specification can lead to changes in the chemical nature and, therefore, affect the fuel's overall utility as a source of combustion.

Among the various fuel properties that are known to affect the utility of a jet fuel adversely, the impact of thermal stability has long maintained paramount interest. Many studies and unique apparatus have been proposed and used in an attempt to determine the nature of the effects of thermal stress on a jet fuel.*

This program was designed to address several specific physical and chemical characteristics experimentally that are intrinsic to current Air Force jet fuels to underscore the physicochemical nature of a fuel's carbonaceous deposit and to provide experimental evidence for the low temperature prepyrolytic (auto-oxidation) of jet fuels by a pseudo-first-order chemical mechanism. In addition, the effects of five current fuel additives were evaluated for their individual effect on the rate of various fuel deposit formations. Chemical kinetic calculations based on a pseudo-first-order mechanism were applied to a temperature versus deposit formation and the resultant activation energies compared to those derived from active oxygen determinations. The latter had not been attempted by any other previous research.

A unique device was designed, fabricated, and tested at the Materials Engineering and Technology's Advanced Fuel and Lubricant Laboratory of Pratt & Whitney Aircraft's Government Products Division to establish the maximum deposition of carbonaceous fuel products by thermal stresses. The experimental coking apparatus (ECA) is described in detail in Appendix A and was used extensively to establish both the baseline and fuel-blend deposition data. Evaluation of thermal stressed fuel samples for peroxide concentration was based on ASTM D-7303 and is discussed in Appendix B.

The program is divided into four tasks, each designed to support other work in this investigation. All tasks were dovetailed to provide a maximum effort coordinated toward successful completion of the program.

Task 1 is entitled Literature Search and addresses the current and past scientific and technical literature to establish a working technical base. Task 2 provides assimilation of equipment and materials including both fuels and additives. Task 3 utilizes a selection of six Air Force jet fuels to establish fuel deposit baselines using the experimental coking apparatus, and Task 4 concludes the program with a precise evaluation of four selected fuels blended singly with current fuel additives. Each of these tasks was initially proposed as a logical sequence to the timely conclusion of the program. However, during the course of the program, the initial testing of four additives in Task 4 was increased to five additives. This could be done without an

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* CRC literature survey on the thermal oxidation stability of jet fuel (CRC Project No. CA-43-67), 1978.

SECTION II

LITERATURE SEARCH
(TASK 4.3.1)

The research problems imposed on gas turbine engine development by the intrinsic nature of thermal instability has, for the most part, been directed in one of two directions. Basic research has used chemically pure materials in single, double, triple, etc., blends to approximate a fuel. These blends, in some instances, can give results which are not directly applicable to jet fuels. The use of jet fuels in equipment simulating a representative section of a gas turbine fuel system can give more meaningful results if the representation is precise. Searches were conducted in both chemical and engineering literature for data that were previously established from tests to determine the nature of fuel thermal stability. These searches, as discussed below, were conducted using the following key words and phrases: Thermal Stability, Jet Fuel Deposit, Fuel Instability, Jet Fuel Thermal Stability (Reactions), Fuel Peroxide, Auto Oxidation of Jet Fuel (Pyrolysis), Fuel Aromaticity, and Jet Fuel Cracking.

Several sources of information were utilized to perform the the literature search including a thorough search of DIALOG® (Lockheed Information Systems), the Defense Documentation Center of the Defense Logistics Agency. The literature search included review of more than 8,000,000 citations. A list of available articles was scrutinized to select only those references related to the program, and these articles were ordered through the P&WA/GPD library branch of the United Technologies Corporation Library. A summary of the reference sources is given below:

1. DIALOG® (Lockheed Information Systems, Palo Alto, California)

    a. Comprehensive Dissertation Abstracts (CDA) includes university dissertations of more than 630,000 citations with monthly updates from virtually every American college and university during the 1861 to December 1982 time frame.

    b. Claims® Patents was searched using the five definitive data bases listed below:

        • *Claims/Chemistry: From 1950 through 1970* includes more than 265,000 sources of US chemical and chemically related patents issued during this time period. Foreign equivalents from Belgium, France, Great Britain, West Germany, and the Netherlands are included.

        • *Claims/Class* is the classification code and title directory for all classes and selected subclasses of the US Patent Classification System. More than 15,000 sources were reviewed using this data base to facilitate the other searches.

        • *Claims/US Patents: From 1971 to 1978,* which contains more than 485,000 records

utilizing quarterly updates of all US patents, was reviewed for corrosion inhibiting additives in oil lubricant systems.

- *Claims/US Patents: From 1978 to the present* contains more than 85,000 records that were reviewed as described above for corrosion inhibitors for engine oil systems.

- Claims/US Patent Abstracts Weekly was reviewed to supplement the two claims listed above for the month of October 1979 only. Approximately 3,000 citations were reviewed.

c. Metadex (Metals Abstracts/Alloys Index) from 1966 to present contains more than 370,000 citations with monthly updates from the American Society of Metals. These citations were reviewed for fuel compatibility.

d. Scisearch®, a multidiscipline index to the literature of science and technology, was reviewed to the full extent of its 2,700,000 citations. The references searched were derived from more than 2600 of the major scientific and technical journals.

e. ISMEC, the Information Service of Mechanical Engineering indices, provides a review of the significant articles of mechanical engineering from approximately 250 journals published throughout the world. This search included more than 90,000 citations for corrosion inhibitors.

f. CA Search, covering Chemical Abstracts from 1967 to the present and including approximately 4,000,000 citations, was reviewed in its entirety.

g. Smithsonian Science Information Exchange (SSIE) Current Research includes only the last two years, approximately 253,000 citations. This data base contains reports of both Government-funded and privately funded scientific research projects from more than 1300 organizations that fund research.

h. NTIS, National Technical Information Service, includes citations from reports of Government-funded studies.

i. COMPENDIX, an Engineering Index, reviews magazines and articles in the engineering field.

j. Conference Papers Index reviews national and international conference presentations documented by publications in the area of scientific research and development.

2. Defense Documentation Center of the Defense Logistics Agency in Alexandria, Virginia, includes reports from Wright Patterson Air Force Base, Naval Air Development Center, Southwest Research Institute, and other Government agencies.

SECTION III

MATERIAL ACQUISITION
(TASK 4.3.2)

The principal objective of this task was to locate and acquire all materials necessary for the successful, cost effective, timely completion of all tests and fuel analyses conducted in Tasks 4.3.3 and 4.3.4. Also included in this task was acquisition of pertinent literature references which were determined, through the abstract review of Task 4.3.1, to be intrinsic to the tests conducted in this program.

Fuel samples were received from Wright-Patterson Air Force Base (WPAFB) during the first several months of this program. Samples included the following:

- 230 gallons of JP-4 fuel
- 60 gallons of JP-7 fuel
- 115 gallons of JP-8 fuel
- 60 gallons of light diesel fuel (Occidental Petroleum Co.)
- 60 gallons of Ashland 20-40 solvent.

Fuel additives were acquired either from WPAFB/POSF or directly from the manufacturers. The additives used throughout the fuel blend study are shown in Table 1 together with other pertinent information.

TABLE 1
FUEL ADDITIVES FOR FUEL BLEND STUDY

Additive	Manufacturer	Chemical Description	As-Received Concentration
Antioxidant (A.O.29)	E. I. duPont de Nemours & Co.	2,6-di-tertiary-butyl-4-methylphenol	100%
Corrosion Inhibitor (DCI-4A)	E. I. duPont de Nemours & Co.	Organic acids	75%
Fuel System Icing Inhibitor (FSII)	Fisher Scientific (Item 13092)	2-methoxyethanol	100%
Conductivity Improver (Stadis 450)	E. I. duPont de Nemours & Co.	Polymeric nitrogen and sulfur compounds	25%
Metal Deactivator (DMD-2)	E. I. duPont de Nemours & Co.	N,N'-disalicylidene-1,2-propane diamine	50%

Acquisition of all support and test materials was completed by the third month of the program. However, due to the later addition of peroxide analyses (ASTM 3703) on the thermal stressed fuel samples of Tasks 4.3.3 and 4.3.4, the materials for the peroxide analyses were not obtained until the fourth month after the beginning of the contract.

SECTION IV

BASELINE STUDY
(TASK 4.3.3)

The principal objective of this task was to provide a set of baseline fuel deposit data for six select Air Force jet fuels. These data were generated on the experimental coking apparatus (ECA) at auto-oxidation temperatures from 121 to 288°C. Appendix A details the test procedure used for fuel tests throughout this task. Data analysis and the development of the Arrhenius parameters are discussed in detail in Section VI. Pertinent details involving the baseline tests follow together with notes on the specially developed procedures for fuel preparations.

Five fuels were received from AFWAL/POSF and were immediately evaluated for their physical and chemical characteristics as shown in Table 2. The thermal stability of these selected fuels was the primary reason for their selection. The breakpoint temperatures, as shown in Table 2, represent the range in thermal stabilities derived according to ASTM D-3241. Initially samples of these fuels were received in five-gallon epoxy-lined steel containers. After the first three months, larger 55-gallon epoxy-lined drums were received. The delay initially occuring at the beginning of this program concerning these fuel shipments was due to receipt and assembly of a 34°F cold storage room. All fuel and fuel-additive blends used throughout this program were stored at 34°F (±3°) under a dry nitrogen head at atmospheric pressure. Care was taken throughout to maintain a nitrogen atmosphere over each fuel including transfer from the larger 55-gallon drums to smaller 1- or 5-gallon containers. All containers were lined with epoxy to inhibit oxidation. Analyses of the JP-4 and JP-8 as-received samples were duplicated at the end of the program to verify that the fuel integrity had not been altered during the course of this investigation.

The six fuel samples to be evaluated were as follows: JP-7, JP-8, JP-4 with 10% aromatics, JP-4 with 25% aromatics, JP-4 with 35% aromatics (aromatic concentrations in volume percents) and light diesel oil (Occidental Petroleum Co. referred to as OCCI-Light). Prior to each ECA test, a sample of fuel to be tested was clay treated, severely, to eliminate polar compounds and fuel additives. These would include nitrogen, oxygen and sulfur compounds as well as polar additives such as antioxidants. The procedure for clay treatment followed the technique discussed in ASTM D-2550 with one exception. The amount of attapulgus clay used was five times that recommended in the ASTM procedure. A high clay-to-fuel ratio was used to strip each fuel to a standard, repeatable composition. Low, repeatable conductivity measurements were used to verify successful fuel stripping. The technique of preparing a repeatable baseline fuel was considered extremely important to the success of the tests scheduled for Task 4.3.4 because fuel blends of baseline fuels together with selected fuel additives were to be studied relative to their rates of fuel deposition.

After each fuel was severely clay treated (the label C.T. designates clay treated), baseline data were developed on the ECA. A minimum of seven temperatures between 121 and 288°C were tested with at least three up to five repeat tests to verify the validity of the fuel deposit rate.

Two of the original six selected baseline fuels were a blend of the original JP-4 fuel (10% aromatics) with the Ashland 20-40 solvent. Table 3 presents an organic type of analysis of the 20-40 solvent used in this program. These two fuels had a final concentration of 25% aromatics and 35% aromatics. It should be noted that the JP-4 with 10% aromatics was clay treated but the 20-40 solvent was not clay treated. The aromatic concentration in JP-4 did not change, via ASTM D-1319, due to clay filtration. Five-gallon blends of these two fuels were prepared as necessary for all subsequent testing.

TABLE 2
FUEL SAMPLE ANALYSIS AS RECEIVED

	JP-4		20/40 Solv		Occidental Shale Derived/ Diesel		JP-7		JP-8	
API Grav/60°F	54.9		13.8		39.3		45.5		46.5	
SP Grav/60°F	0.7591		0.9732		0.8285		0.7994		0.7949	
Distillation, °C (°F)										
IBP	79	(174)	191	(376)	160	(320)	187 (1)	150 (2)	157 (1)	116 (2)
10%	106	(223)	214	(417)	185	(365)	200	186	173	154
20%	115	(239)	222	(432)	194	(381)	207	198	178	169
30%	124	(255)	227	(441)	199	(390)	210	208	182	172
40%	134	(274)	233	(451)	205	(401)	213	215	186	186
50%	147	(296)	237	(459)	212	(414)	216	223	190	194
60%	163	(325)	242	(468)	217	(423)	220	230	195	202
70%	179	(355)	247	(477)	229	(444)	224	234	201	211
80%	204	(399)	253	(487)	233	(451)	228	244	208	222
90%	224	(435)	263	(505)	250	(482)	234	253	218	234
End Point	248	(478)	277	(531)	270	(518)	257	272	249	270
Residue, %	1.0		1.4		1.1		1.2		1.3	
Loss, %	1.0		1.1		0.9		0.3		0.2	
Water, ppm	70		330/70 a		c		30		60	
Particulates 0.8μ, mg/ℓ	0.04		0.001		1.4		0.001		0.0002	
Aromatics, % volume	9.88		98.10		36.73		4.13		16.98	
Olefins, % volume	1.39		BDL b		3.23		1.01		0.71	
Flash Point, °F	-		175 (PM)		125 (PM)		145 (3)	160 (4)	109 (3)	118 (4)
Net Heat of Combustion, MJ/kg (Btu/lb)	43.70 (18,787)		40.08 (17,230)		42.47 (18,173)		43.50 (18,702)		43.36 (18,641)	
Thermal Stab., ASTM D-3241 Breakpoint Temperature, °C (°F) (After Clay Treatment)	285	(545)	N/A		190	(374)	410	(770)	340	(644)

a. H$_2$O content reduced to 70 ppm from 330 ppm after fuel treatment with Linde 3A Molecular Sieve
b. Below detectable limits
c. Non-conclusive analysis by Karl Fischer
d. Lines of separation by FIA, ASTM D-1019, not defined sharply
(1) ASTM D-86, (2) ASTM D-2887, (3) ASTM D-56, (4) ASTM D-93 (PM) Pensky-Martin

TABLE 3
HYDROCARBON TYPE ANALYSIS OF 2040 AROMATIC SOLVENT*

Hydrocarbon Type	Percent by Volume
Paraffinic	1.9
Monocycloparaffinic	0.5
Alkyl benzenes	24.3
Indan/tetralins	7.1
Indene/dihydronaphthalenes	1.2
Naphthalenes	65.0
Hydrogen content	8.27 w/o

*Data courtesy of Major D. Potter, WPAFB/POSF

Test pressures were developed in the following manner. Previous work has detailed the intrinsic relationship of the critical pressure of hydrocarbon mixtures at elevated temperatures. Gas turbine fuels, as a first approximation, were considered to follow the API gravity-mean boiling point function. Therefore, to determine the test pressure necessary to establish a quality fluid in the ECA at specific preselected temperatures, the curves for hydrocarbon mixtures established by W. B. Kay and represented by R. E. Maxwell were used with the fuel or fuel

blend API gravity-me a boiling point. The critical pressure thus derived is commonly referred to as the pseudo-critical pressure. Table 4 lists the corresponding pseudo-critical pressures and the pressures used throughout this program for each fuel, together with other critical parameters.

TABLE 4
CRITICAL CONSTANTS FOR SELECTED AIR FORCE JET FUELS

Fuel Sample *	Average Boiling Point (°C)	API Gravity at 60°F	P_c (MPa)	T_c (°C)	Test Pressure Range (MPa)
JP-7	217	47.0	2.089	396	2 275 - 2.379
JP-8	194	47.9	2.310	374	2.551 - 2.620
JP-4-10% ARO	159	55.0	2.482	338	2.758 - 2.827
JP-4-25% ARO	172	47.5	2.586	357	2.827 - 2.930
JP-4-35% ARO	179	41.2	2.730	371	3.034 - 3.172
OCCI-Light	216	39.0	2.365	238	2.551 - 2.620
* All Samples Clay Treated					

By establishing the test pressure as equivalent to 10% above the pseudo-critical pressure, the fuel was maintained in liquid form and no boiling off was anticipated. This was confirmed by placing a cryotrap downstream of the ECA exhaust. A continuous effluent sample was condensed from the ECA reaction chamber; no fuel was collected which substantiated the liquid fuel quality in the reaction chamber.

All test runs on the ECA were conducted for a one-hour duration except for the JP-7 fuel. This fuel, which has a high thermal stability (JFTOT break point $\approx 410°C$), required a minimum of three hours and in most cases four hours to produce a deposit on the 1 by 2 inch stainless steel coupons. On the other extreme, the OCCI-light produced inordinate amounts of deposit, so much so that the coupons were sealed in the coupon holder. Upon removal, the deposit cracked and fell away, making gravimetric evaluations difficult. No problems were encountered with the JP-8 or JP-4 fuels. Appendix C contains all baseline rate data from the six selected fuels and Section VI presents the Arrhenius data analyses.

The variation or more specifically the efficiency of oxygen utilization during the ECA testing of a specific fuel is a direct function of the ease and affinity that various fuel components have for high-energy molecular oxygen. A gas chromatograph and a time-of-flight mass spectrometer were added to the ECA test equipment to measure this oxygen utilization by the various fuels during their baseline tests. Both units performed up to standard; however, the amount of change found in the oxygen concentration from free flowing air into and out of the ECA reaction chamber was below detectable limits. Modifications to the sensitivity of both units was attempted but did not allow repeatable oxygen analyses to be made.

The oxygen measurements were deleted from the original statement of work and were replaced by the measurement of the fuel formed peroxide concentration. Peroxides form as precursers to the end product acids and polymerized material characteristic to the deposit from auto oxidation of jet fuels. The methodology used for determining the peroxide concentration is discussed in Appendix B as derived from a modified ASTM D3703-78 procedure. Data derived for each baseline fuel test are presented in Appendix D. Section VI presents the Arrhenius evaluation of these data.

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SECTION V

FUEL BLEND STUDY
TASK 4.3.4

This task had multiple purposes. First, a series of fuel blends were prepared from four selected fuels used in Task 4.3.3 (Section IV) with fuel additives current to gas turbine fuel technology. Subsequent to preparation of stable fuel-additive blends, a series of ECA tests were used to provide the necessary data for an Arrhenius analysis and a comparison to the original baseline generated in Task 4.3.3.

After completion of the fuel baseline study, four fuels were selected by the Air Force program monitor based on the fuel properties and characteristics common to current and projected Air Force utilization. These fuels were the JP-8 (MIL T-83133A), the JP-4 (MIL T-5624L) with the two blends of 20-40 solvent and JP-4.

The additives initially suggested for study, as single-constituent fuel blends, are summarized in Table 1. Table 5 further defines the chemical and physical characteristics of each additive. Only three of the five additives were in a form or were described in detail well enough that they could be reconstructed analytically for repeat use. Therefore, enough of each additive was obtained so that the program usage would amount to 50% of the total available additive. No attempt was made to purify any of the additives further. Any additive purification would not reflect performance available additives and may have lead to subsequent misleading conclusions.

Fuels used to prepare the fuel-additive blends were treated with Attapulgus clay in the manner described in Section IV for the fuel baseline study. As in this study, each clay treated fuel was freshly prepared in 18-liter quantities, maximum, stored in a cold room at 1°C ($\pm 0.5°$), and used as needed. All fuel additive blends were mixed and used within one month after blending. Excess clay treated fuel was not prepared because of the potential that auto-oxidation could result and invalidate the final test results. All fuels were sparged and blanketed with dry nitrogen until use.

Fuel-additive blends were prepared prior to use by the following procedure. An 18-litre clay treated fuel sample was weighted to ± 0.1 gm on a Sauter E49-ED2180 balance. Then a prescribed mass, in grams of additive, was added to provide the necessary concentration of the additive in the selected fuel. Tables 6 through 9 present the additive concentrations in terms of parts-per-million and as milligrams per liter of additive.

These values take into account the fuel density and the dilution factor or active ingredient concentration of the as-received additive. Each table contains the uniform concentration of each of the additives. This uniform concentration was used to calculate the required milligrams per liter of additive for each fuel-additive blend. This was done so that all fuels would contain the same concentration of additive on a parts-per-million by weight basis. The rate of deposit formation was, therefore, comparable if the additive part-per-million concentrations were used. The basic limits for the additive concentration are two to three times the current military fuel or additive specification as described in Table 10.

The individual fuel additive limits can be described as follows: (1) Anti-oxidant, AO-29, and the corrosion inhibitor were blended as (a) the minimum effective concentration, (b) half-way between the minimum effective and maximum allowable concentration, (c) the maximum allowable concentration and (d) twice the maximum allowable concentration. The metal deactivator was prepared in four concentrations: (a) one-half the maximum allowable, (b) the

maximum allowable, (c) twice and (d) three times the maximum allowable specification concentration. Finally the fuel system icing inhibitor was blended at (a) less than the maximum, (b) the maximum, (c) twice and (d) three times the maximum allowable specification concentration. Finally, the fuel conductivity additive was added to clay treated fuel samples until the desired conductivity in picosiemens, was reached. This last additive proved to be unstable, requiring blends to be prepared and monitored with additive adjustments over a period of three to four days. After this time the fuel would remain stable at the set conductivity for at least three weeks during which time the ECA tests were completed. Another method of working with the conductivity additive was to passivate glass containers with a final rinse after cleaning with a 50/50% mixture of methanol and toluene. Conductivity measurements were made on a daily basis to ensure that no change had taken place. In the additive tables (Tables 6 through 9), which list the additive concentrations used in these fuel blend studies, the minimum effective and maximum allowable concentrations are listed as pounds per thousand barrels for the antioxidant and the corrosion inhibitor. The fuel system icing inhibitor minimums and maximums are given in volume percentages and the metal deactivator is given as milligrams per liter. Master blends, which contained the maximum concentration of fuel additive, were prepared and provided to the program monitor at the conclusion of the fuel blend study.

ECA tests were conducted in 50°F intervals in the manner described in Appendix A. Occasional changes in test conditions occurred during several tests which were cause for termination of the test. One such condition was that of autoignition. Since the concentration of oxygen within the reaction chamber was in excess of 18%, autoignition was experienced several times with all fuel blends when an excess amount of heat was generated too rapidly. Large amounts of carbon were subsequently formed within the reaction chamber which required cleaning prior to further testing. The only other major problem occurred with fuel leakage at the lower insulated Swageloc® fitting. Refer to Figure 1.
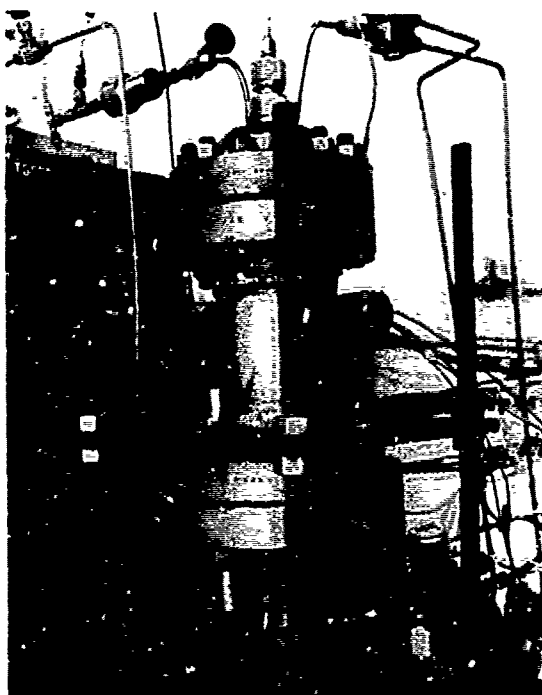
Figure 1. Fuel Leakage Source at Lower Swageloc Fitting

After each test a peroxide analysis was conducted as reviewed in Appendix B. A fuel sample of 250 to 300 milliliters was collected while the fuel was still under pressure and at elevated temperature. The sample bottle was prior washed, rinsed with ethyl alcohol (100%) and dried with nitrogen. The fuel sample thus taken was sparged with nitrogen and analyzed immediately in three aliquots for the total concentration of peroxide. Carbon deposition data together with the peroxide data have been listed in Appendices C and D and analyzed in Section VI. For most peroxide analyses the spread on the data was less than 3%; however, data with a ±5% variation was considered acceptable.

TABLE 5
FUEL ADDITIVE PROPERTIES

	A029	DCI-4A	FSII	Stadis-450	DMD-2
Physical Form	Colorless to Pale Yellow Flakes	Dark Amber Liquid	Colorless Liquid	Clear-Yellow Liquid	Light-Yellow Liquid
Specific Gravity (16/16C)	$0.61^{(6)}$	0.94	$0.966^{*(3)}$	0.9	0.99
Melting Point, °C	69	-	-	-	-
Boiling Point, °C	266	N/A	124.5	90	140
Flash Point, °C	$132^{(1)}$	$32^{(2)}$	$43^{(4)}$	$4.4^{(4)}$	$33^{(4)}$ $41^{(5)}$
Solubility, Wt % (20°C)$^{(6)\,(7)}$					
Isopentane	50	CM	CM	PM-CM	PM-CM
Benzene	40	CM	CM	PM	CM
Toluene	43	CM	CM	PM	CM
Water	I/S	-	CM	I/S	I/S
Solvent	None	Xylene	None	Toluene 74 v/o and isopropyl alcohol 3 v/o	
Chemical Description	2,6-Diteriary Butyl-4-Methyl-Phenol	Proprietary	Ethylene-Glycol Monomethyl Ether (EGME)	Proprietary Nitrogen and Sulfur Polymeric Compounds	N,N'-Disalicylidene-1,2-Propanediamine

(1) ASTM D92 (COC)	(5) ASTM D-1310 (TOC)
(2) ASTM D93 (PMCC)	(6) Untapped Density, Gram Per Cubic Centimeter
(3) 20°C	(7) CM - Completely Miscible, PM - Partly Miscible
(4) ASTM D-56 (TCC)	

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TABLE 6
PARTS-PER-MILLION CONCENTRATIONS FOR VARIOUS ANTIOXIDANT-FUEL BLENDS (2,6-DITERTIARY-BUTYl-4-METHYl-PHENOL)

Clay Treated Fuel		Pounds/1000 Barrels			
		6.0	7.2	8.4	16.8
JP-4	10% Aromatics	22.7	27.2	31.7	63.5
JP-4	25% Aromatics	21.2	25.4	29.6	59.3
JP-4	35% Aromatics	20.6	24.7	28.9	57.7
JP-8	17% Aromatics	21.6	26.0	30.3	60.6
Proposed Uniform Concentration		21.0	26.0	31.0	62.0

	Required Milligrams per Liter Equivalent to Uniform Concentration			
JP-4 — 10% Aromatics	15.852	19.630	23.408	46.816
JP-4 — 25% Aromatics	16.988	21.030	25.073	50.172
JP-4 — 35% Aromatics	17.437	21.612	25.760	51.493
JP-8 — 17% Aromatics	16.618	20.581	24.544	49.062

TABLE 7
PARTS-PER-MILLION CONCENTRATIONS FOR VARIOUS JET FUEL CORROSION INHIBITOR — FUEL BLENDS (DCI-4A)*

Clay Treated Fuel	Pounds/1000 Barrels			
	3.0	5.5	8.0	16.0
JP-4 — 10% Aromatics	11.3	20.8	30.2	60.5
JP-4 — 25% Aromatics	10.6	19.4	28.2	56.4
JP-4 — 35% Aromatics	10.3	18.9	27.5	55.0
JP-8 — 17% Aromatics	10.8	19.8	28.8	57.7
Proposed Uniform Concentration	11.0	20.0	29.0	58.0

	Required Milligrams per Liter Equivalent to Uniform Concentration			
JP-4 — 10% Aromatics	11.061	20.145	29.203	58.406
JP-4 — 25% Aromatics	11.871	21.594	31.281	62.563
JP-4 — 35% Aromatics	12.188	22.158	32.127	64.254
JP-8 — 17% Aromatics	11.625	21.101	30.612	61.189

*As Received Concentration of DCI-4A Is Taken as 75% Active Ingredient

TABLE 8
PARTS-PER-MILLION CONCENTRATIONS FOR VARIOUS JET FUEL SYSTEM ICING INHIBITOR — FUEL BLENDS (2-METHOXYETHANOL)

Clay Treated Fuel	Percent by Volume			
	0.05	0.15	0.30	0.45
JP-4 10% Aromatics	639.9	1919.6	3839.1	5758.6
JP-4 25% Aromatics	597.2	1791.4	3582.9	5374.3
JP-4 35% Aromatics	581.6	1744.9	3489.7	5234.6
JP-8 17% Aromatics	610.5	1831.5	3663.0	5494.5
Proposed Uniform Concentration	607.0	1823.0	3644.0	5466.0

Required Milligrams per Liter Equivalent
for Proposed Uniform Concentration

JP-4 — 10% Aromatics	458.336	1376.513	2751.599	4127.371
JP-4 — 25% Aromatics	491.123	1474.980	2948.349	4422.537
JP-4 — 35% Aromatics	504.227	1514.373	3027.081	4540.608
JP-8 — 17% Aromatics	480.370	1442.721	2883.857	4325.786

TABLE 9
PARTS-PER-MILLION CONCENTRATIONS FOR VARIOUS JET FUEL METAL DEACTIVATOR BLENDS (N,N¹-DISALICYLIDENE-1,2-PROPANEDIAMINE)*

Clay Treated Fuel	Milligrams per Liter			
	2.9	5.8	11.6	17.4
JP-4 — 10% Aromatics	3.8**	7.7	15.4	23.0
JP-4 — 25% Aromatics	3.6	7.2	14.3	21.5
JP-4 — 35% Aromatics	3.5	7.0	14.0	21.0
JP-8 — 17% Aromatics	3.7	7.3	14.7	22.0
Proposed Uniform Concentration	3.6	7.3	14.6	21.9

Required Milligrams per Liter for Proposed Uniform
Concentration at 50% Active Ingredient

JP-4 — 10% Aromatics	5.495	11.017	22.008	33.025
JP-4 — 25% Aromatics	5.865	11.810	23.593	35.403
JP-4 — 35% Aromatics	6.050	12.100	24.227	36.328
JP-8 — 17% Aromatics	5.760	11.546	23.091	34.610

*As Received Concentration is 50% Active Ingredient
**Parts-per-Million Based on 100% Active Ingredient

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TABLE 0
ADDITIVE CONCENTRATIONS, POUNDS PER 1000 BARRELS

Fuel	Antioxidant				Corrosion Inhibitor				Fuel System Icing Inhibitor*				Conductivity Additive**				Metal Deactivator +		
	C1	C2	C3	C4	C1	C2	C3	C4	C1	C2	C3	C4	C1	C2	C3	C4	C1	C2	C3
JP-4 — 10% Aromatics	6.0	7.2	8.4	16.8	3	5.5	8	16	0.05	0.15	0.30	0.45	200	600	1200	1800	2.9	5.8	11.6	17.4
JP-4 — 25% Aromatics	6.0	7.2	8.4	16.8	3	5.5	8	16	0.05	0.15	0.30	0.45	200	600	1200	1800	2.9	5.8	11.6	17.4
JP-4 — 35% Aromatics	6.0	7.2	8.4	16.8	3	5.5	8	16	0.05	0.15	0.30	0.45	200	600	1200	1800	2.9	5.8	11.6	17.4
JP-8 — 17% Aromatics	6.0	7.2	8.4	16.8	3	5.5	8	16	0.05	0.15	0.30	0.45	200	600	1200	1800	2.9	5.8	11.6	17.4

*   Units of Concentration = Volume %
**   Units = Picosiemens/Meter (pS/m)
     (1 pS/m = 1CS (Conductivity Unit))
     Indicates Desired Conductivity Level = 50 pS/m
+   Milligrams of Metal Deactivator per Liter of Fuel

SECTION VI

DATA ANALYSIS

The principium for determining the rate of jet fuel deposition, as described in this program, was to provide the basis for an Arrhenius evaluation and determination of the activation energy for each of the four selected fuels. As discussed in Section V the fuels were: JP-4 with 10% aromatics, JP-4 with 25 and 35% aromatics, and JP-8 with 17% aromatics; all fuels were clay treated and blended with specific, qualified additives. These tests were conducted on freshly prepared fuel blends using the Experimental Coking Apparatus (ECA) as discussed in Appendix A. Immediately after each ECA test, a sample of the fuel was evaluated by ASTM D-3703 for peroxide content. These data were then plotted against the reciprocal of the absolute test temperature and comparisons were made to the deposition and peroxide levels of the baseline fuels.

Each data set was then evaluated using a linear regression analysis to determine the Arrhenius factors, the activation energy and the pre-exponential factor.* Values are listed for each fuel and fuel-additive blend in Tables 11 through 14. Comparison of the fuel-additive blends with the baseline fuel preserves the effect of the additive on the fuel deposit rate of formation. At first glance, the JP-4-10% aromatics shows a lower specific deposit rate than the fuel blends to 25 and 35% with the 2040 solvent. Also, the JP-4-25% aromatics blend deposition rate was less than the JP-4-35% aromatics.

The antioxidant (AO-29;AO) conductivity improver (Stadis-450; CDI), and the metal deactivator (DMD-21; MDA) had visible effects on all fuels tested. The AO decreased the rate of the overall fuel deposition relative to the fuels baseline for JP-4 fuels. An increase in aromatic content of the JP-4 fuel also affected the deposition by decreasing the effectiveness of the AO-29 according to the following order:

JP-4-35% aromatics > JP-4-25% aromatics > JP-4-10% aromatics

The JP-8 rate of deposition also decreased with the decrease approximately equal to the JP-4-10% aromatics. The CDI and the MDA deposition rates were adversely affected. In all tests the deposition increased in clay treated fuel samples of JP-4 and JP-8. The CDI and MDA deposition increased according to the following:

JP-4-10% aromatics < JP-4-25% aromatics < JP-4-35% aromatics

JP-8-17% aromatics affected the baseline rate of deposition between that of JP-4-10% and JP-4-25% aromatics.

Both the corrosion inhibitor (DC1-4A; CI) and the fuel system icing inhibitor (2-methoxyethanol; FSII) indicate a relatively small influence on the deposition rates of the four selected fuels. The CI had a small negative effect (increase) in fuel deposition at the 25 and 35% aromatic level in JP-4. The 35% aromatic JP-4 reflected a larger deposition than the 25% JP-4.

Most of the peroxide levels were in relative agreement with the rates of deposition; that is, the peroxide level increased with an increase in the deposition rate. All AO treated fuels had a decrease in peroxide level while the CDI and the MDA peroxide levels were higher than their respective baseline. The JP-8/CDI blend peroxide data indicated a lower peroxide concentration (Figure C-5 in Appendix C) than expected. Peroxide concentrations were consistently lower for

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* Benson, Sidney W., The Foundations of Chemical Kinetics, 1960, McGraw-Hill Book Co., pg. 66-8

greater than expected from the ECA deposition data. Peroxide data established using the CI and the FSII blends paralleled with deposition rate data. When little or no shift from the fuel baseline deposition was recorded, the peroxide concentration also repeated.

Each Arrhenius evaluation was completed per fuel/additive blend as follows: A specific set of deposition rates and fuel temperatures were curve fit using a first-degree linear curve fit. Then, using the slope and y-intercept, the linear equation of the form $y = mx + b$ was evaluated at 149, 204, 260 and 316°C. Specific deposition rates which can be specified in this manner can be used subsequently to relate relative comparisons of similar fuels or fuel blends. This comparison formed the basis of the conclusions in Section VII. In addition to the preceeding, the curve fit yields a coefficient of determination which, for this investigation, was at least 0.90. This value indicates that 90% of the data used to generate the curve fit will be within a 1σ band.

NOTE: The basic interpretation of the Arrhenius Equation has, since the late 1800's, been used to relate the temperature dependence of chemically reactant systems. The basic mathematical relation, developed from sucrose inversion studies,* can be written as

$$\frac{d \ln k'}{dT} = \frac{E^*}{RT^2}$$

where T is the Kelvin temperature, k' the specific reaction rate, and E^* is the Arrhenius activation energy. When integrated this equation, after assuming that the activation energy remains linear over the range of T, yields the textbook equation

$$k'(T) = A \exp(-E^*/RT).$$

In most theoretical discussions involving the Arrhenius activation energy, it is often neglected, sometimes assumed, that the real interpretation of E^* is known to the reader. Here this is not the case. Specifically the Arrhenius model represents the intermediate active form of the reactant/product molecules characteristic to a given reaction. In the case of this investigation, this active form cannot be described by any simple chemical formula; even an empirical formula would perhaps be too bold. Instead it is utilization of the activated complex that is noteworthy and that there is no definitive relationship between the energy necessary to achieve the activated complex and the magnitude of the specific reaction rate. A decrease in fuel deposition is not necessarily coupled to a decrease in the energy necessary to achieve that deposition. Subsequently no rational judgement about these two quantities can be m. le based on the data of this investigation.

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* Arrhenius, S., Z. Physik Chem., 4, 226 (1889)

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

The deposition rate data from the tests conducted in Task 4.3.3, Fuel Baseline Study, confirmed the effects of aromatic compounds. The baseline data curve fit to a straight line in Figures D-1, D-6, D-11 and D-16 show the deposition rates for JP-8, JP-4-10%-aromatics, JP-4-25% aromatics and JP-4-35% aromatics as increasing. The JFTOT thermal stability breakpoint temperatures for these fuels decreases in this same order. Also, the aromatic content was the only change made to the original clay treated fuel for the JP-4 fuels. The breakpoints decrease as the aromatic contents increased. This change paralleled the increase in the specific reaction rate.*

Experimental specific rate data, as tabulated in Appendix C for each specific jet fuel and additive combination, was used as data in the solution of a linear regression analysis. The reciprocal of the absolute temperature (degrees Kelvin) was taken as the independent variable and the specific rate (grams per square centimeter-second) as the dependent variable. The linear regression was further applied in the subsequent Arrhenius analyses by conversion of the dependent variables to their common logarithm. Tables 11 through 14 represent the activation energies (calories per mole) and the Arrhenius pre-exponential factors for the four jet fuels.

A low Arrhenius activation energy projects a low energy threshold to the hypothetical chemically active transition state. In general, the lower the activation energy the lower the energy required to reach the reaction products. This in turn specifies that the deposition will occur at a lower thermal energy input level as compared to another fuel at a higher activation energy. This does not directly relate to the quantitative measure of a fuels deposition or deposition rate. Comparison of the baseline activation energies reflects a decrease as the aromatic concentrations of the JP-4 fuels are increased. The JP-8 activation energy is approximately 100 calories less than the JP-4-10% aromatics. Subsequent comparisons of the additives used in the fuel-blend study yields the following conclusions:

1. The antioxidant (AO-29) effectively reduces the activation energies in all fuels tested. AO-29 also reduces the specific rates of each fuel tested.

2. The corrosion inhibitor (DCI-4A) and the fuel system icing inhibitor (2-methoxyethanol) show little or no variation from the clay treated baseline.

3. Both the conductivity additive (Stadis-450) and the metal deactivator (DMD-2) increased the activation energy at all concentrations.

The Arrhenius pre-exponential factor can be considered a measure of the entropy of the activated transition state and can be used to relate the order/disorder of this transition state. Even under the most highly ordered reaction schemes the pre-exponential factor is difficult to relate accurately to a reactions characteristic. Close comparison of the calculated pre-exponential factors for this study did not result in any further absolute information.

In addition to the Arrhenius analyses of Tables 11 through 14 the linear regressions were used in each fuel and/or fuel-blend test to establish the fuel deposit expected at 149 (300), 204 (400), 260 (500) and 316°C (600°F). Tables 15 through 18 represent these data in similar order to the Arrhenius constants. The data calculated at 149 and 204°C deviate from the baseline only

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* The specific reaction rate, being unique for each fuel or fuel additive, as used here refers to the measured deposition in grams normalized to one cubic centimeter and one second.

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in relatively small quantities, whereas the 260 and 316°C levels show dominant deviations from their baselines. Variations for each of the additives directly paralleled the variations previously discussed for the Arrhenius activation energies and are summarized as follows:

1. Virtually all specific rates increased when relating the fuels in the order of JP-8, JP-4-10% aromatics, JP-4-25% aromatics and JP-4-35% aromatics.

2. The antioxidant tests revealed a progressive decrease in deposit formation at constant temperature coupled with an increase in the deposit reduction with test temperature.

3. The metal deactivator and the conductivity additive paralleled their activation energies, respectively, an increase.

4. The fuel system icing inhibitor and the corrosion inhibitor maintained their deposition relative to the baseline except at elevated temperatures.

At elevated temperatures which approach the region of pyrolysis, variation in deposit formation would be expected to decrease and the concentrations of water vapor and oxides of carbon would increase, both with little or small correlation. In this study the peroxide concentrations were evaluated and are reported in Appendix D. At deposit temperatures in excess of 260°C (500°F), the peroxide concentration decreased; however, within the temperature range of 149 to 260°C (300 to 500°F) a trend very similar to the specific rate variation was established. The peroxide analyses were evaluated using the same linear regression as used with the specific rate data. However, due to the variation in analytical results using the procedure discussed in Appendix B, an accurate Arrhenius analysis could not be made. The basic trend in the peroxide concentrations were to parallel the deposition rate as expected based on the theories concerning fuel deposition.*

*(1) Hammond, G. S. and Soffer, L. M., J. Am. Chem. Soc., Vol. 72, 4711 (1951):
(2) Shine, H. and Ayrey, G., Chem. Rev., Vol. 63, 645 (1963);
(3) Bevington, J. C., et.al, Trans. Faraday Society, Vol. 54, 863 (1958);
(4) Walling, C., J. Phys. Chem., Vol 71, 2361 (1967).

TABLE 11
ARRHENIUS CONSTANTS FOR A JP-8 FUEL AS DERIVED FROM A PSEUDO FIRST-ORDER REACTION BETWEEN 121°C AND 316°C

Fuel	Specific Rate of Deposit Formation		Specific Rate of Peroxide Formation	
	Activation Energy	Preexponential Factor	Activation Energy	Preexponential Factor
	(cal mole^{-1})	(cm^{-2} sec^{-1})	(cal mole^{-1})	(sec^{-1})
Baseline CT	7822	2.335×10^{-6}	8077	1.373×10^{4}
AO 29				
MEC	7634	1.658×10^{-6}	7285	5.673×10^{3}
$\frac{1}{2}$ MAC	7304	9.104×10^{-7}	8507	1.781×10^{3}
MAC	7003	7.492×10^{-7}	6826	3.034×10^{3}
2 MAC	6422	3.466×10^{-7}	7609	6.316×10^{3}
DCI-4A				
MEC	7761	2.238×10^{-6}	6146	1.836×10^{3}
2 MAC	7775	2.207×10^{-6}	6840	3.723×10^{3}
FSII				
<< MAC	8002	2.815×10^{-6}	11540	3.509×10^{5}
3 MAC	7965	2.638×10^{-6}	6490	2.533×10^{3}
Stadis 450				
MEC	7897	2.551×10^{-6}	8378	1.846×10^{4}
MAC	8114	3.375×10^{-6}	6757	3.377×10^{3}
2 MAC	8200	3.938×10^{-6}	7552	7.456×10^{3}
3 MAC	8218	4.341×10^{-6}	7455	6.717×10^{3}
DMD-2				
$\frac{1}{2}$ MAC	Negligible effect on baseline data			
MAC	8143	3.372×10^{-6}	7345	7.018×10^{3}
2 MAC	8391	4.825×10^{-6}	7625	9.551×10^{3}
3 MAC	8597	7.250×10^{-6}	7659	1.066×10^{4}

TABLE 12
ARRENIUS CONSTANTS FOR A JP-4 FUEL CLAY TREATED WITH A 10% TOTAL AROMATIC CONCENTRATION AS DERIVED FROM A PSEUDO FIRST-ORDER REACTION BETWEEN 121°C AND 316°C

Fuel	Specific Rate of Deposit Formation		Specific Rate of Peroxide Formation	
	Activation Energy	Preexponential Factor	Activation Energy	Preexponential Factor
	(cal mole^{-1})	(cm^{-2} sec^{-1})	(cal mole^{-1})	(sec^{-1})
Baseline CT	8769	3.126×10^{-5}	9758	1.524×10^5
AO-29				
MEC	8506	2.044×10^{-5}	8218	2.040×10^4
½ Σ MC	7730	7.149×10^{-5}	7710	1.074×10^4
MAC	7259	3.336×10^{-5}	7788	9.672×10^3
2 MAC	6817	1.796×10^{-5}	7175	3.879×10^3
DCI-4A				
MEC	8764	3.047×10^{-5}	9995	1.820×10^5
2 MAC	8904	3.597×10^{-5}	9553	1.243×10^5
FSII				
<< MAC	8625	2.672×10^{-5}	9613	1.168×10^5
3 MAC	7869	1.077×10^{-5}	9634	1.319×10^5
Stadis 450				
MEC	8911	3.295×10^{-5}	9897	1.755×10^5
MAC	8926	3.826×10^{-5}	11290	9.062×10^5
2 MAC	9112	4.944×10^{-5}	10741	4.015×10^5
3 MAC	9325	6.600×10^{-5}	9847	2.631×10^5
DMD-2				
½ MAC	8962	4.058×10^{-5}	10221	2.741×10^5
MAC	8979	4.338×10^{-5}	9599	2.114×10^5
2 MAC	9067	5.046×10^{-5}	10492	4.401×10^5
3 MAC	8993	4.841×10^{-5}	10951	9.066×10^5

TABLE 13
ARRHENIUS CONSTANTS FOR A JP-4 FUEL CLAY TREATED WITH A 25% TOTAL AROMATIC CONCENTRATION AS DERIVED FROM A PSEUDO FIRST-ORDER REACTION BETWEEN 121°C AND 316°C

Fuel	Specific Rate of Deposit Formation		Specific Rate of Peroxide Formation	
	Activation Energy	Preexponential Factor	Activation Energy	Preexponential Factor
	$(cal\ mole^{-1})$	$(cm^{-2}\ sec^{-1})$	$(cal\ mole^{-1})$	(sec^{-1})
Baseline CT	8727	3.798×10^{-5}	9239	1.247×10^5
AO-29				
MEC	8354	2.281×10^{-5}	8810	7.366×10^4
½ Σ MC	8449	2.209×10^{-5}	8720	$6 257 \times 10^4$
MAC	7892	1.137×10^{-5}	8526	4.821×10^4
2 MAC	7603	7.907×10^{-6}	8652	5.678×10^4
DCI-4A				
MEC	8729	3.782×10^{-5}	9314	1.346×10^5
½ Σ MC	8753	3.916×10^{-5}	9725	2.255×10^5
MAC	8595	3.256×10^{-5}	8903	1.005×10^5
2 MAC	8790	4.381×10^{-5}	9229	1.366×10^5
FSII				
<< MAC	8679	3.586×10^{-5}	8973	9.627×10^4
3 MAC	8637	3.457×10^{-5}	9037	1.016×10^5
Stadis 450				
MEC	8804	4.215×10^{-5}	9580	1.741×10^5
MAC	8904	5.241×10^{-5}	8828	8.321×10^4
2 MAC	9116	6.396×10^{-5}	8439	6.245×10^4
3 MAC	9159	7.279×10^{-5}	9539	2.203×10^4
DMD-2				
½ MAC	8692	3.911×10^{-5}	8698	7.593×10^4
MAC	8678	4.080×10^{-5}	9337	1.547×10^4
2 MAC	8704	4.468×10^{-5}	8667	7.616×10^4
3 MAC	8890	6.083×10^{-5}	8931	1.120×10^4

TABLE 14
ARRHENIUS CONSTANTS FOR A JP-4 FUEL CLAY TREATED WITH
A 35% TOTAL AROMATIC CONCENTRATION DERIVED FROM A PSEUDO
FIRST-ORDER REACTION BETWEEN 121°C AND 316°C

Fuel Additive Concentration	Specific Rate of Deposit Formation		Specific Rate of Peroxide Formation	
	Energy	Activation Factor	Preexponential Energy	Activation Factor
	(cal mole⁻¹)	(cm²sec⁻¹)		
Baseline CT	8493	3.486×10^{-5}	8969	1.265×10^5
AO–29				
MEC	8134	2.213×10^{-5}	8515	7.263×10^4
½ Σ MC	7995	1.528×10^{-5}	8292	5.189×10^4
MAC	7852	1.487×10^{-5}	8234	4.329×10^4
2 MAC	7592	1.019×10^{-5}	7787	2.534×10^4
DCI-4A				
MEC	8332	3.001×10^{-5}	9019	1.281×10^5
½ Σ MC	8453	3.276×10^{-5}	9383	2.054×10^5
MAC	8579	4.100×10^{-5}	8749	1.108×10^5
2 MAC	8817	5.634×10^{-5}	9330	2.026×10^5
FSII				
⪅ MAC	8185	2.511×10^{-5}	9241	1.674×10^5
3 MAC	8249	2.730×10^{-5}	8795	1.056×10^5
Stadis 450				
MEC	8635	4.141×10^{-5}	8825	1.069×10^5
MAC	8516	3.89×10^{-5}	9127	1.504×10^5
2 MAC	8898	6.217×10^{-5}	8790	1.094×10^5
3 MAC	9146	8.785×10^{-5}	9365	2.069×10^5
DMD-2				
½ MAC	8461	3.739×10^{-5}	8613	9.354×10^4
MAC	8545	5.000×10^{-5}	8734	1.078×10^5
2 MAC	8601	5.299×10^{-5}	8990	1.369×10^5
3 MAC	8795	7.943×10^{-5}	9021	1.481×10^5

TABLE 15
JP 8 FUEL DEPOSITS AT SELECTED TEMPERATURES DERIVED FROM A
LINEAR REGRESSION OF EXPERIMENTAL DATA BETWEEN 121°C AND 316°C

Fuel	Fuel Temperature			
	149°C	204°C	260°C	316°C
Baseline CT	0.019	0.057	0.135	0.273
AO-29				
MEC	0.017	0.049	0.114	0.227
½ Σ MC	0.017	0.046	0.102	0.193
MAC	0.016	0.043	0.094	0.176
2 MAC	0.015	0.037	0.075	0.134
DCI-4A				
MEC	0.020	0.058	0.136	0.273
2 MAC	0.019	0.056	0.133	0.268
FSII				
<< MAC	0.019	0.057	0.137	0.282
3 MAC	0.018	0.055	0.133	0.272
Stadis 450				
MEC	0.019	0.057	0.138	0.279
MAC	0.020	0.060	0.148	0.307
2 MAC	0.021	0.064	0.159	0.333
3 MAC	0.023	0.070	0.173	0.361
DMD-2				
3 MAC	0.024	0.078	0.202	0.436
2 MAC	0.020	0.064	0.163	0.346
MAC	0.019	0.058	0.144	0.299
½ MAC	Negligible effect on baseline data			

TABLE 16
JP-4-10% AROMATICS FUEL DEPOSITS AT SELECTED TEMPERATURES
DERIVED FROM A LINEAR REGRESSION OF EXPERIMENTAL DATA
BETWEEN 121°C AND 316°C

Fuel	Fuel Temperature			
	149°C	204°C	260°C	316°C
Baseline CT	0.084	0.280	0.740	1.624
AO-29				
MEC	0.075	0.242	0.619	1.324
½ Σ MC	0.066	0.192	0.451	0.903
MAC	0.054	0.147	0.328	0.630
2 MAC	0.044	0.126	0.268	0.494
DCI-4A				
MEC	0.082	0.275	0.725	1.591
2 MAC	0.082	0.280	0.749	1.666
FSII				
<< MAC	0.085	0.279	0.724	1.570
3 MAC	0.085	0.249	0.596	1.208
Stadis 450				
MEC	0.084	0.232	0.749	1.652
MAC	0.085	0.291	0.781	1.740
2 MAC	0.088	0.309	0.846	1.917
3 MAC	0.092	0.329	0.925	2.135
DMD-2				
½ MAC	0.087	0.297	0.801	1.790
MAC	0.091	0.312	0.842	1.885
2 MAC	0.095	0.331	0.902	2.035
3 MAC	0.100	0.343	0.927	2.078

TABLE 17.
FUEL DEPOSIT FROM A SELECTED JP-4 CLAY TREATED WITH 25% AROMATIC CONCENTRATION AT TEMPERATURES DERIVED FROM A LINEAR REGRESSION OF ECA EXPERIMENTAL DATA

Fuel Additive Concentration	Temperature			
	149°C	204°C	260°C	316°C
Baseline CT	0.107	0.354	0.931	2.037
AO-29				
MEC	0.101	0.317	0.799	1.690
½ Σ MC	0.087	0.277	0.707	1.509
MAC	0.087	0.257	0.616	1.250
2 MAC	0.085	0.242	0.563	1.113
DCI-4A				
MEC	0.107	0.354	0.929	2.034
½ Σ MC	0.107	0.357	0.941	2.063
MAC	0.108	0.351	0.908	1.964
2 MAC	0.115	0.384	1.017	2.237
FSII				
<< MAC	0.107	0.353	0.924	2.012
3 MAC	0.109	0.356	0.927	2.013
Stadis 450				
MEC	0.109	0.364	0.965	2.126
MAC	0.120	0.407	1.092	2.427
2 MAC	0.114	0.398	1.091	2.472
3 MAC	0.123	0.432	1.192	2.711
DMD-2				
½ MAC	0.115	0.380	0.996	2.171
MAC	0.122	0.430	1.053	2.293
2 MAC	0.130	0.429	1.125	2.456
3 MAC	0.142	0.480	1.285	2.853

TABLE 18
JP-4-35% AROMATICS FUEL DEPOSITS AT SELECTED TEMPERATURES DERIVED FROM A LINEAR REGRESSION OF EXPERIMENTAL DATA BETWEEN 121°C AND 316°C

Fuel	Temperature			
	149°C	204°C	260°C	316°C
Baseline CT	0.130	0.418	1.071	2.296
AO-29				
MEC	0.127	0.388	0.954	1.979
½ Σ MC	0.119	0.350	0.837	1.692
MAC	0.110	0.329	0.796	1.639
2 MAC	0.111	0.316	0.733	1.448
DCI-4A				
MEC	0.136	0.426	1.073	2.265
½ Σ MC	0.128	0.410	1.045	2.231
MAC	0.138	0.449	1.162	2.508
2 MAC	0.143	0.480	1.275	2.811
FSII				
<< MAC	0.135	0.417	1.031	2.149
3 MAC	0.136	0.424	1.056	2.213
Stadis 450				
MEC	0.131	0.428	1.113	2.414
MAC	0.140	0.452	1.160	2.490
2 MAC	0.143	0.486	1.303	2.895
3 MAC	0.151	0.532	1.463	3.323
DMD-2				
½ MAC	0.145	0.464	1.184	2.529
MAC	0.153	0.505	1.318	2.864
2 MAC	0.174	0.567	1.470	3.181
3 MAC	0.207	0.692	1.834	4.037

APPENDIX A

THEORY AND OPERATION OF THE
EXPERIMENTAL COKING APPARATUS

The experimental coking apparatus (ECA) was initially designed to study the rates of jet fuel deposits found in the mechanical fuel systems aboard gas turbine powered aircraft. It is basically a stainless steel, 2-liter cylindrical reaction chamber which contains the necessary material and induction coil to heat a sample of jet fuel to any prescribed temperature inductively from ambient to 340°C. Table A-1 presents the original design criteria to which the ECA was designed and fabricated.

The ECA was used throughout this program to establish, gravimetrically, the maximum amount of deposit that can be realized from a prescribed volume of fuel. The experimental test conditions were as follows:

1. The test temperature is in the range characteristic to auto-oxidation from ambient to 288°C. For the purposes of this study the minimum temperature was taken as 121 to 135°C. Both chromel/alumel and platinum/ platinum-rhodium thermocouples were used to measure test temperatures.

2. Test pressures were recorded on both helicoil pressure gages and digital readouts using Teledyne® transducers. The test pressures were set according to the pseudo-critical pressures as discussed in the body of this report.

3. Standardized, compressed air cylinders were used to supply a steady, continuous flow of oxygen into the base of the reaction chamber of the ECA. The flow rate was 300 standard cubic centimeters per minute measured continuously at a downstream location by a Matheson Model 8240 mass flow controller. The kinetic analyses and Arrhenius evaluations that are used to relate fuel deposit characteristics to the changes in fuel composition based on a first-order rate mechanism were the only concentration variables in the fuel component. This air flow is of utmost importance because of the necessity to provide a very high concentration of oxygen compared to the amount of fuel components that will produce fuel deposits at the test condition.

4. The duration of each ECA test was established by measuring the time necessary to condense a gravimetrically determinable fuel deposit on a 4 square inch coupon. For the selected fuels in this study a 60-minute test duration at temperature was used, however, three to four hours was necessary for JP-7 to provide a measurable deposit.

The ECA is shown in Figure A-1 in schematic form. During the tests conducted with the fuel baseline and blend tasks, a modified test procedure was used and is outlined as follows: The reaction chamber was manually filled with 1 liter of fuel to be tested. This would cover both the susceptor and the induction coil. The induction heater leads, which are located inside the reaction chamber, are coated with a composite material that has no effect on the thermal or chemical stability of jet fuels at elevated temperatures and pressures. These leads were also covered with fuel. After the fuel had been added, two sample coupons of stainless steel were placed into the sample holder, Figure A-2. The platinum thermocouples were placed into the susceptor and the sample holder was placed in the top of the reaction chamber. A visual

inspection was made prior to each test from the top of the ECA. After confirming that the coil, susceptor and sample coupons were all in their proper places, the top was positioned with an ATC AES 1002-2 AGC Fluorocarbon Elastomer Gasket. The nitrogen system was activated to 207 kPa, the reaction chamber was pressure checked for leaks, and then the pressure was reduced to atmospheric. This would complete the pretest setup and checkout.

The 15-kilowatt Tocco induction heater was then brought on line per the manufacturer's instructions and the temperature of the susceptor was increased from ambient to 38°C. The susceptor was held at this temperature for one minute to activate the Leeds and Northrop Model 165 temperature controller. Next, the high pressure regulated air supply was activated and the reaction chamber pressure was brought to 10'. above the psuedo-critical pressure. After a stable pressure was established, the Matheson mass flow controller was turned on and a flowrate of 300 SCCM of dry standard air was maintained during the remainder of the test. With both the pressure and flowrate set and constant, the induction heater was turned to full power and simultaneously control was transferred to the temperature controller. The Leeds and Northrop controller not only controlled the maximum test temperature but also would control the rate of heating or the variation of temperature flux to the fuel from the susceptor. A timer on the Tocco control unit was set to the required run time after the test temperature had been reached.

At the conclusion of each test the reaction chamber was allowed to cool for one hour at ambient pressure and at 300 SCCM of nitrogen as a system purge. The sample coupons (Figure A-3) were removed from the sample holder, washed with a solution of hexane and toluene and placed in a vacuum oven at 100°C for one hour at a pressure of five inches of mercury. After the initial drying period, one sample coupon was labeled and placed into an amber or brown jar, covered with a nitrogen blanket and sealed for shipment to Wright-Patterson Air Force Base. The other coupon was weighted on a Mettler Model M5SA six place to within 1 microgram. The coupon was then cleaned with a proprietary multiple-solvent to remove all deposit material and the coupon reweighted. This gravimetric differential was used as the basis for the specific deposit rate for the test fuel. Figure A-4 shows a series of sample coupons from tests run from 121 to 288°C in 28° increments. Both the baseline and fuel blend deposition rates were established as just described; refer to Appendix C.

Fuel samples for the peroxide analyses (as discussed in Appendix B) were taken immediately at the conclusion of the preset time at temperature. A 75 gram sample of fuel was withdrawn, under pressure, into a nitrogen purged borosilicate glass sample bottle. The sample was divided into at least three separate samples and each sample was analyzed for the level of peroxide in parts per million per ASTM D-3703-78. Data and Arrhenius plots are presented in Appendix D.

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EXPERIMENTAL COKING APPARATUS
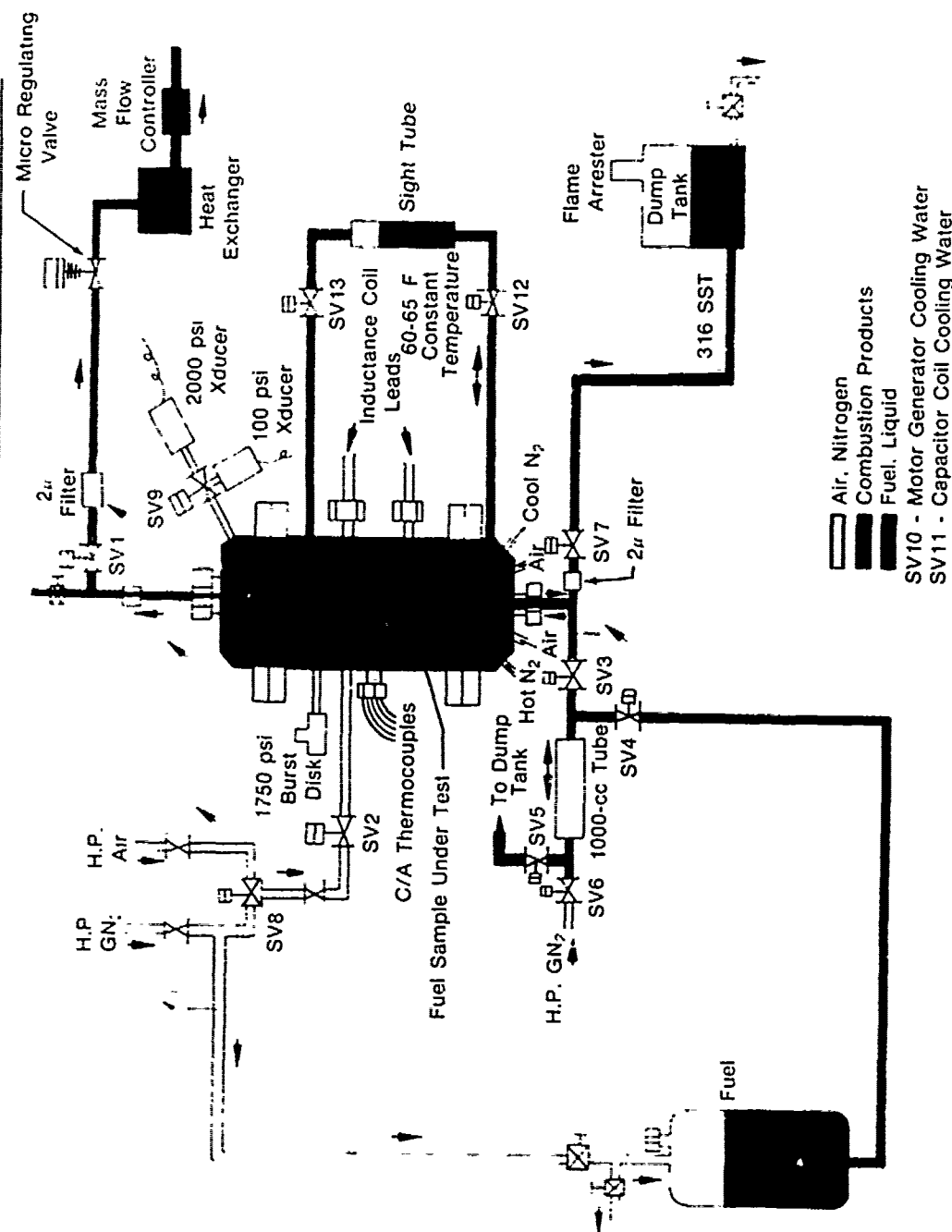
Figure A-1. Schematic of Experimental Coking Apparatus
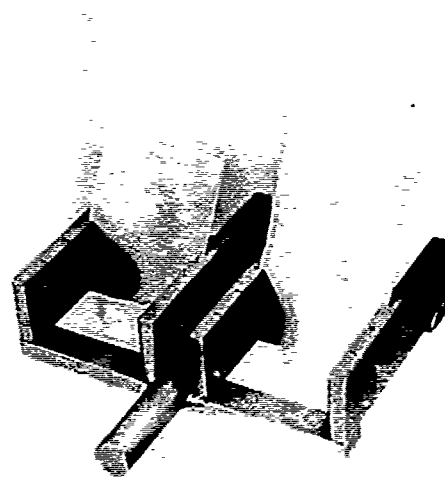
Figure A-2. Sample Coupons Mounted in Holder
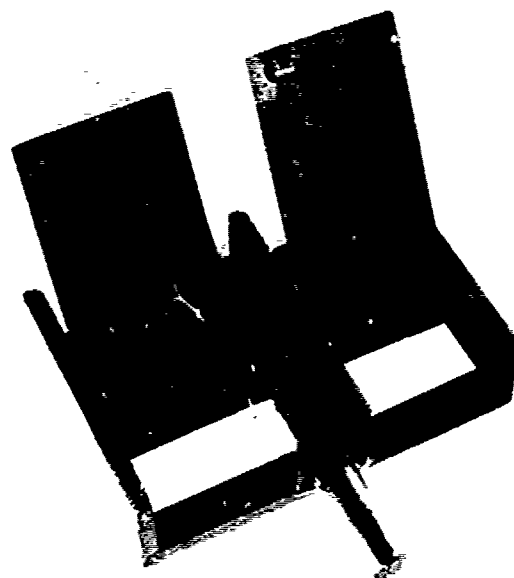
Figure A-3. Sample Coupons Removed from Holder and Washed

31
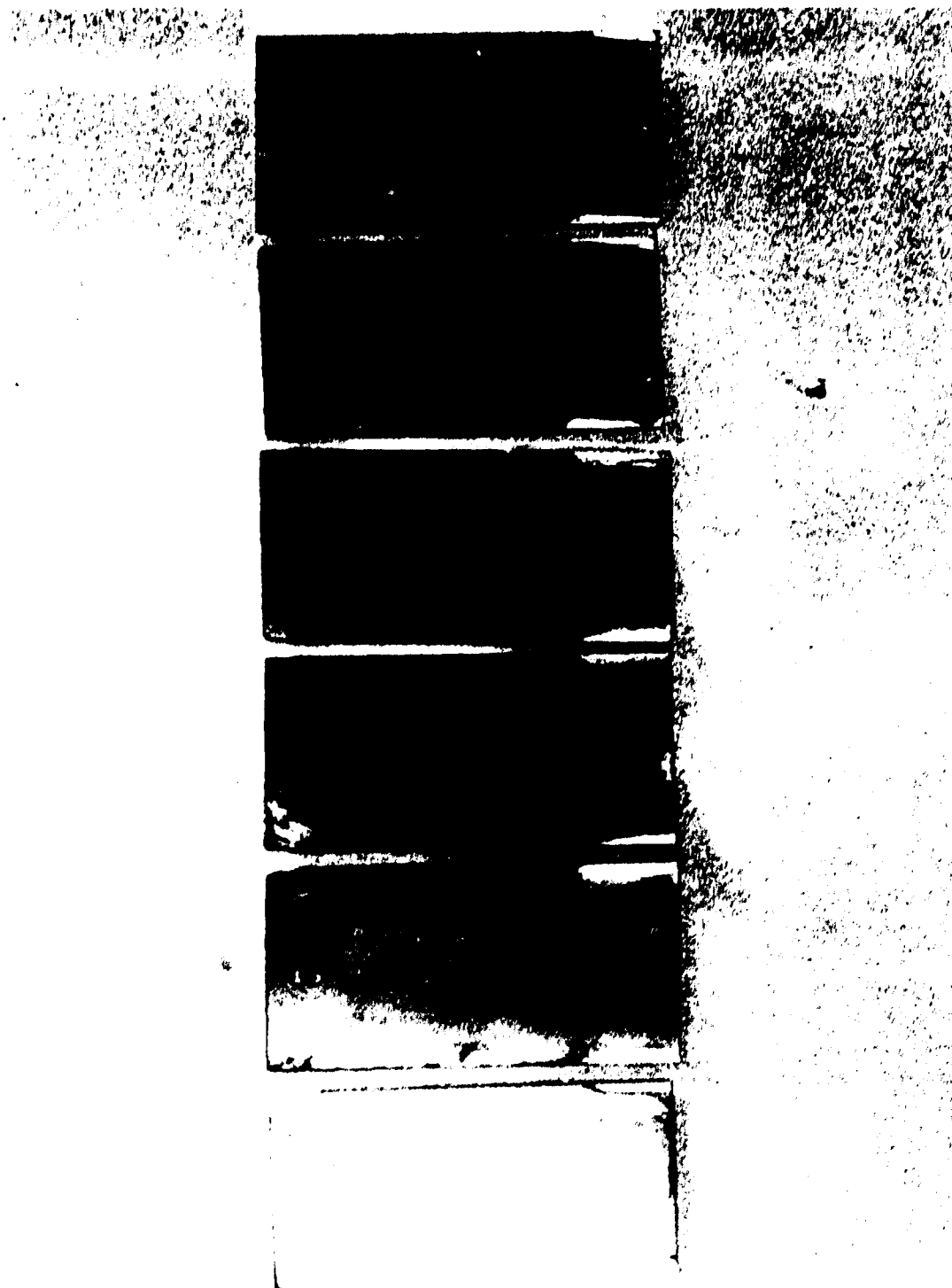
Figure A-4. Sample Coupons Tested at Temperatures from 21 to 288°C

APPENDIX B

A TEST METHOD FOR THE DETERMINATION OF THE PART-PER-MILLION LEVEL OF ACTIVE OXYGEN IN AVIATION TURBINE FUELS

The products of auto-oxidation of gas turbine fuels contain substantial and measurable quantities of oxygen in addition to other elements. Chemical mechanisms have been proposed that treat the chemical reactions responsible for incorporation of molecular oxygen into the products of fuel auto-oxidations. The procedure that follows is a modification of the ASTM D3703-78, a standard test method for evaluating the peroxide number of aviation turbine fuels and was used explicitly to determine the part-per-million level of peroxide in fuel samples. The samples evaluated by this method were analyzed immediately after thermal stressing had been completed on the experimental coking apparatus. Fuel samples were not held overnight nor refrigerated due to potential continuation of possible peroxy-free radical reactions.

A sample of fuel to be tested was divided into three aliquots and weighed to ±0.002 gram. The sample was immediately sparged with pure, dry nitrogen gas. The sparging was carried out in a 250 ml iodine flask for samples with a peroxide concentration of 75 ppm or more while a 500 ml iodine flask was used for concentrations less than 75 ppm. The iodine flasks and all other equipment that came into contact with the fuel sample had been final rinsed with pure ethyl alcohol just prior to use to remove any trace quantities of moisture. The iodine flasks also were flushed with pure, dry nitrogen just prior to introduction of the fuel sample.

After the sample was sparged for a minimum of 3 minutes at a rate of 200 SCCM, 25 ml of Freon 113 was added and the sparging was continued for a minimum of 5 minutes. A stirring motor utilizing a magnetic stir bar was used to agitate the solution vigorously after the Freon 113 was added to the fuel sample. Without stopping the sparging, 20 ml of Ultrex acetic acid was added followed by 2 to 3 ml of freshly prepared/stabilized potassium iodide.

Note: The use of the terminology "stabilized" may be misleading when used without explanation. In these analyses, the potassium iodide was prepared freshly on a daily basis as follows: First, 50 ml of deionized water was filtered (0.8 micron) and sparged vigorously with pure, dry nitrogen for three minutes while the temperature was increased to 90°C. Then, 75 grams of ACS reagent grade potassium iodide was slowly added and magnetically stirred until the iodide was completely dissolved. Finally, the solution was cooled to room temperature and topped off with nitrogen. Every effort was made to ensure a "less than detectable" amount of free iodine would be formed through complete exclusion of molecular oxygen.

After the potassium iodide had been added, the nitrogen flow was increased to 500 SCCM and held there for 30 seconds after which time the nitrogen flow was terminated and the flask was set aside for 5 minutes ± 3 seconds. During this time, the peroxides present in the original fuel sample react and oxidize iodide ion to free iodine which is then titrated with a standard sodium thiosulfate as discussed in Section 8.3 of ASTM 3703-78. The resultant calculations of parts-per-million were converted into both millimoles of active oxygen* per liter of fuel and millequivalents of active oxygen per kilogram of fuel. Figure B-1 shows various chemical apparatus used in these analyses and Table B-1 lists the specific chemicals.

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* Active oxygen is defined as one-half of the oxygen of a fuel-derived hydroperoxide. Millequivalent weight of 8.

Figure B-1. Chemical Apparatus Used During Analyses

TABLE B-1
PEROXIDE ANALYSIS EQUIPMENT/MATERIALS

Burets, Fisher Brand Machlett Automatic Burets

$Na_2S_2O_3$	Capacity	Subdivision	Tolerance	Reservoir Capacity	Cat. No.
0.1N	2ml	1/100ml	± 0.02ml	500ml	03-847A
0.01N	10ml	5/100ml	± 0.06ml	1000ml	03-847D
0.005N	25ml	1/10ml	± 0.06ml	2000ml	03-847E
Freon 113	25ml	1/10ml	± 0.06ml	2000ml	03-847E

NOTE: Filters, Plugs, and Silica Gel Come With Burets.

Fisher Support Assembly for Machlett Burets, Rectangular Cast Iron Support

Model, 14-679

This Stand Is for One Buret Only. Included Are, Clamps and Ring Supports.

Fisher Scientific Co.

Graduated Cylinder With Stopper. Cat. No. 08-565D

Fisher Scientific Co.

Pyrex Brand Flask - 250ml, Cat. No. 10-094B
Stopper No. 14-640-3.

Fisher Scientific Co.

Kimax Brand Flask, 500ml, Cat. No. 10-096C

Fisher Scientific Co.

Kimax Brand, 25ml, Cat. No. 10-100B. Stopper No. 16.

VWR Scientific Inc. Borosilicate Glass Pasteur Pipets.

Length 5-3/4 in. Cat. No. 14673-010
Length 9 in. Cat. No. 14673-043

VWR Scientific Inc. Disposable Pasteur Pipets.

Length 5-3/4 in. Cat. No. 14672-200
Length 9 in. Cat. No. 14672-380

Fisher Scientific Co.

Corning Magnetic Stirrers, Model - PC353-14-511-200.

VWR Scientific Inc., Stir Bars, Magnetic, Star Head Nalgenc.

Height Y Diameter = 5/16 × 3/8 in., Nalge No, 6600-00-10, Cat. No., 58958-502
Height × Diameter = 9/16 × 3/8 in., Nalge No., 6600-00-14, Cat. No., 58948-513.

Fisher Scientific Co., Kimax Brand, Reusable Glass Culture Tubes.

OD × L
25 × 150, Cat. No. 14-930-10J
Screw Caps, GCMI Size, 24-410, Cat. No. 14-930-15J.
Blue, Epoxy Coated Rack, 28 cm × 21 cm × 10 cm, Cat. No. 14-793-4.

Fisher Scientific Co.

Balance-Mettler, PC Series, Model PC 220.

Matherson

Regulator-Model No., 3104.

Fisher Scientific Co., Racon 113, Freon.

Trichloro-1,2,2, Trifluoroethane.

APPENDIX C

EXPERIMENTAL DEPOSIT RATE DATA OF SELECTED CLAY TREATED AIR FORCE JET FUELS AS EVALUATED FROM THE EXPERIMENTAL COKING APPARATUS

The following deposition rate data were established for selected Air Force jet fuels between 250 and 550°F. Reaction pressures were held constant at 10% above the pseudocritical pressure for each fuel. Test parameters are (1) test temperature in degrees fahrenheit which reflects the fuel deposit temperature at equilibrium during the ECA test, (2) test pressures are the total fuel pressures recorded as pounds per square inch gage, and (3) air flow rate reported as standard cubic centimeters per (SCCM) minute of 80°F air. Deposit rate data are presented as grams per square centimeter-second, as normalized specific deposit rates.
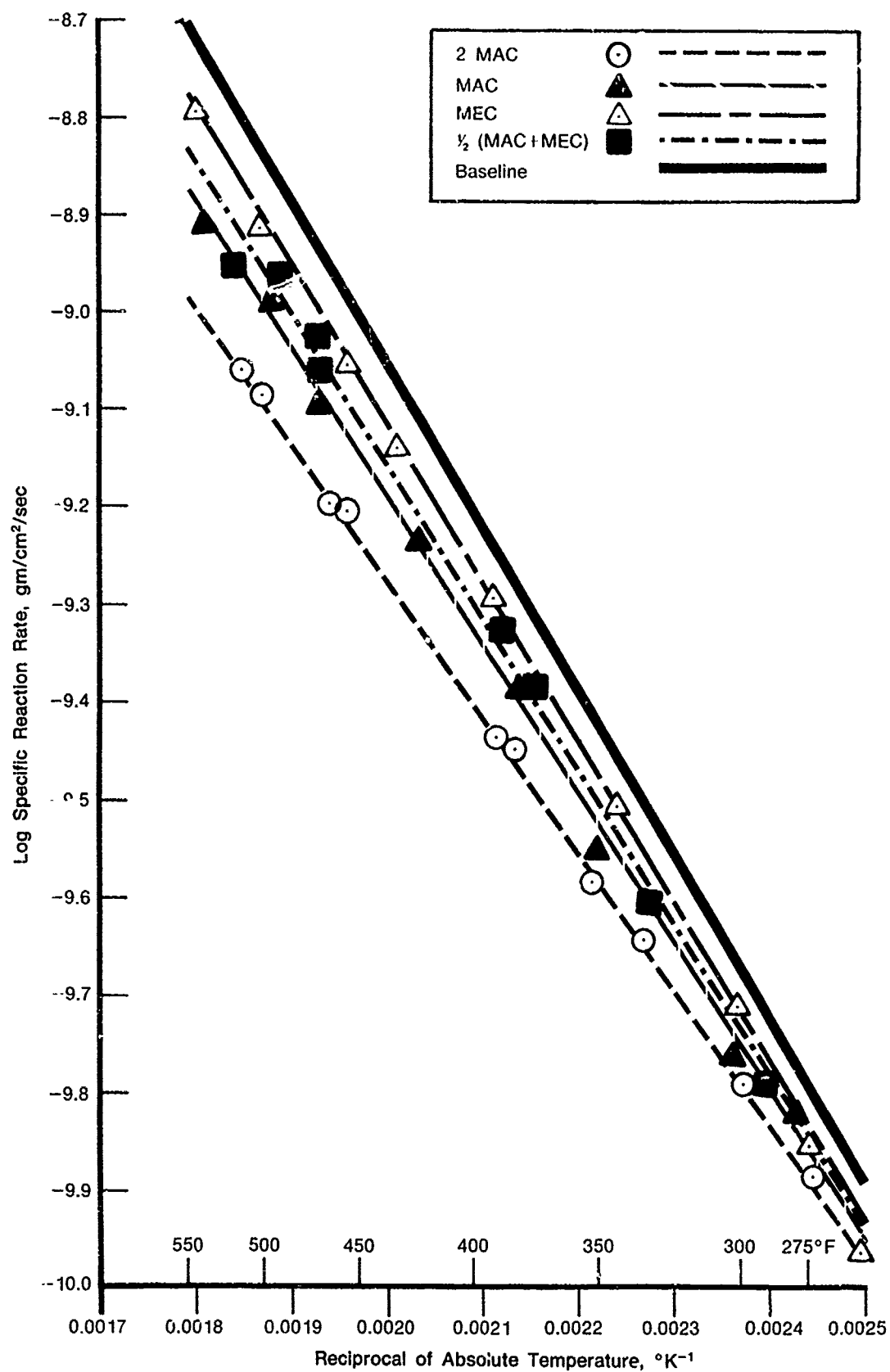
Figure C-1. Variation of Fuel Deposit Rate as a Function of Fuel Temperature: Effect of Antioxidant Additive on Clay Treated JP-8 Fuel
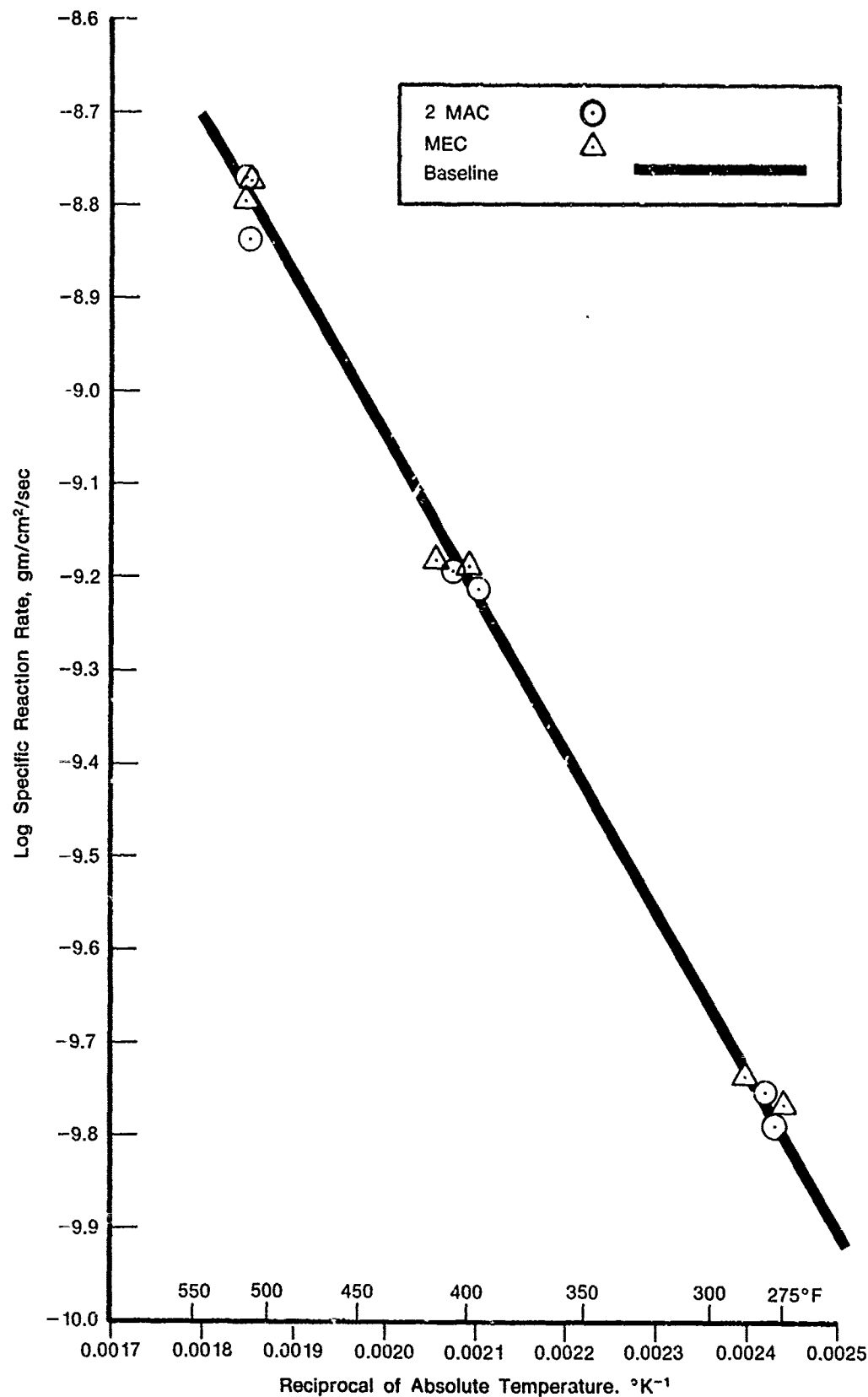
Figure C-2. Variation of Fuel Deposit Rate as a Function of Fuel Temperature: Effect of Corrosion Inhibitor on Clay Treated JP-8 Fuel
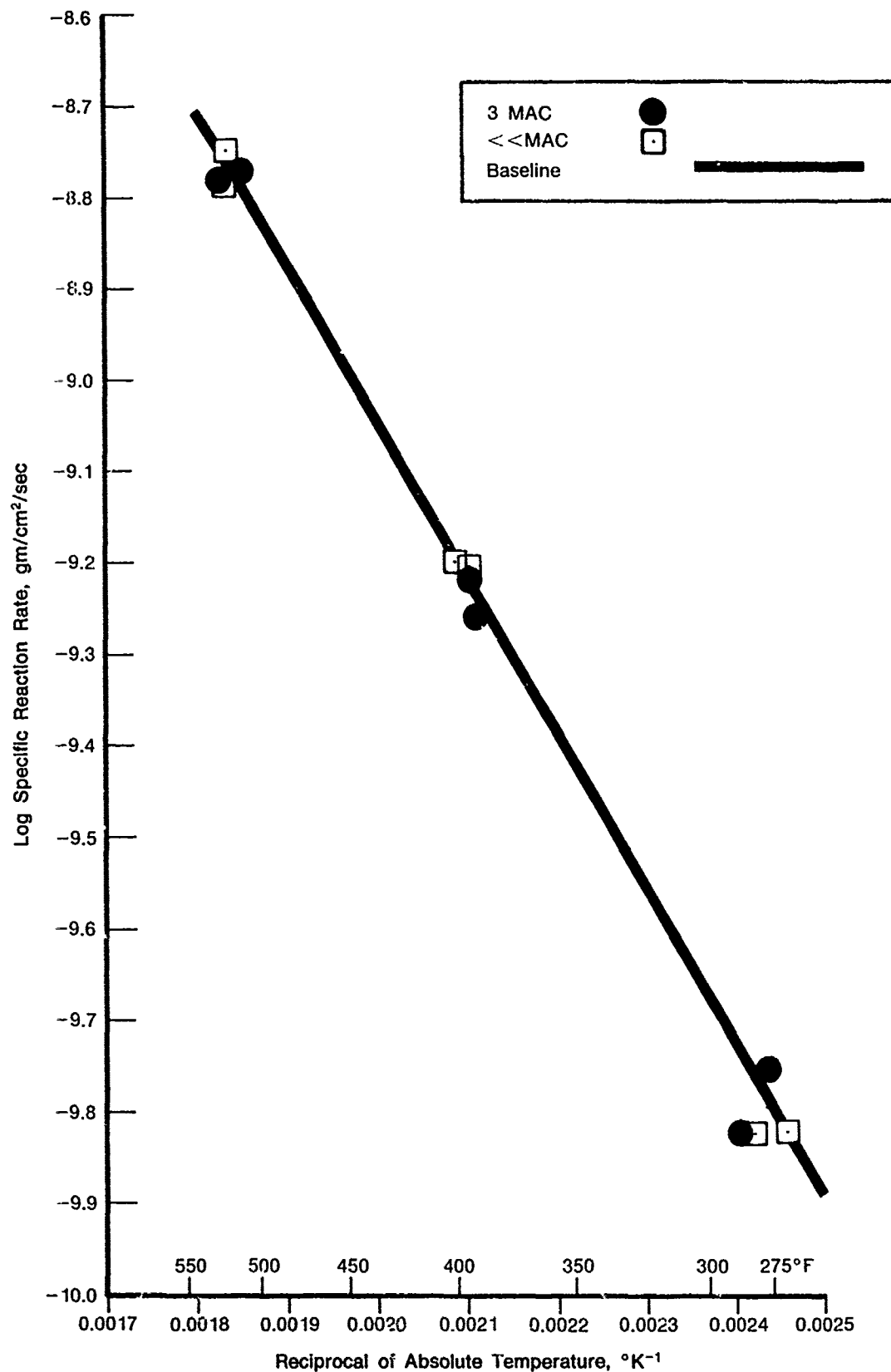
Figure C-3. Variation of Fuel Deposit Rate as a Function of Fuel Temperature: Effect of Fuel System Icing Inhibitor on Clay Treated JP-8 Fuel

39
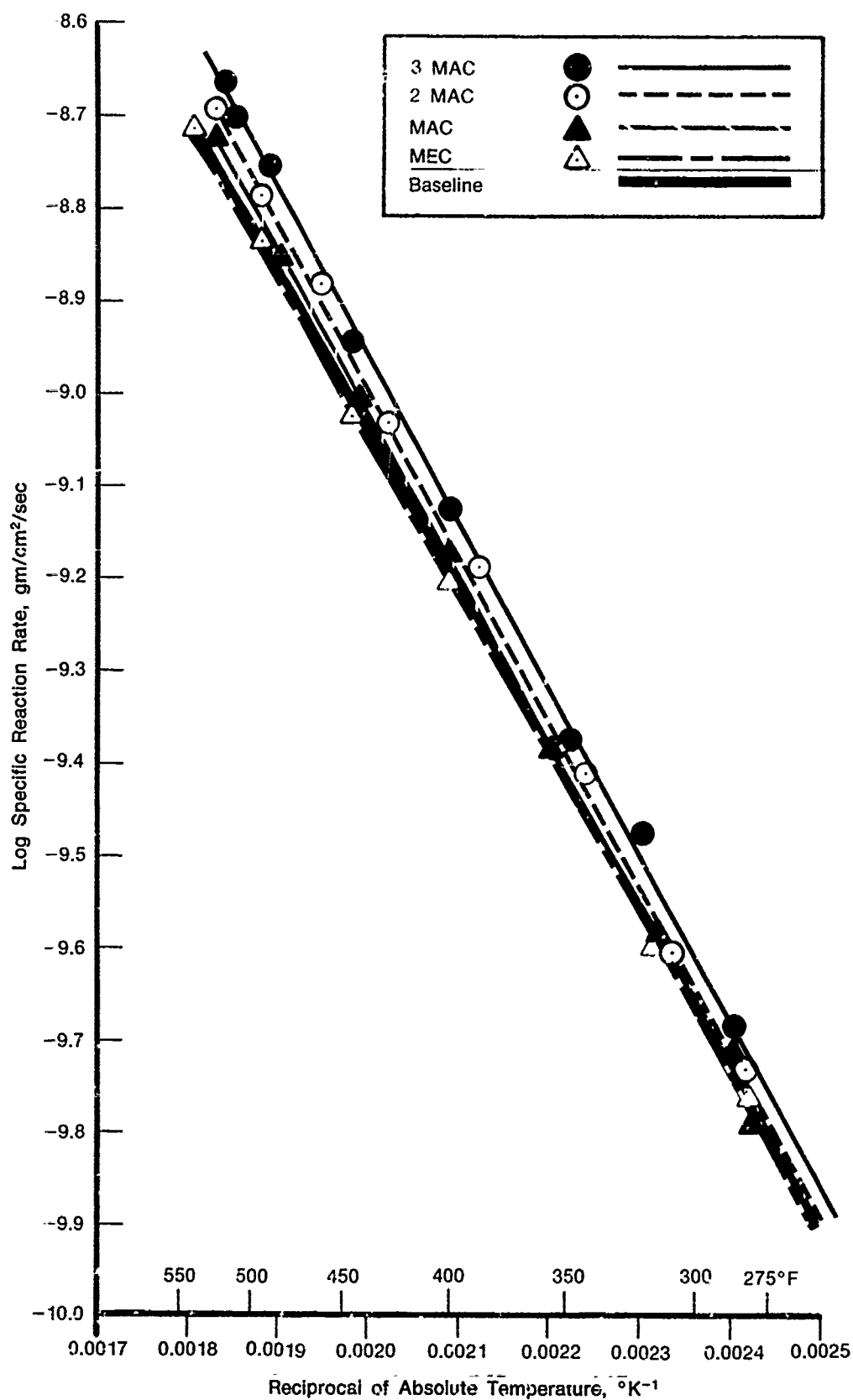
Figure C-4. Variation of Fuel Deposit Rate as a Function of Fuel Temperature: Effect
of Conductivity Additive on Clay Treated JP-8 Fuel

40
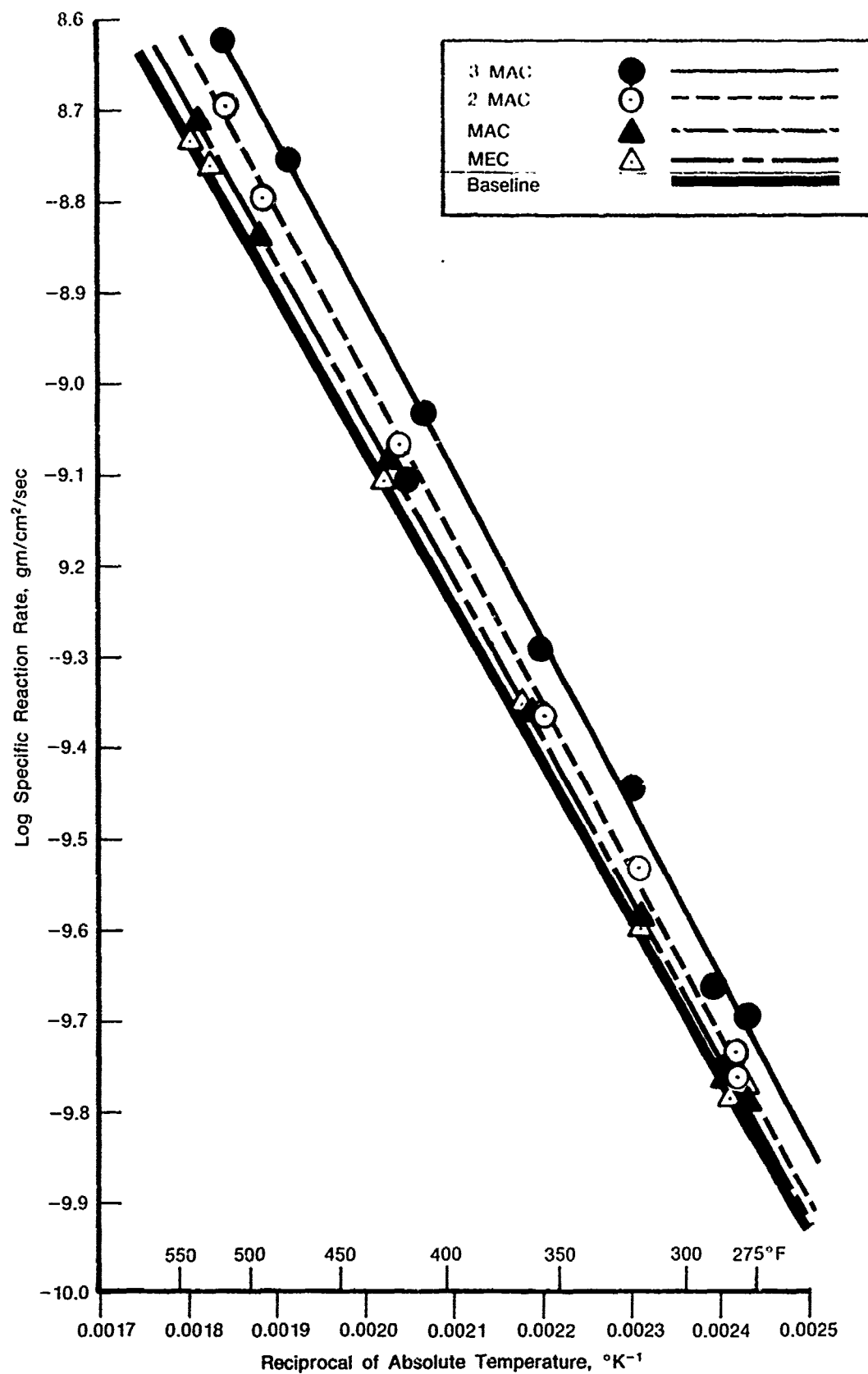
Figure C-5. *Variation of Fuel Deposit Rate as a Function of Fuel Temperature: Effect of Metal Deactivator on Clay Treated JP-8 Fuel*
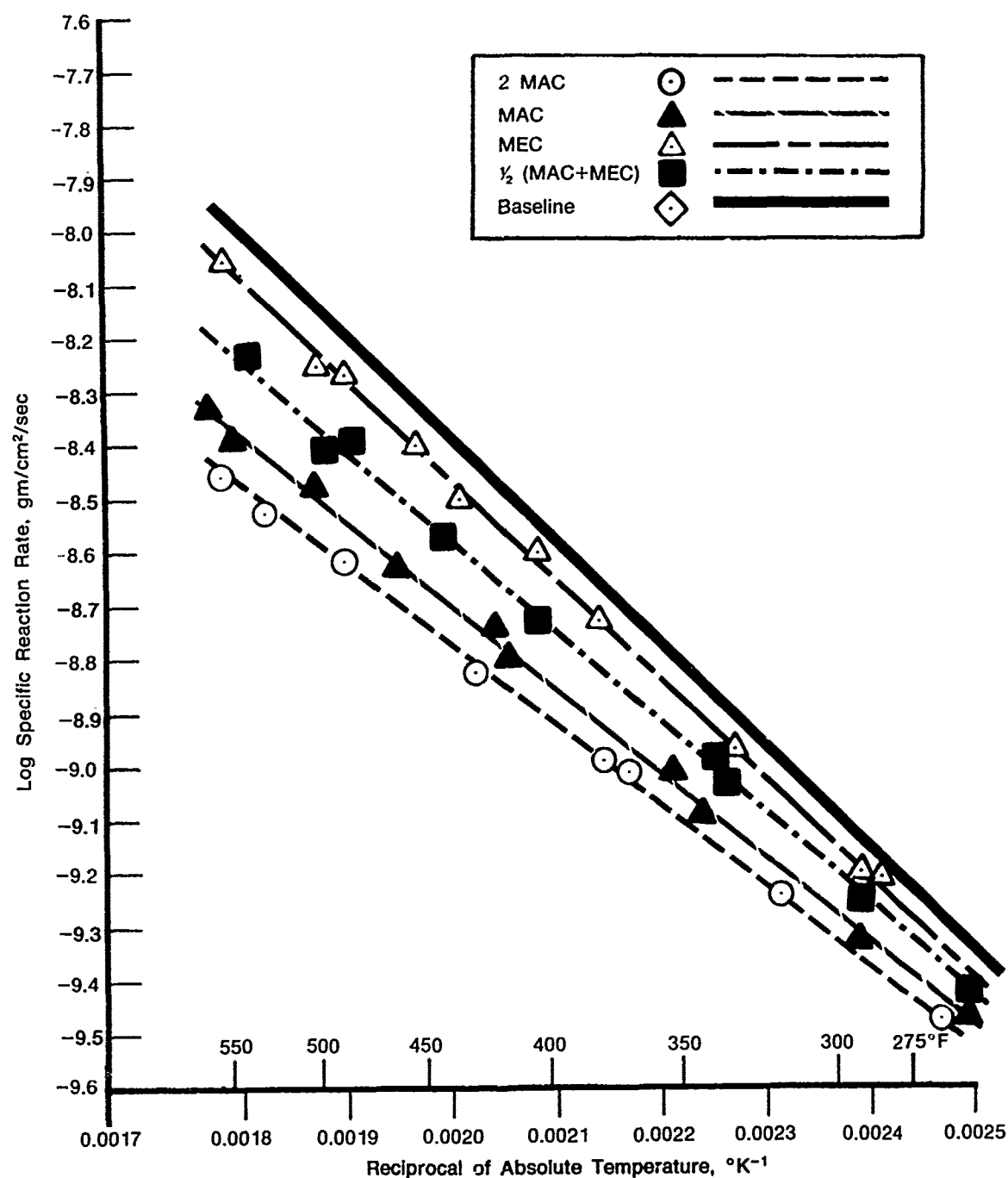
Figure C-6. Variation of Fuel Deposit Rate as a Function of Fuel Temperature: Effect
of Antioxidant Additive on Clay Treated JP-4 Fuel with 10% Total
Aromatics

42
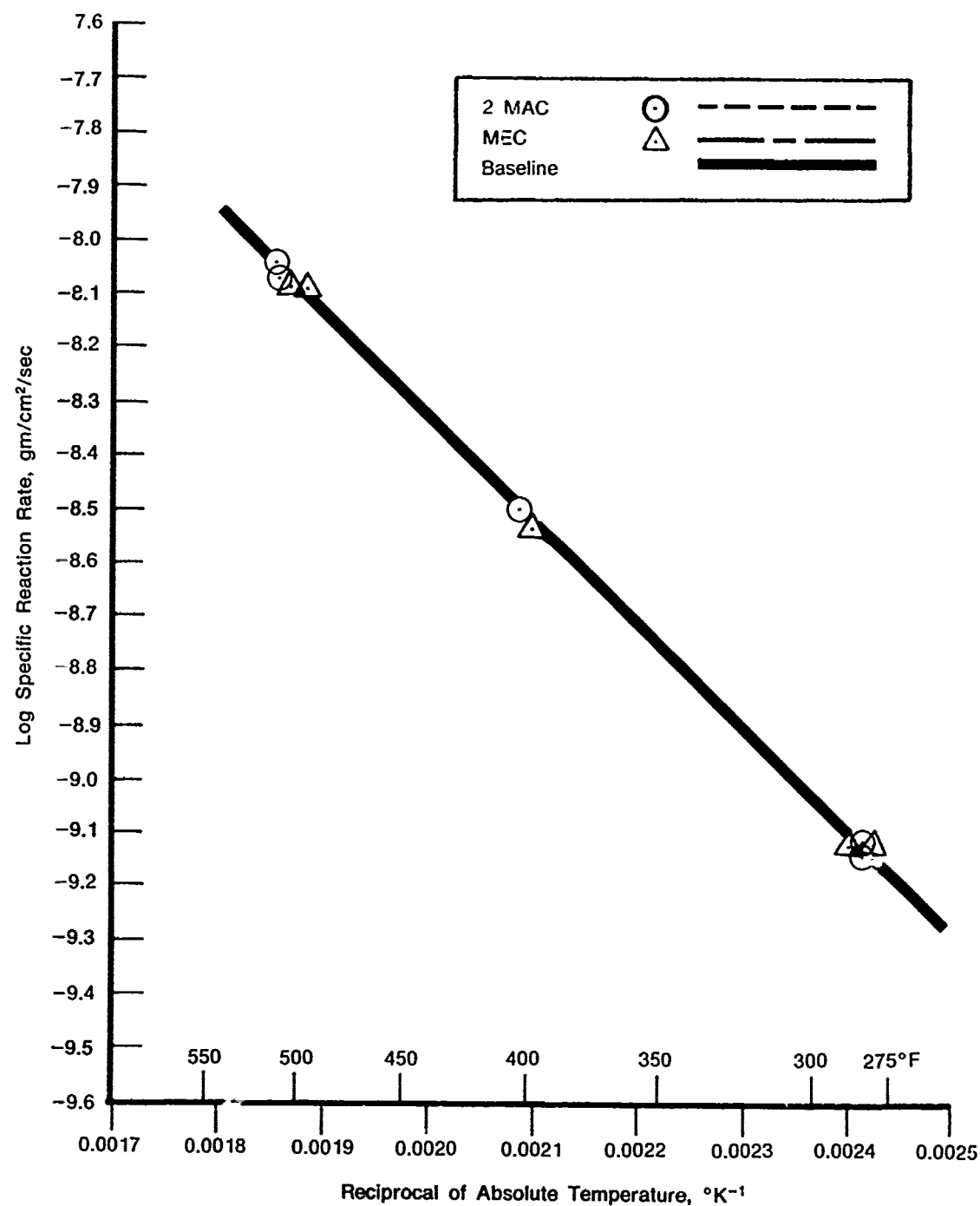
Figure C-7. Variation of Fuel Deposit Rate as a Function of Fuel Temperature: Effect
of Corrosion Inhibitor on Clay Treated JP-4 Fuel with 10% Total
Aromatics

43
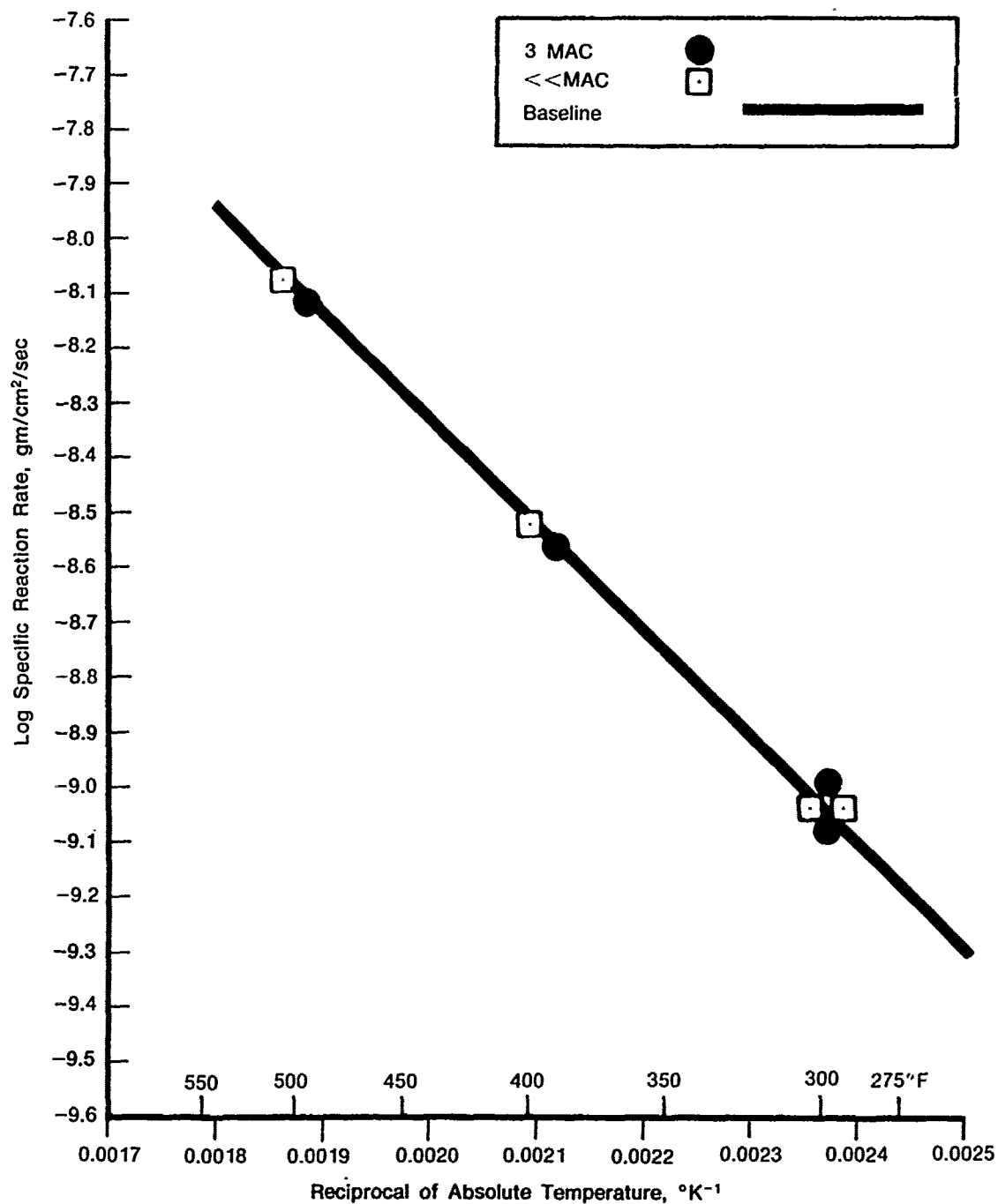
Figure C-8. *Variation of Fuel Deposit Rate as a Function of Fuel Temperature: Effect of Fuel System Icing Inhibitor on Clay Treated JP-4 Fuel with 10% Total Aromatics*

44
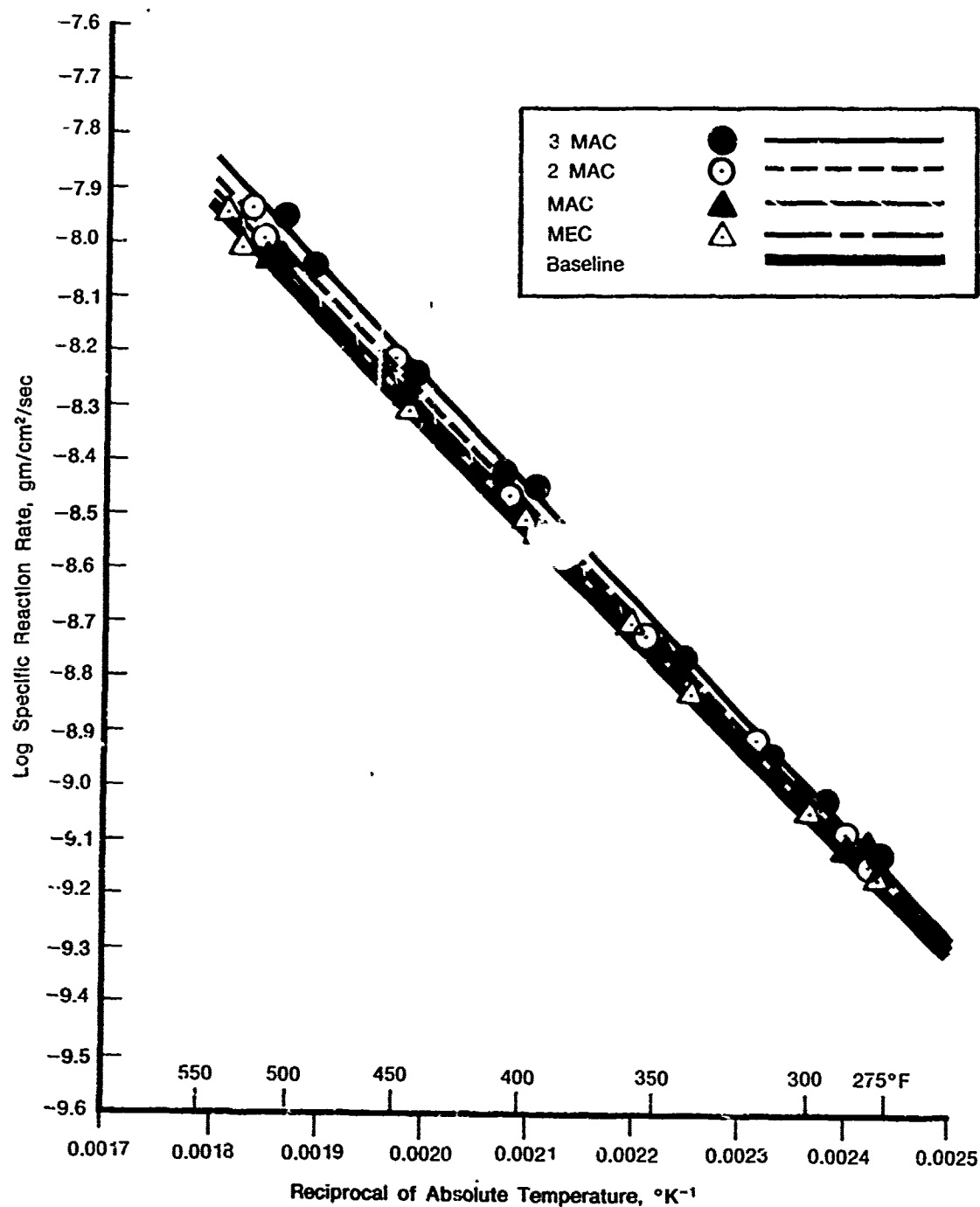
Figure C-9. *Variation of Fuel Deposit Rate as a Function of Fuel Temperature: Effect of Conductivity Additive on Clay Treated JP-4 Fuel with 10% Total Aromatics*

45
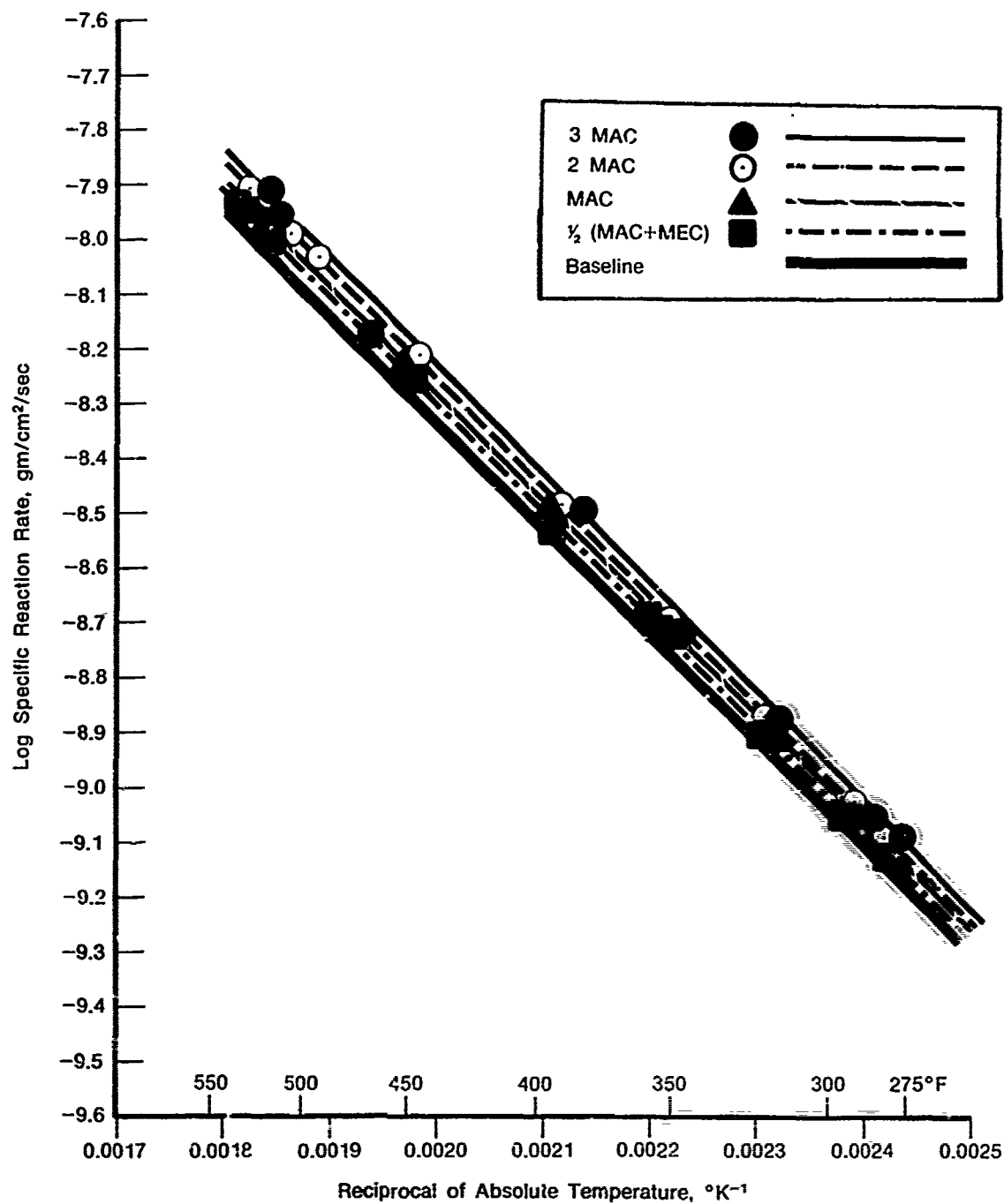
Figure C-10. Variation of Fuel Deposit Rate as a Function of Fuel Temperature: Effect of Metal Deactivator on Clay Treated JP-4 Fuel with 10% Total Aromatics

46
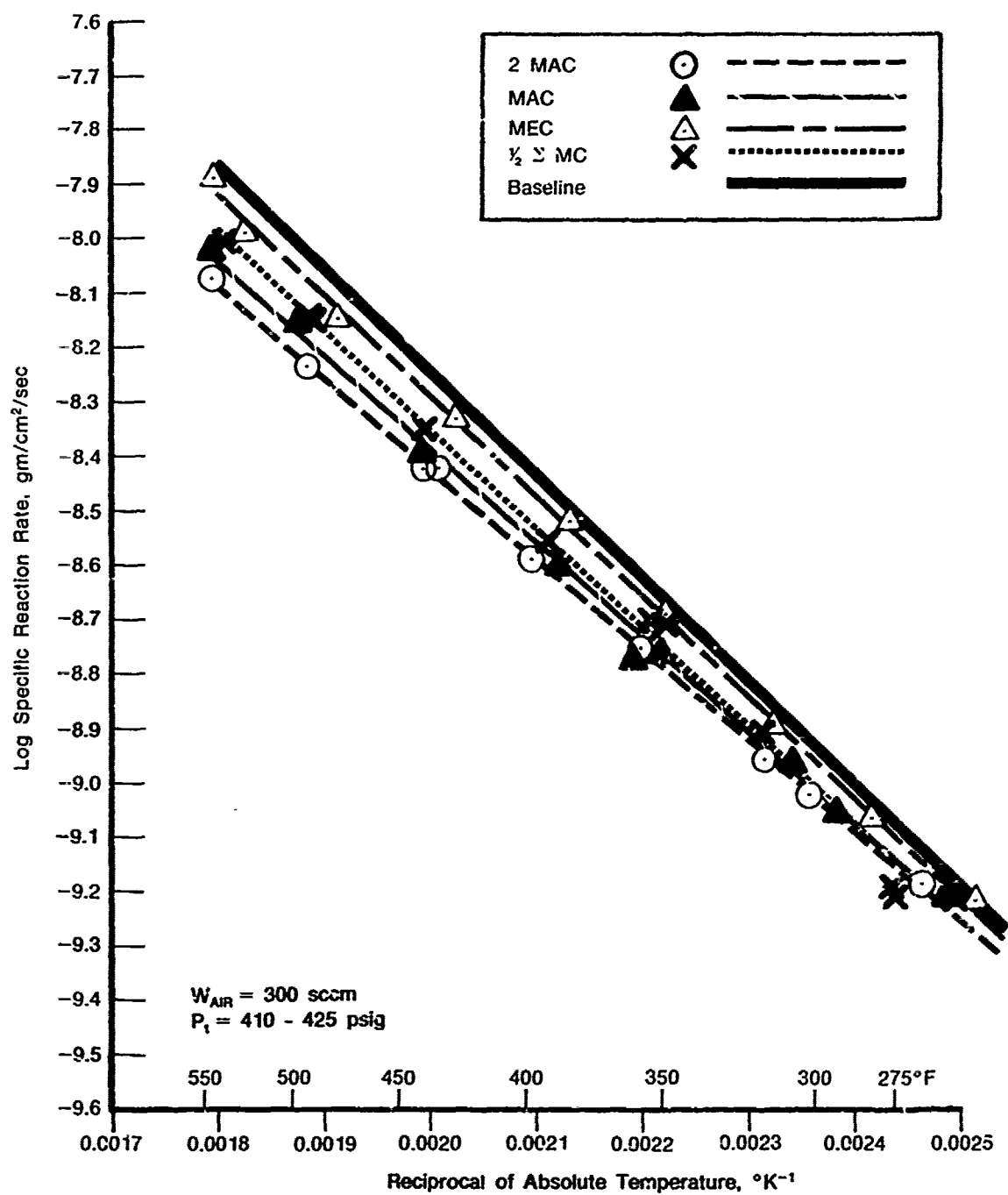
Figure C-11. Variation of Fuel Deposit Rate as a Function of Fuel Temperature
Effect of Antioxidant Additive on Clay Treated JP-4 Fuel with 25%
Total Aromatics

47

Log Specific Reaction Rate, gm/cm²/sec

-7.6
-7.7
-7.8
-7.9
-8.0
-8.1
-8.2
-8.3
-8.4
-8.5
-8.6
-8.7
8.8
-8.9
-9.0
-9.1
-9.2
-9.3
-9.4
-9.5
9.6

2 MAC   ⊙   ------
MAC   ▲
MEC   △
½ Σ MC   ✕
Baseline   ▬▬▬▬▬

W_{AIR} = 300 sccm
P_T = 410 - 425 psig

550   500   450   400   350   300   275°F

0.0017   0.0018   0.0019   0.0020   0.0021   0.0022   0.0023   0.0024   0.0025

Reciprocal of Absolute Temperature, °K⁻¹
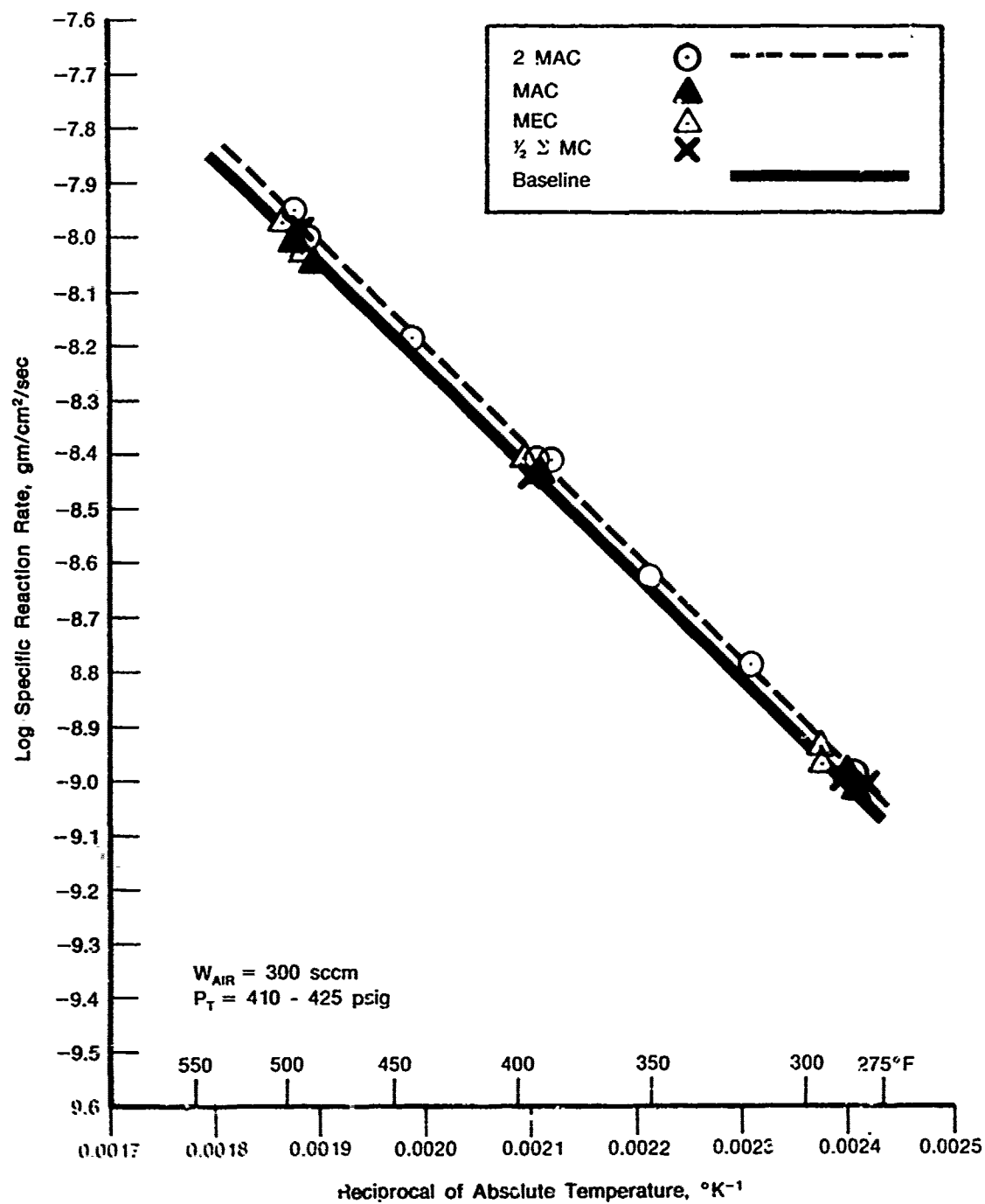
Figure C-12. Variation of Fuel Deposit Rate as a Function of Fuel Temperature: Effect of Corrosion Inhibitor Additive on Clay Treated JP-4 Fuel with 25% Total Aromatics

48
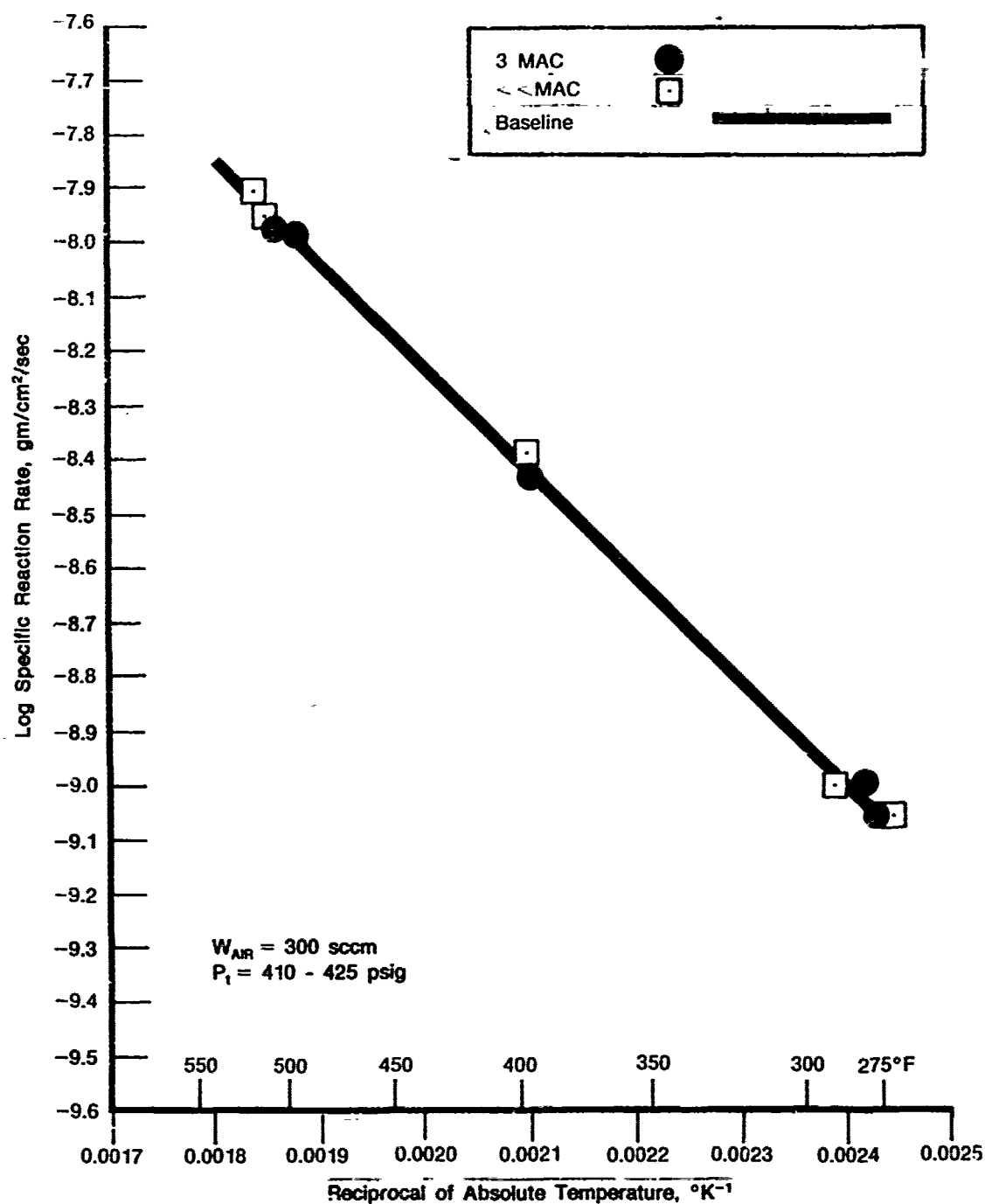
Figure C-13. *Variation of Fuel Deposit Rate as a Function of Fuel Temperature:*
Effect of Fuel System Icing Inhibitor on Clay Treated JP-4 Fuel with
25% Total Aromatics

49
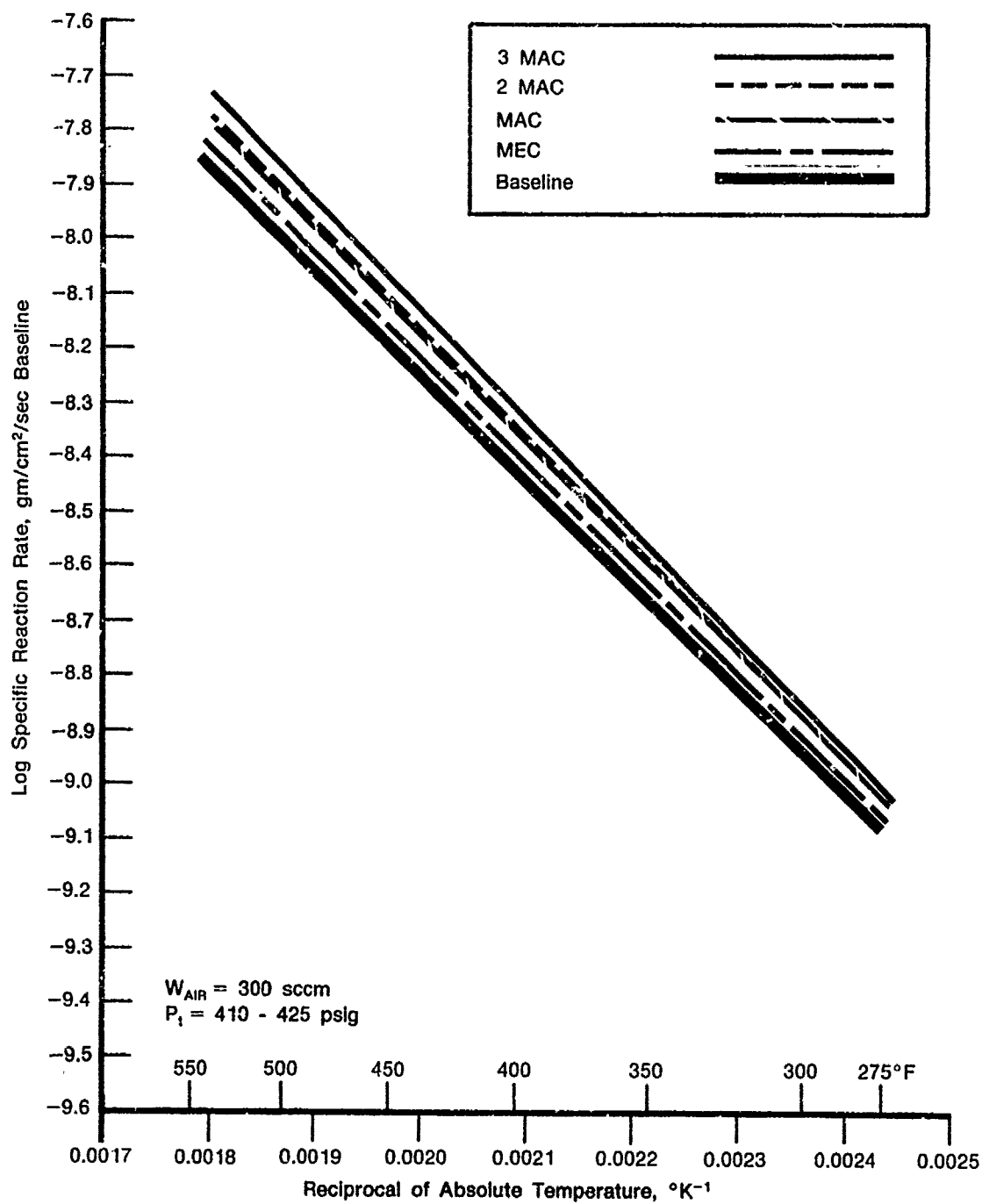
Figure C-14. Variation of Fuel Deposit Rate as a Function of Fuel Temperature: Effect of Conductivity Additive on Clay Treated JP-4 Fuel with 25% Total Aromatics

50
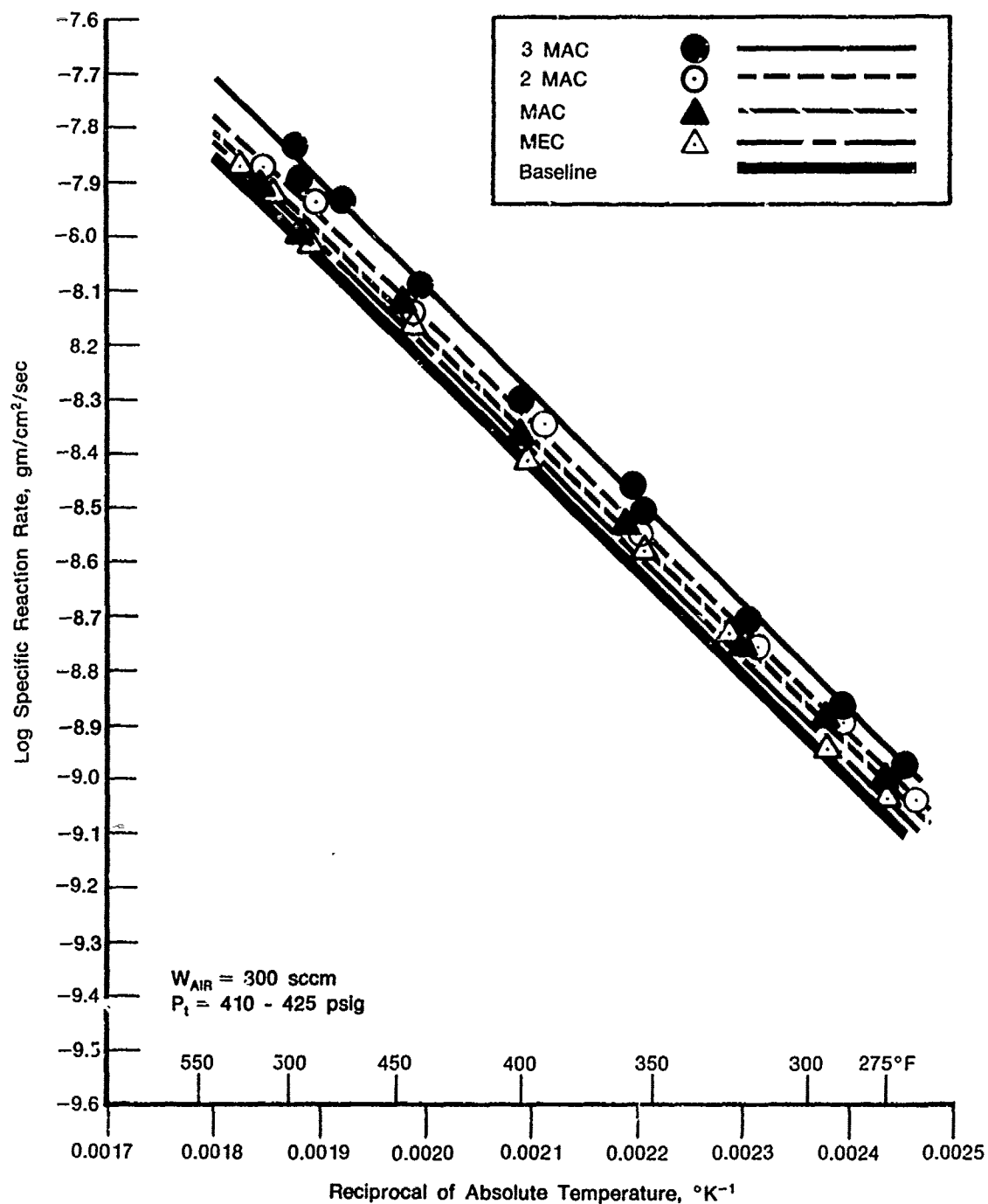
Figure C-15. Variation of Fuel Deposit Rate as a Function of Fuel Temperature. Effect of Metal Deactivator on Gas-Treated JP-4 Fuel with 25% Total Aromatics.
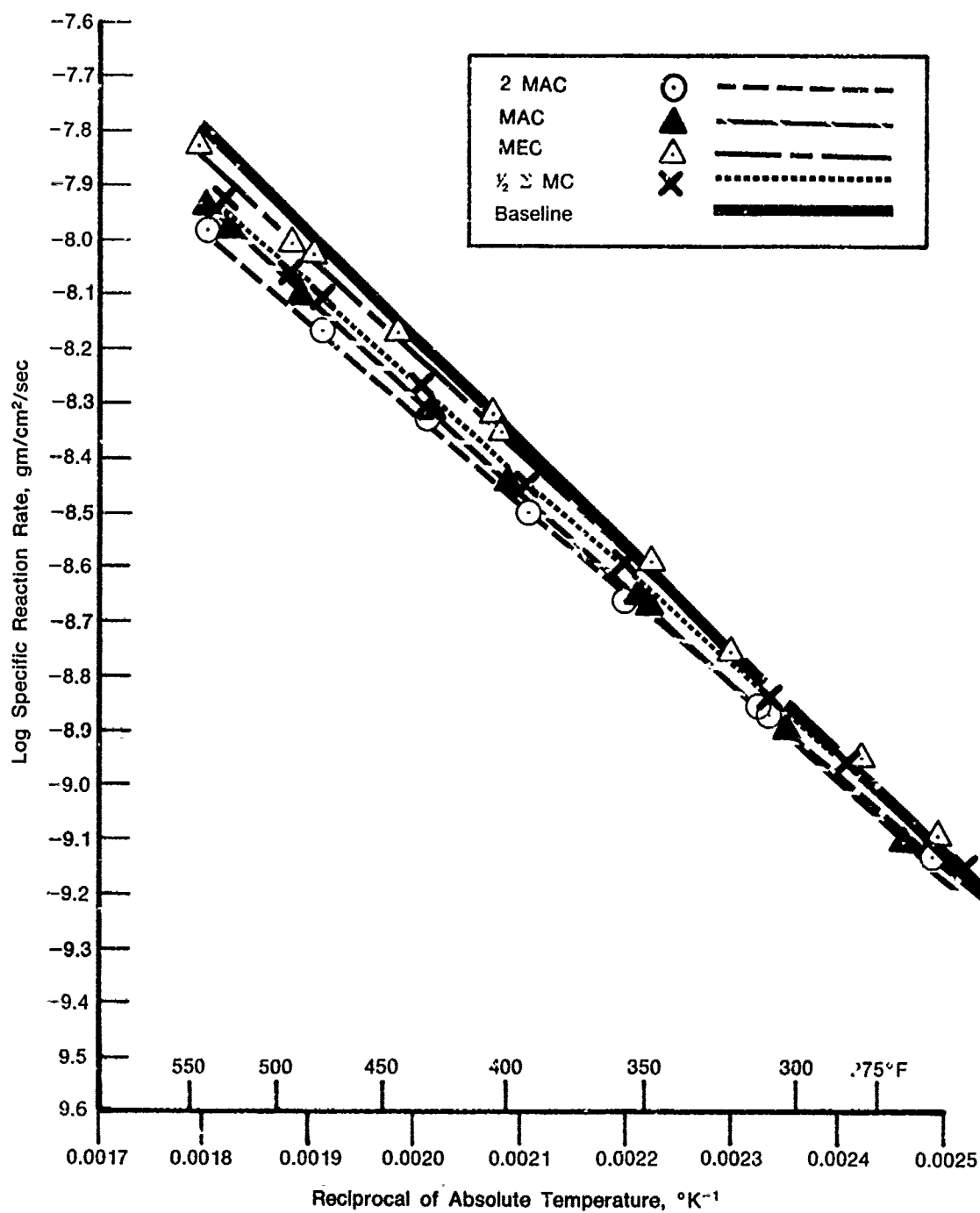
Figure C-16. Variation of Fuel Deposit Rate as a Function of Fuel Temperature: Effect of Antioxidant Additive on Clay Treated JP-4 Fuel with 35% Total Aromatics

52
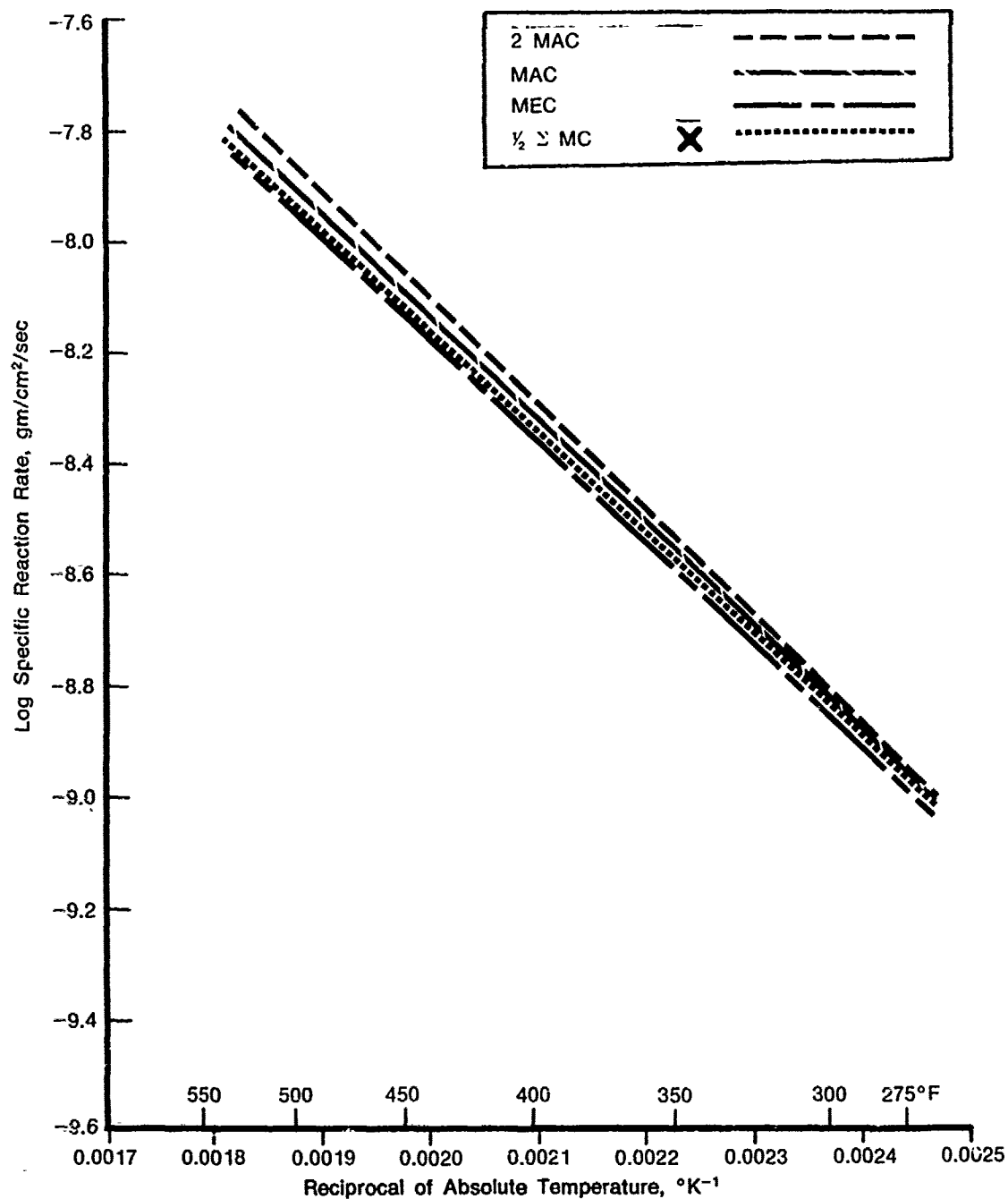
Figure C-17. *Variation of Fuel Deposit Rate as a Function of Fuel Temperature: Effect of Corrosion Inhibitor on Clay Treated JP-4 Fuel with 35% Total Aromatics*
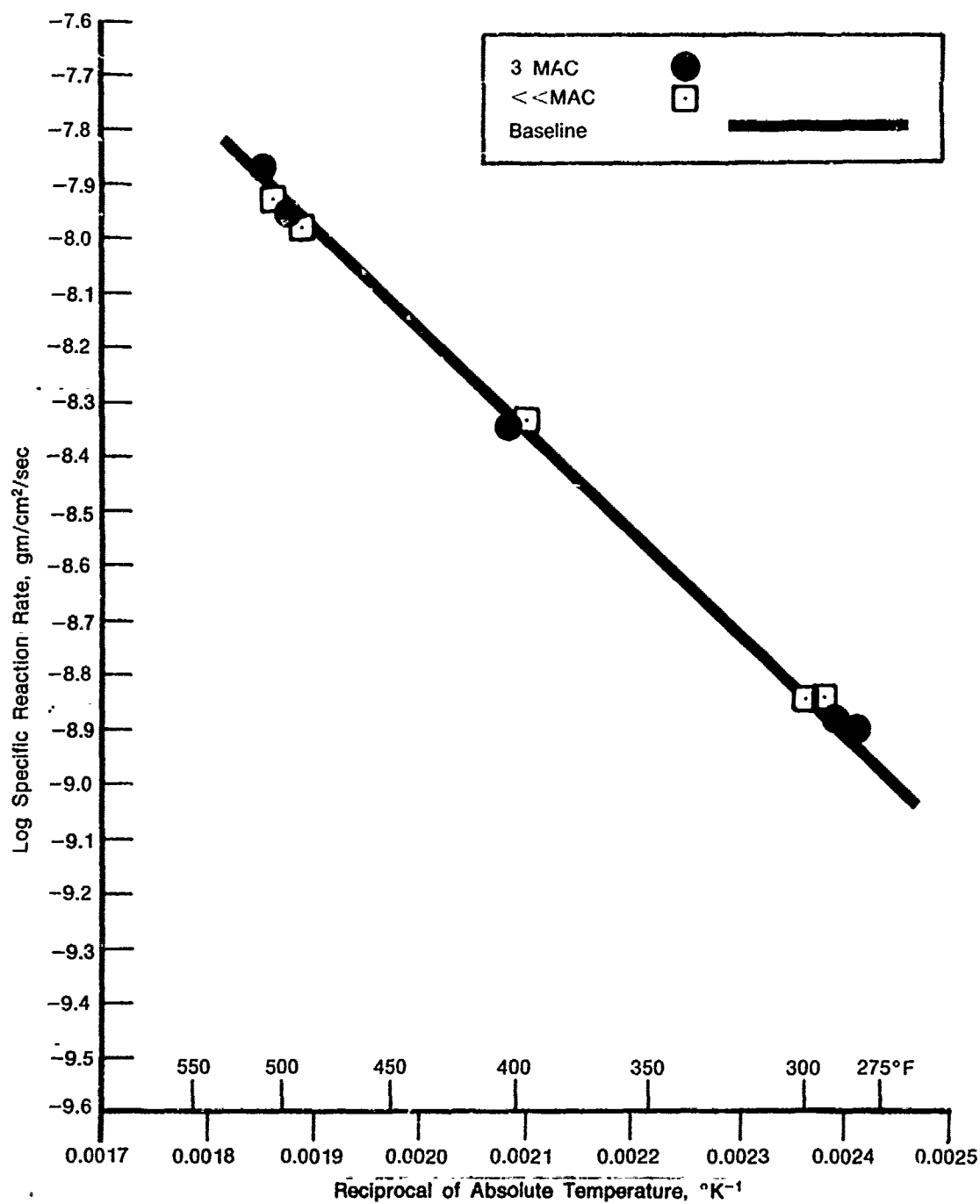
Figure C-18. Variation of Fuel Deposit Rate as a Function of Fuel Temperature:
Effect of Fuel System Icing Inhibitor on Clay Treated JP-4 Fuel with
35% Total Aromatics

54
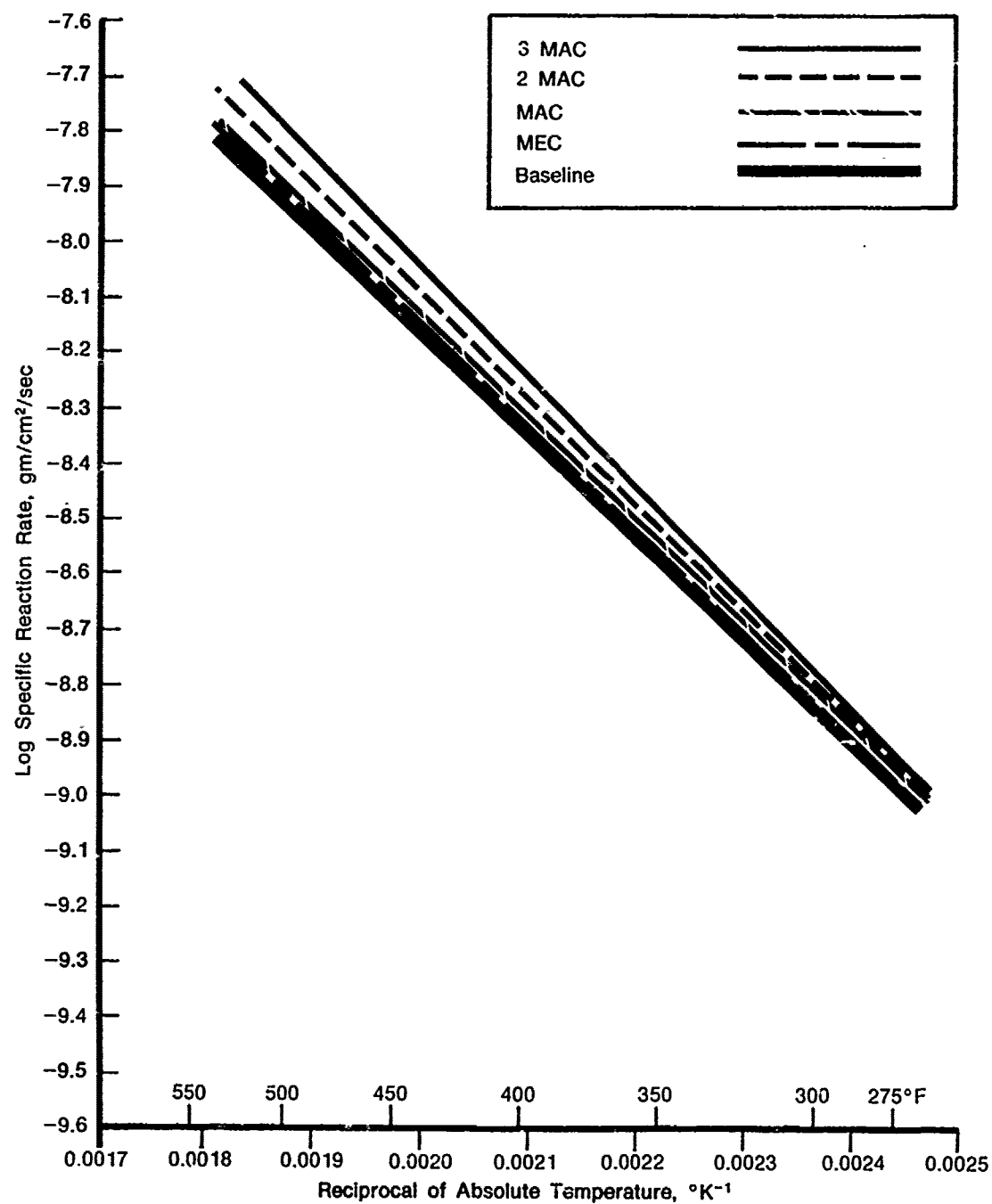
Figure C-19. Variation of Fuel Deposit Rate as a Function of Fuel Temperature: Effect of Conductivity Additive on Clay Treated JP-4 Fuel with 35% Total Aromatics

55
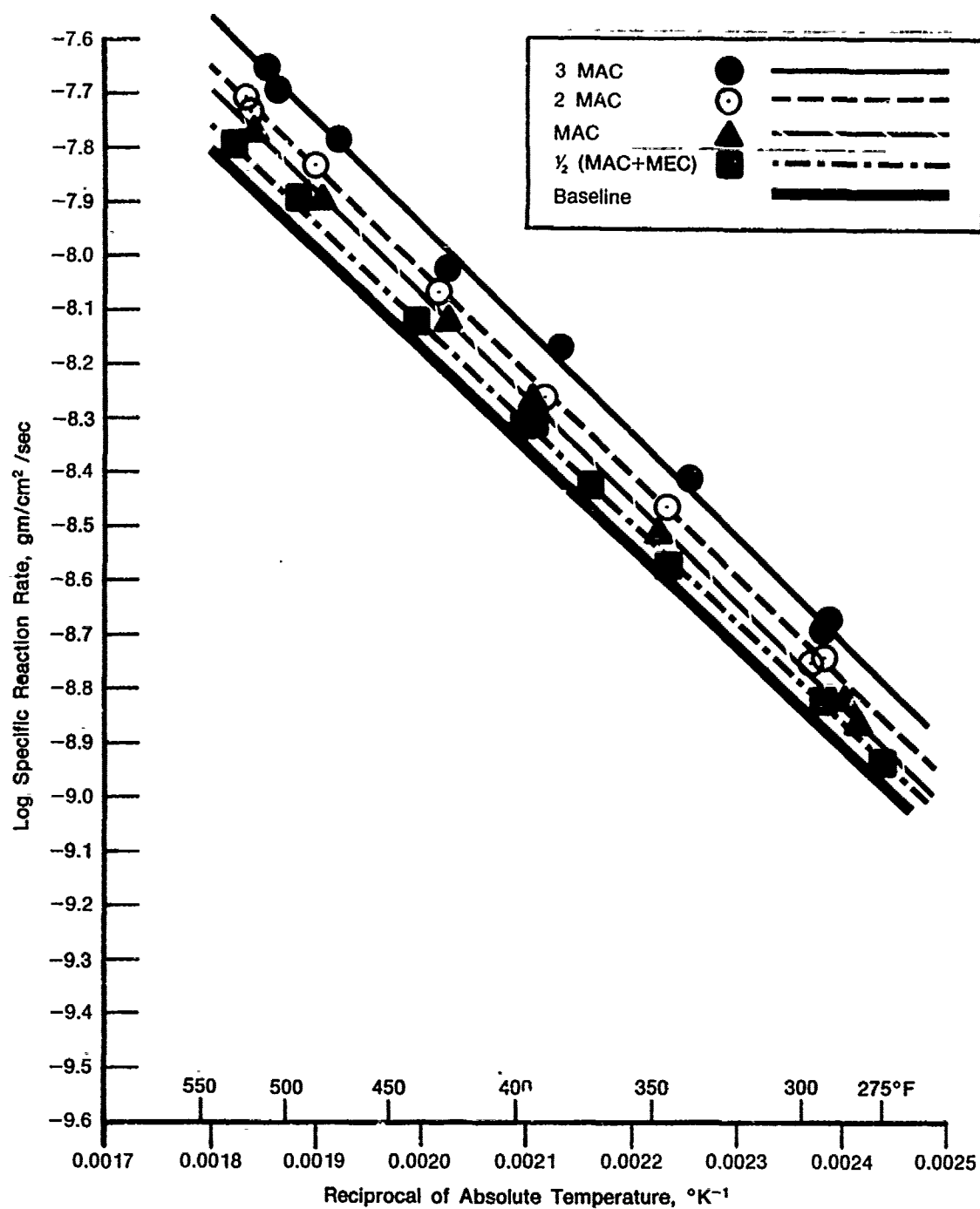
Figure C-20. Variation of Fuel Deposit Rate as a Function of Fuel Temperature: Effect of Metal Deactivator on Clay Treated JP-4 Fuel with 35% Total Aromatics

56

TABLE C-1
CLAY TREATED JP-8 BASELINE

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-10})
260	375	301	1.292
275	374	300	1.507
315	371	302	2.691
359	381	303	3.870
362	384	298	3.870
393	376	298	6.028
440	375	299	8.826
441	380	299	9.687
483	381	301	13.445
539	382	303	17.976

TABLE C-2
CLAY TREATED JP-8, ANTIOXIDANT AT TWICE MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-10})
512	438	300	8.719
501	432	300	8.181
466	436	300	6.351
458	435	301	6.243
390	430	302	3.670
382	439	301	3.552
351	435	303	2.583
333	438	306	2.260
299	435	301	1.615
276	435	302	1.292

TABLE C-3
CLAY TREATED JP-8, ANTIOXIDANT AT MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-10})
531	381	302	12.271
497	385	301	10.226
472	384	300	7.998
423	376	300	5.812
381	375	300	4.090
350	381	300	2.799
302	382	300	1.722
281	380	302	1.507
276	376	301	1.292

TABLE C-4

CLAY TREATED JP-8, ANTIOXIDANT AT
MIDSPECIFICATION CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate $((gm/cm^2\ sec)\ 10^{-10})$
516	375	302	11.087
491	375	300	10.872
473	374	301	8.611
469	370	301	9.365
431	381	305	6.351
388	381	301	4.736
376	376	299	4.090
330	375	299	2.476
291	374	299	1.615

TABLE C-5

CLAY TREATED JP-8, ANITOXIDANT AT
MINIMUM EFFECTIVE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate $((gm/cm^2\ sec)\ 10^{-10})$
536	380	301	16.038
502	380	300	12.163
457	381	300	8.719
433	375	300	7.212
393	375	301	5.059
341	376	302	3.014
300	374	302	1.938
278	373	301	1.399
261	374	303	1.076

TABLE C-6

CLAY TREATED JP-8, CORROSION INHIBITOR
AT MINIMUM EFFECTIVE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate $((gm/cm^2\ sec)\ 10^{-10})$
279	376	301	1.722
291	374	301	1.830
400	381	300	6.459
415	380	300	6.566
515	379	300	16.038
511	380	301	16.899

TABLE C-7
CLAY TREATED JP-8, CORROSION INHIBITOR AT TWICE MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻¹⁰)
375	375	301	1.615
376	376	301	1.722
377	377	301	6.135
376	376	301	6.351
374	374	300	14.639
381	381	300	17.007

TABLE C-8
CLAY TREATED JP-8, ICING INHIBITOR AT THREE TIMES MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻¹⁰)
280	376	301	1.722
289	375	302	1.615
394	381	300	5.490
396	380	300	6.028
526	376	300	16.469
513	378	296	16.792

TABLE C-9
CLAY TREATED JP-8, ICING INHIBITOR AT LOW RELATIVE CONCENTRATION RELATIVE TO MAXIMUM

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻¹⁰)
273	375	301	1.5069
284	376	301	1.5069
396	377	298	6.2431
402	374	298	6.3507
521	371	300	17.76
520	381	298	16.361

TABLE C-10
CLAY TREATED JP-8, CONDUCTIVITY ADDITIVE AT MINIMUM EFFECTIVE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻¹⁰)
283	375	300	1.722
317	376	301	2.476
400	375	300	6.243
446	376	299	9.365
497	380	299	14.531
535	381	298	19.375

TABLE C-11
CLAY TREATED JP-8, CONDUCTIVITY ADDITIVE
AT MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-10})
283	375	301	1.615
289	380	300	1.937
316	380	300	2.583
355	380	299	4.090
400	381	298	6.674
443	376	298	9.795
485	376	300	13.993
521	372	301	18.837

TABLE C-12
CLAY TREATED JP-8, CONDUCTIVITY ADDITIVE
AT TWICE MAXIMUM ALLOWABLE CONCENTRA-
TION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-10})
286	376	301	1.830
310	375	302	2.476
343	376	301	3.875
389	390	300	6.458
431	380	300	9.257
463	380	301	13.132
497	376	301	16.361
523	375	300	20.021

TABLE C-13
CLAY TREATED JP-8, CONDUCTIVITY ADDITIVE
AT THREE TIMES MAXIMUM
ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-10})
289	375	302	2.045
322	371	301	3.337
348	371	301	4.198
398	373	301	7.535
447	380	302	11.302
488	380	303	17.653
511	376	303	19.590
516	374	301	21.529

TABLE C-14
CLAY TREATED JP-8, METAL DEACTIVATOR AT THREE TIMES MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-10})
527	376	300	27.233
511	379	300	23.681
474	380	300	17.545
408	381	301	9.257
358	381	299	5.059
321	382	298	3.552
291	383	299	2.153
281	381	300	2.045

TABLE C-15
CLAY TREATED JP-8, METAL DEACTIVATOR AT MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-10})
528	379	300	19.483
494	381	301	14.424
428	381	302	8.181
362	381	303	4.306
319	381	301	2.583
289	381	300	1.722
280	382	300	1.615

TABLE C-16
CLAY TREATED JP-8, METAL DEACTIVATOR AT TWICE MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-10})
511	379	300	9.236
492	380	300	13.146
419	381	301	8.611
418	382	302	7.858
358	381	303	4.306
319	381	304	2.906
285	380	300	1.722
284	376	300	1.830

TABLE C-17
CLAY TREATED JP-4 BASELINE

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
257	424	300	0.474
279	426	299	0.689
329	425	299	1.249
374	426	299	2.368
401	424	300	2.928
435	427	300	4.779
480	425	299	6.114
482	427	300	6.415
535	426	300	11.410

TABLE C-18
CLAY TREATED JP-4 WITH 10% AROMATICS, ANTIOXIDANT AT MINIMUM EFFECTIVE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
283	427	295	0.614
278	425	295	0.614
321	425	296	1.055
369	423	295	1.862
391.5	425	296	2.508
421	426	294	3.143
440	425	296	4.004
472	426	295	5.425
485	427	296	5.500
532	425	295	8.751

TABLE C-19.
CLAY TREATED JP-4 WITH 10% AROMATICS, ANTIOXIDANT AT TWICE MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate $((gm/cm^2\ sec)\ 10^{-9})$
533	425	300	3.713
509	425	300	2.982
471	425	301	2.422
416	427	301	1.475
366	423	299	1.001
357	422	300	0.958
307	424	300	0.576
258	421	299	0.334

TABLE C-20
CLAY TREATED JP-4 WITH 10% AROMATICS, ANTIOXIDANT AT MIDSPECIFICATION CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate $((gm/cm^2\ sec)\ 10^{-9})$
519	425	300	5.888
480	429	300	3.961
472	428	302	4.004
428	427	301	2.659
391	428	301	1.841
327	425	301	1.012
325	425	302	0.926
283	425	301	0.560
252	425	303	0.398

TABLE C-21
CLAY TREATED JP-4 WITH 10% AROMATICS, ANTIOXIDANT AT MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate $((gm/cm^2\ sec)\ 10^{-9})$
538	425	301	4.628
527	423	300	4.069
483	424	300	3.315
449	424	300	2.314
408	422	300	1.819
403	423	302	1.572
342	423	301	0.969
333	422	300	0.797
233	424	300	0.463
253	423	300	0.334

TABLE C-22
CLAY TREATED JP-4 WITH 10% AROMATICS, CORROSION INHIBITOR AT TWICE MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
285	419	305	0.710
287	423	302	0.732
400	422	300	3.078
509	425	298	8.493
510	419	300	8.956

TABLE C-23
CLAY TREATED JP-4 WITH 10% AROMATICS, CORROSION INHIBITOR AT MINIMUM EFFECTIVE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
283	422	301	0.743
290	426	302	0.732
399	419	304	2.809
497	422	300	8.041
506	425	300	8.008

TABLE C-24
CLAY TREATED JP-4 WITH 10% AROMATICS, ICING INHIBITOR AT LOW RELATIVE CONCENTRATION RELATIVE TO MAXIMUM

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
296	422	305	0.926
306	426	304	0.9150
399	425	300	3.078
490	421	304	6.652
504	419	300	8.546

TABLE C-25
CLAY TREATED JP-4 WITH 10% AROMATICS, ICING INHIBITOR AT THREE TIMES MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
300	423	300	0.829
302	420	298	0.990
393	418	304	2.723
497	419	301	7.330

TABLE C-26
CLAY TREATED JP-4 WITH 10% AROMATICS, CONDUCTIVITY ADDITIVE AT THREE TIMES MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
409	426	301	3.778
508	427	299	11.194
492	421	296	9.052
444	423	296	5.726
396	423	300	3.541
342	429	302	1.722
312	421	305	1.141
296	419	303	0.926
280	422	302	0.753

TABLE C-27
CLAY TREATED JP-4 WITH 10% AROMATICS, CONDUCTIVITY ADDITIVE AT TWICE MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
521	419	302	11.485
516	423	301	10.118
454	427	300	6.071
404	426	303	3.348
354	427	301	1.884
317	428	302	1.227
289	419	300	0.829
282	426	302	0.721

TABLE C-28
CLAY TREATED JP-4 WITH 10% AROMATICS, CONDUCTIVITY ADDITIVE AT MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
512	426	301	9.182
509	421	302	9.397
449	420	301	5.231
396	425	300	2.917
349	423	300	1.765
304	424	299	0.980
290	423	302	0.764
284	419	301	0.753

TABLE C-29*
CLAY TREATED JP-4 WITH 10% AROMATICS,
CONDUCTIVITY ADDITIVE AT MINIMUM
EFFECTIVE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-9})
533	419	304	11.431
529	421	299	9.752
449	420	298	4.854
398	426	304	3.100
360	427	300	1.991
340	427	301	1.453
300	431	300	0.893
279	419	301	0.689

TABLE C-30
CLAY TREATED JP-4 WITH 10% AROMATICS,
METAL DEACTIVATOR AT ONE-HALF MAXIMUM
ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-9})
534	424	303	11.776
518	427	300	9.709
450	421	299	5.554
395	424	298	2.982
361	426	299	2.067
356	423	300	1.970
322	422	301	1.249
296	426	301	0.8719
283	427	301	0.7320

TABLE C-31
CLAY TREATED JP-4 WITH 10% AROMATICS,
METAL DEACTIVATOR AT MAXIMUM
ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-9})
526	427	300	11.399
519	421	300	10.839
456	425	300	5.845
396	424	301	3.294
351	426	301	1.873
317	421	300	1.238
292	420	302	0.8719
282	422	300	0.7535

TABLE C-32·
CLAY TREATED JP-4 WITH 10% AROMATICS, METAL DEACTIVATOR AT TWICE MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-9})
286	425	300	0.818
293	424	301	0.947
321	429	301	1.345
352	428	301	2.024
391	425	300	3.294
449	421	297	6.071
499	422	297	9.397
505	421	300	10.398
528	426	301	12.217

TABLE C-33·
CLAY TREATED JP-4 WITH 10% AROMATICS, METAL DEACTIVATOR AT THREE TIMES MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-9})
383	416	300	3.218
280	422	300	0.818
288	423	301	0.883
316	429	302	1.335
469	416	300	6.749
511	425	300	11.087
518	423	298	12.443
347	424	299	1.959

TABLE C-34
CLAY TREATED JP-4 WITH 25% AROMATICS BASELINE

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-8})
393	484	301	0.340
260	484	302	0.065
263	482	300	0.067
313	485	299	0.141
362	489	298	0.250
431	486	302	0.545
436	482	299	0.589
492	481	298	0.868
513	483	301	1.137
540	482	300	1.429

TABLE C-35
CLAY TREATED JP-4 WITH 25% AROMATICS, ANTIOXIDANT AT MINIMUM EFFECTIVE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-8})
543	493	302	1.282
527	495	301	1.016
482	490	301	7.115
429	491	301	4.704
385	496	300	3.014
350	491	300	2.024
315	486	303	1.259
285	487	300	0.861
256	493	304	0.603

TABLE C-36
CLAY TREATED JP-4 WITH 25% AROMATICS, ANTIOXIDANT AT MIDSPECIFICATION CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-9})
537	493	300	9.860
492	492	293	7.158
495	490	295	7.201
443	495	299	4.456
392	489	301	2.788
355	490	300	1.970
349	490	300	1.948
280	495	302	0.635
319	494	304	1.238
261	493	300	0.603
275	495	299	0.614

TABLE C-37
CLAY TREATED JP-4 WITH 25% AROMATICS, ANTIOXIDANT AT MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-9})
545	491	301	9.418
501	490	302	6.996
444	487	304	4.047
389	485	306	2.497
352	490	310	1.722
362	491	300	1.579
309	491	303	1.08⁻
296	495	301	0.8826
265	491	300	0.5135

TABLE C-38
CLAY TREATED JP-4 WITH 25% AROMATICS, ANTIOXIDANT AT TWICE MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
545	491	300	8.450
496	496	301	5.612
443	483	304	3.757
437	489	304	3.800
399	490	310	2.551
359	493	306	1.744
318	491	302	1.152
304	487	302	0.947
271	489	299	0.644

TABLE C-39
CLAY TREATED JP-4 WITH 25% AROMATICS, CORROSION INHIBITOR AT TWICE MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
501	415	303	11.184
493	421	302	10.28
446	416	300	6.523
395	412	302	3.896
389	413	301	3.875
354	414	298	2.336
320	415	300	1.636
286	418	297	1.033

TABLE C-40
CLAY TREATED JP-4 WITH 35% AROMATICS, CORROSION INHIBITOR AT MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
501	410	302	9.784
491	410	302	8.945
394	414	303	3.692
291	418	310	1.033
289	411	305	0.9688

TABLE C-41
CLAY TREATED JP-4 WITH 25% AROMATICS, CORROSION INHIBITOR AT MIDSPECIFICATION CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-9})
497	414	302	10.204
496	415	300	9.784
398	410	301	3.584
292	410	302	1.001
285	410	303	0.920

TABLE C-42
CLAY TREATED JP-4 WITH 25% AROMATICS, CORROSION INHIBITOR AT MINIMUM EFFECTIVE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-9})
504	412	302	10.538
496	414	300	9.375
399	413	301	3.875
298	415	302	1.152
298	409	301	1.066

TABLE C-43
CLAY TREATED JP-4 WITH 25% AROMATICS, ICING INHIBITOR AT LOW RELATIVE CONCENTRATION RELATIVE TO MAXIMUM

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-9})
277	415	302	8.719
294	412	301	9.795
399	408	306	40.365
522	405	306	124.43
516	410	304	105.92

TABLE C-44
CLAY TREATED JP-4 WITH 25% AROMATICS, ICING INHIBITOR AT THREE TIMES MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-9})
233	420	302	0.8826
285	421	299	1.001
398	421	300	3.692
499	416	300	10.280
509	412	302	10.516

TABLE C-45
CLAY TREATED JP-4 WITH 25% AROMATICS, CONDUCTIVITY ADDITIVE AT THREE TIMES MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate $((gm/cm^2 sec)\ 10^{-9})$
292	405	300	1.152
299	402	300	1.270
325	412	301	1.937
361	404	303	2.917
362	403	299	3.078
405	408	301	5 091
448	407	297	7.610
491	406	299	12.185
497	404	300	12.077

TABLE C-46
CLAY TREATED JP-4 WITH 25% AROMATICS. CONDUCTIVITY ADDITIVE AT TWICE MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate $((gm/cm^2 sec)\ 10^{-9})$
492	410	300	11.011
490	411	300	10.495
457	408	302	7.675
409	407	301	4.844
368	407	300	3.121
327	406	301	1.808
296	416	301	1.152
300	410	300	1.162

TABLE C-47
CLAY TREATED JP-4 WITH 25% AROMATICS, CONDUCTIVITY ADDITIVE AT MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate $((gm/cm^2 sec)\ 10^{-9})$
498	410	301	10.893
497	412	301	10.398
449	408	302	6.953
407	408	316	7.050
369	406	310	2.842
327	409	300	1.830
304	410	302	1.313
292	413	304	1.098

TABLE C-48
CLAY TREATED JP-4 WITH 25% AROMATICS, CONDUCTIVITY ADDITIVE AT MINIMUM EFFECTIVE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
287	412	301	1.012
304	410	301	1.173
324	412	298	1.159
365	411	295	2.73
407	406	299	4.155
455	407	300	7.050
494	411	300	9.634
507	410	300	11.194

TABLE C-49
CLAY TREATED JP-4 WITH 25% AROMATICS, METAL DEACTIVATOR AT THREE TIMES MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
501	412	302	14.682
498	415	301	12.820
478	417	301	11.668
443	414	301	8.256
401	413	301	4.962
360	410	300	3.531
357	412	296	3.078
322	413	302	1.981
292	418	304	1.378
274	416	300	1.055

TABLE C-50
CLAY TREATED JP-4 WITH 25% AROMATICS, METAL DEACTIVATOR AT TWICE MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
516	414	302	13.423
491	415	301	11.690
447	419	302	7.276
393	418	300	4.510
358	417	310	2.852
318	416	306	1.744
292	417	302	1.270
271	416	310	0.9149

TABLE C-51,
CLAY TREATED JP-4 WITH 25% AROMATICS,
METAL DEACTIVATOR AT MAXIMUM
ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
517	420	302	12.443
499	418	301	11.851
451	418	310	7.459
402	420	310	4.306
363	421	300	2.949
324	414	310	1.744
297	412	302	1.292
280	416	308	0.990

TABLE C-52:
CLAY TREATED JP-4 WITH 25% AROMATICS,
METAL DEACTIVATOR AT MINIMUM
EFFECTIVE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
528	412	300	13.423
510	413	300	11.959
493	410	301	9.655
446	410	296	6.846
400	411	301	3.875
356	411	299	2.659
297	418	300	1.1302
279	420	301	0.9149
327	417	310	1.851

TABLE C-53
CLAY TREATED JP-4 WITH 35%
AROMATICS BASELINE

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁸)
257	278	303	0.076
291	281	303	0.125
313	282	302	0.158
315	283	302	0.171
351	282	302	0.276
395	282	302	0.416
422	281	303	0.587
451	280	301	0.776
459	280	301	0.763
498	280	303	1.119
516	281	299	1.344

TABLE C-54
CLAY TREATED JP-4 WITH 35% AROMATICS, ANTIOXIDANT AT TWICE MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
538	312	301	10.463
482	310	301	6.835
434	311	302	4.662
394	311	303	3.272
356	310	300	2.185
313	310	301	1.399
310	311	301	1.324
262	312	301	0.7535

The Deposit Rate column header reads $((gm/cm^2\ sec)\ 10^{-9})$.

TABLE C-55
CLAY TREATED JP-4 WITH 35% AROMATICS, ANTIOXIDANT AT MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
529	310	300	10.333
490	300	299	7.858
429	301	298	4.898
402	305	299	3.617
353	303	300	2.260
351	305	299	2.142
304	304	300	1.302
271	309	299	0.764
538	307	300	11.603

TABLE C-56
CLAY TREATED JP-4 WITH 35% AROMATICS, ANTIOXIDANT AT MIDSPECIFICATION CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
529	303	300	12.023
498	299	300	8.514
483	300	300	7.556
438	298	301	5.371
394	300	300	3.552
359	303	299	2.573
311	300	300	1.442
287	302	300	1.098
256	300	300	0.721

TABLE C-57
CLAY TREATED JP-4 WITH 35% AROMATICS, ANTIOXIDANT AT MINIMUM EFFECTIVE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-9})
546	300	300	14.962
494	305	300	9.655
488	303	300	8.912
448	305	301	6.727
410	303	300	4.790
406	304	299	4.370
351	310	299	2.573
321	304	299	1.733
284	305	300	1.119
262	300	300	0.807

TABLE C-58
CLAY TREATED JP-4 WITH 35% AROMATICS, CORROSION INHIBITOR AT MINIMUM EFFECTIVE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-9})
296	456	307	1.270
297	456	304	1.388
399	454	306	4.198
520	455	307	14.090
539	456	307	14.822

TABLE C-59
CLAY TREATED JP-4 WITH 35% AROMATICS, CORROSION INHIBITOR AT MIDSPECIFICATION CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-9})
280	452	303	1.195
281	449	306	1.044
396	451	302	4.521
531	452	303	14.09
540	459	304	16.40

TABLE C-60
CLAY TREATED JP-4 WITH 35% AROMATICS,
CORROSION INHIBITOR AT MAXIMUM
ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
527	506	302	16.027
493	452	303	11.690
446	416	302	7.546
400	421	302	4.876
343	431	301	2.594
291	425	304	1.324
273	420	306	1.012

TABLE C-61.
CLAY TREATED JP-4 WITH 35% AROMATICS,
CORROSION INHIBITOR AT TWICE MAXIMUM
ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec 10⁻⁹)
499	451	306	14.090
496	450	316	13.057
443	453	309	8.407
404	452	308	5.177
349	451	307	2.723
296	445	305	1.561
285	456	306	1.206
273	453	307	1.055

TABLE C-62,
CLAY TREATED JP-4 WITH 35% AROMATICS,
ICING INHIBITOR AT THREE TIMES MAXIMUM
ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
287	447	302	1.270
292	447	303	1.313
405	445	302	4.521
502	449	304	11.173
513	450	303	13.487

TABLE C-63
CLAY TREATED JP-4 WITH 35% AROMATICS, ICING INHIBITOR AT LOW RELATIVE CONCENTRATION RELATIVE TO MAXIMUM

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
296	448	303	1.432
302	445	302	1.410
398	450	302	4.596
494	451	304	10.419
507	453	306	11.700

TABLE C-64
CLAY TREATED JP-4 WITH 35% AROMATICS, CONDUCTIVITY ADDITIVE AT MINIMUM EFFECTIVE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
540	445	306	16.985
499	442	305	11.485
447	446	305	75.563
399	445	304	4.721
400	446	304	4.467
354	442	302	2.745
301	442	301	1.442
281	444	306	1.076

TABLE C-65
CLAY TREATED JP-4 WITH 35% AROMATICS, CONDUCTIVITY ADDITIVE AT MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10⁻⁹)
526	445	310	15.919
492	442	308	10.893
440	443	305	76.531
405	442	306	5.231
400	446	305	4.801
357	449	304	3.059
304	446	306	1.550
281	447	304	1.173

TABLE C-66
CLAY TREATED JP-4 WITH 35% AROMATICS, CONDUCTIVITY ADDITIVE AT TWICE MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate $((gm/cm^2 \ sec) \ 10^{-9})$
516	442	304	16.523
513	443	306	14.962
486	445	305	12.529
425	441	304	7.050
391	445	302	4.628
349	444	303	3.014
284	445	305	1.238
290	442	305	1.302

TABLE C-67
CLAY TREATED JP-4 WITH 35% AROMATICS, CONDUCTIVITY ADDITIVE AT THREE TIMES MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate $((gm/cm^2 \ sec) \ 10^{-9})$
517	445	310	19.45
514	447	308	17.298
488	445	309	13.746
438	444	308	8.536
396	442	305	5.619
356	447	304	3.380
292	446	299	1.518
294	448	302	1.432

TABLE C-68
CLAY TREATED JP-4 WITH 35% AROMATICS, METAL DEACTIVATOR AT ONE-HALF MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate $((gm/cm^2 \ sec) \ 10^{-9})$
529	445	310	15.888
496	446	312	12.852
444	443	311	75.563
399	445	310	4.790
394	449	309	4.876
371	440	310	3.757
345	445	309	2.659
296	446	310	1.496
277	445	311	1.141

TABLE C-69
CLAY TREATED JP-4 WITH 35% AROMATICS, METAL DEACTIVATOR AT MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-9})
518	442	310	16.792
485	443	302	12.529
433	445	306	7.416
394	445	307	5.307
350	445	308	2.992
288	444	304	1.464
286	444	303	1.335

TABLE C-70
CLAY TREATED JP-4 WITH 35% AROMATICS, METAL DEACTIVATOR AT TWICE MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-9})
523	446	303	19.493
520	446	304	17.986
485	445	305	14.617
435	449	306	8.514
390	441	305	5.436
345	442	305	3.423
298	443	305	1.722
294	445	304	1.798

TABLE C-71
CLAY TREATED JP-4 WITH 35% AROMATICS, METAL DEACTIVATOR AT THREE TIMES MAXIMUM ALLOWABLE CONCENTRATION

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ((gm/cm² sec) 10^{-9})
509	441	306	22.389
508	441	304	19.999
475	446	302	16.156
430	444	302	9.548
384	444	302	6.760
339	447	304	3.800
296	441	306	2.024
294	442	308	2.045

TABLE C-72.
CLAY TREATED JP-7

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ($(gm/cm^2\ sec)\ 10^{-11}$)
320	349	300	3.229
323	354	310	3.588
355	355	305	5.741
395	353	300	12.56
397	350	295	13.28
420	351	295	19.02
440	346	295	22.96
519	347	300	62.43
541	350	300	83.24
544	352	310	91.49

TABLE C-73-
SHALE DERIVED LIGHT DIESEL OIL
(OCCIDENTAL OIL COMPANY)

Test Temperature (°F)	Test Pressure (psi)	Airflow (SCCM)	Deposit Rate ($(gm/cm^2\ sec)\ 10^{-6}$)
257	352	298	0.573
284	385	301	0.756
326	380	300	1.068
362	385	301	1.417
402	384	299	1.880
431	390	299	2.283
445	384	300	2.586
483	385	301	3.129
493	384	301	3.224
535	385	299	4.151

APPENDIX D

EXPERIMENTAL PEROXIDE ANALYSES OF SELECTED CLAY TREATED AIR FORCE JET FUELS WHICH HAVE BEEN THERMALLY STRESSED USING THE EXPERIMENTAL COKING APPARATUS

The following data represent the peroxide concentrations found in selected, thermally stressed jet fuels. These data correspond to data presented in Appendix C and were determined using a modified ASTM 3703-78 as discussed in Appendix B. These data, as presented here, consist of the fuel stress temperature in fahrenheit degrees, the concentration of active oxygen in parts per million and the milliequivalent weight of oxygen per kilogram of fuel. Each datum is an average of three analyses.
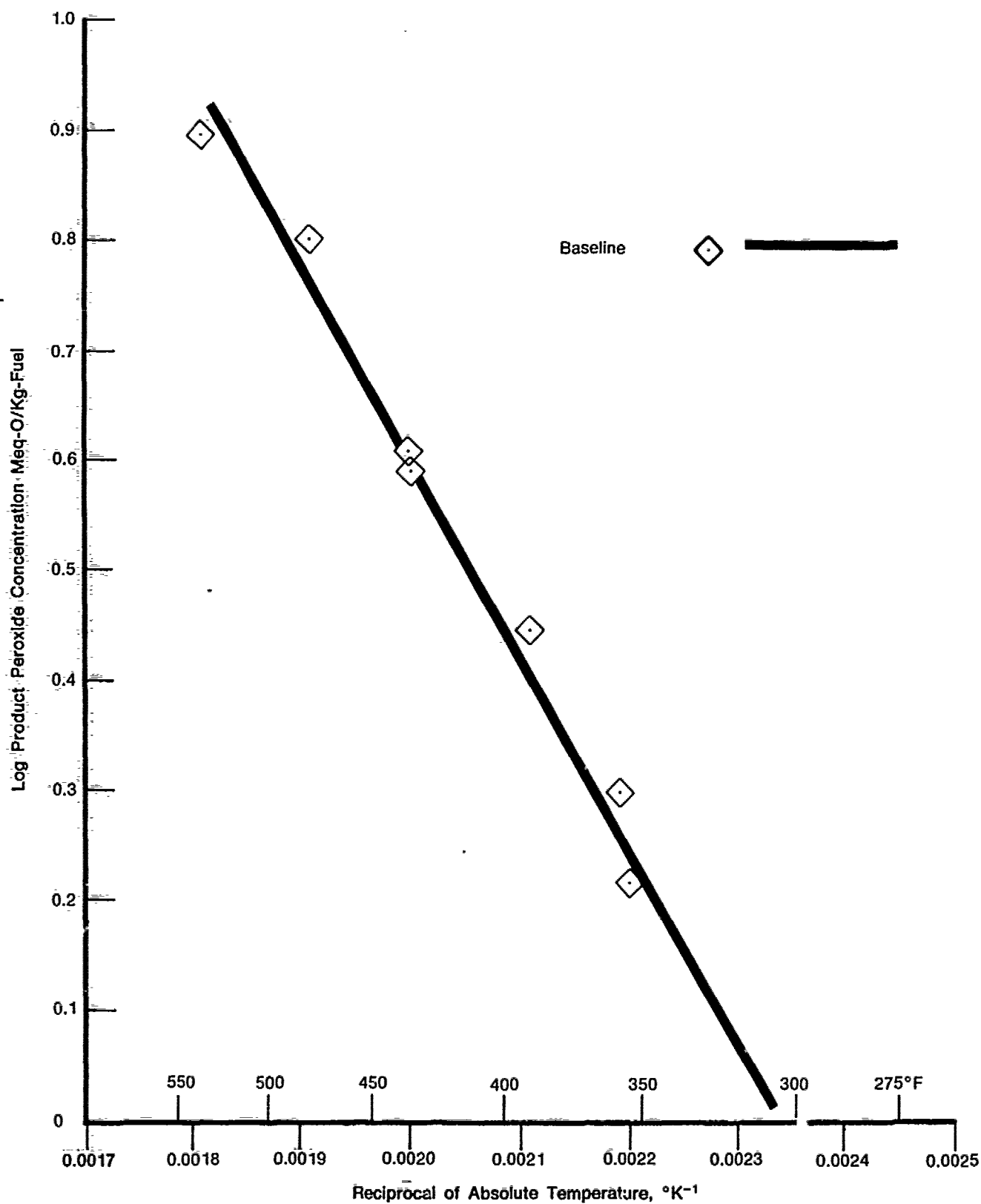
Figure D-1. Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature of a Clay Treated JP-8 Fuel, Baseline Data
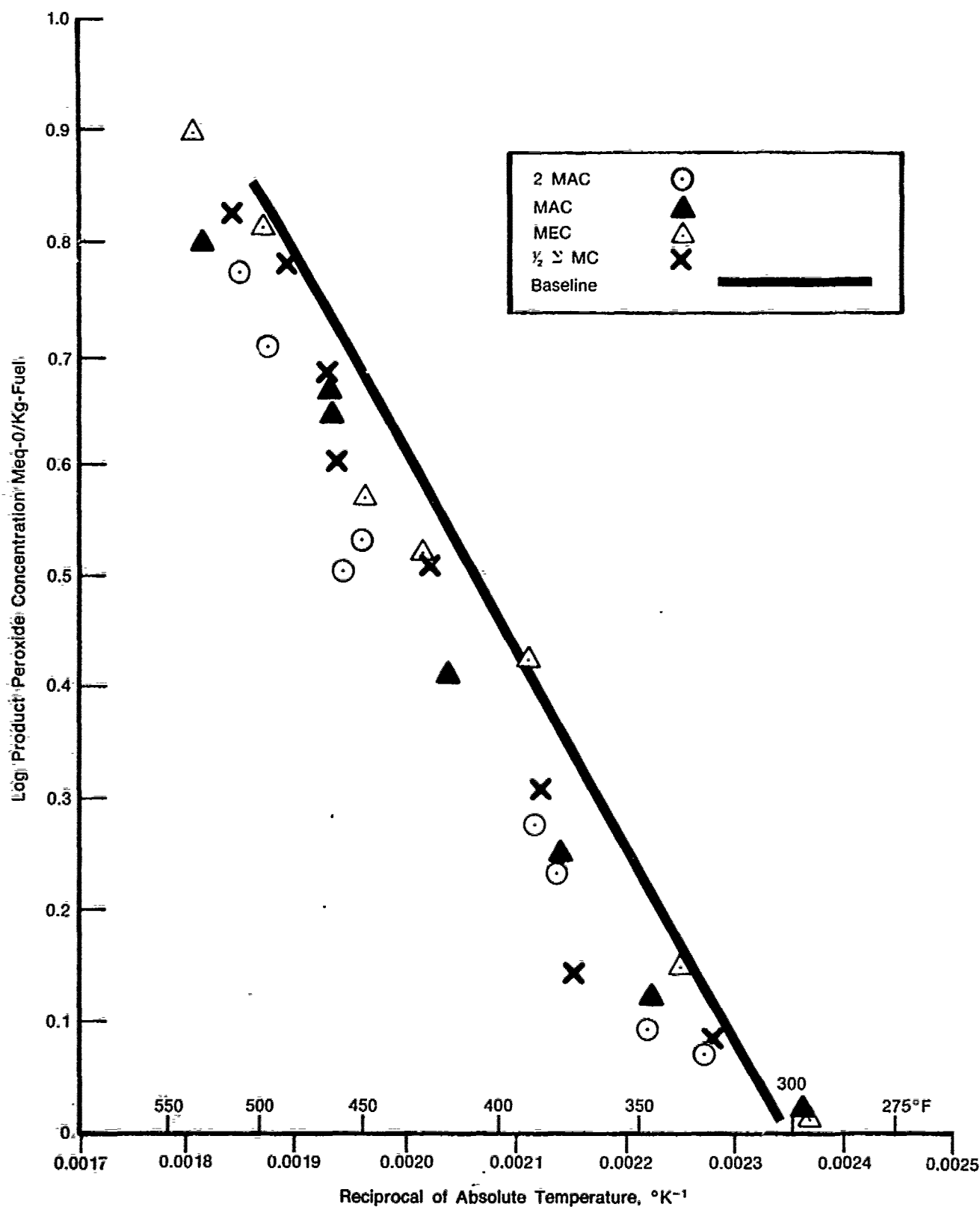
Figure D-2. Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature, Effect of Antioxidant on a Clay Treated JP-8 Fuel
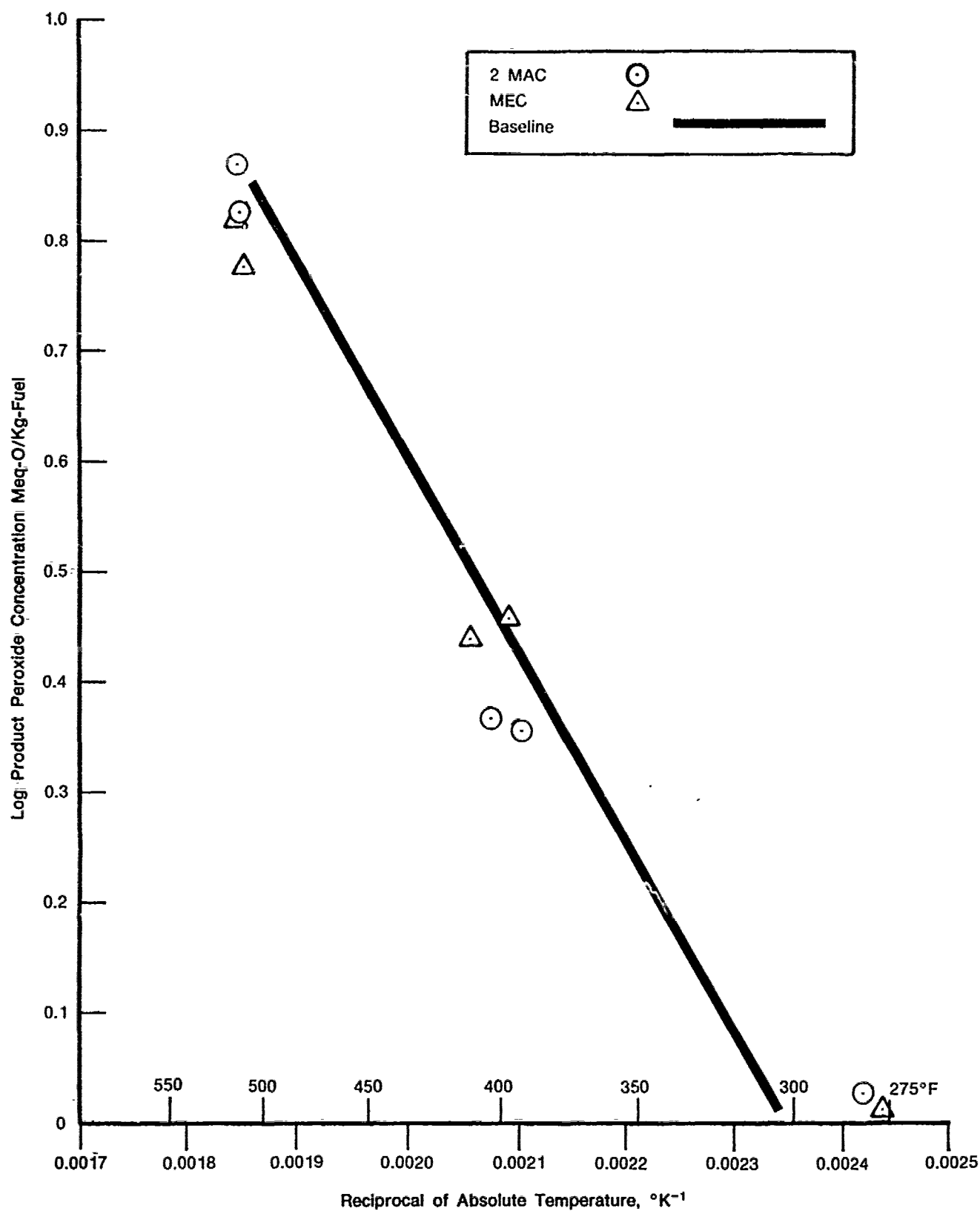
Figure D-3. *Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature, Effect of Corrosion Inhibitor on a Clay Treated JP-8 Fuel*
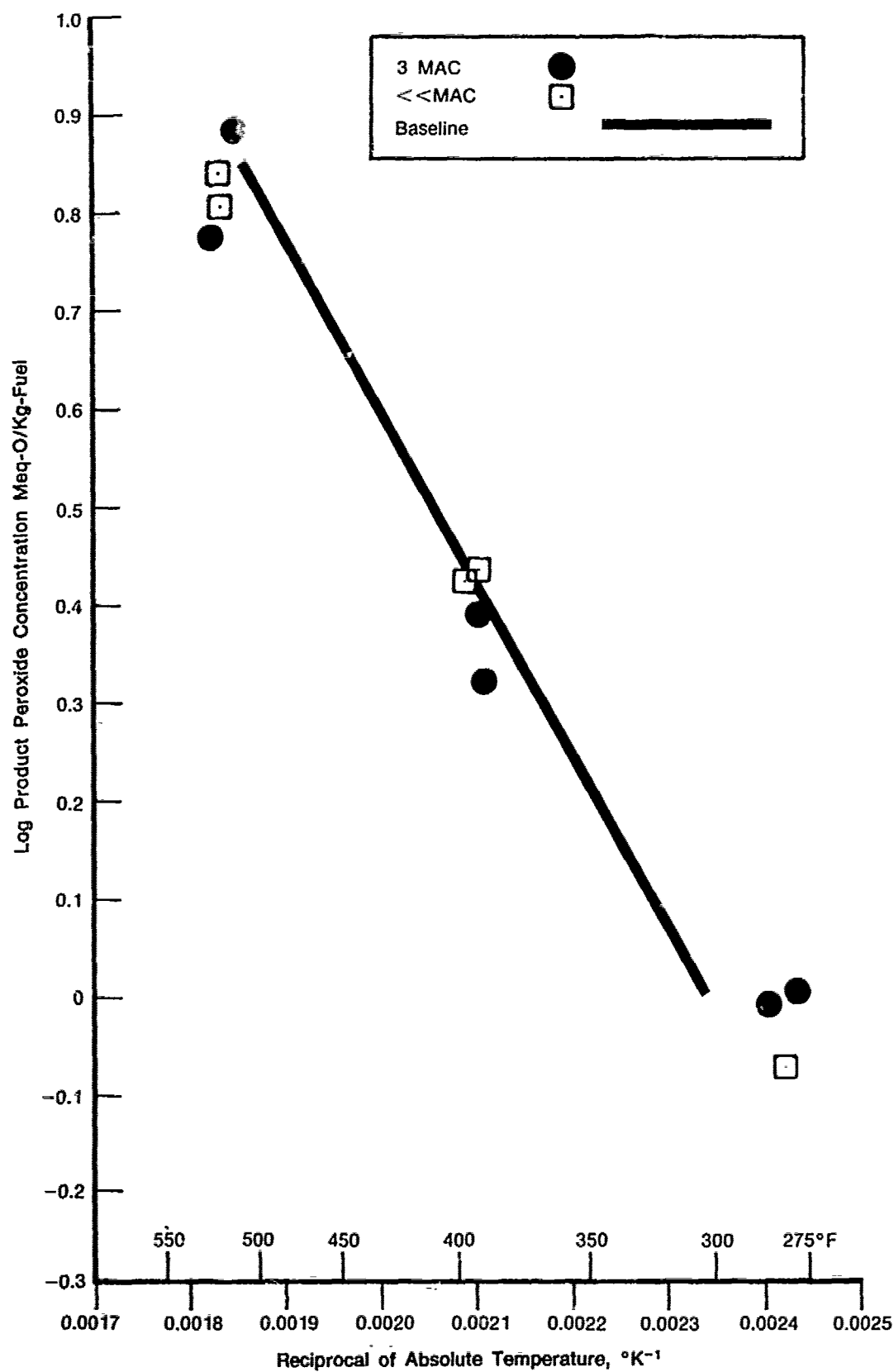
Figure D-4. Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature, Effect of Fuel System Icing Inhibitor on a Clay Treated JP-8 Fuel
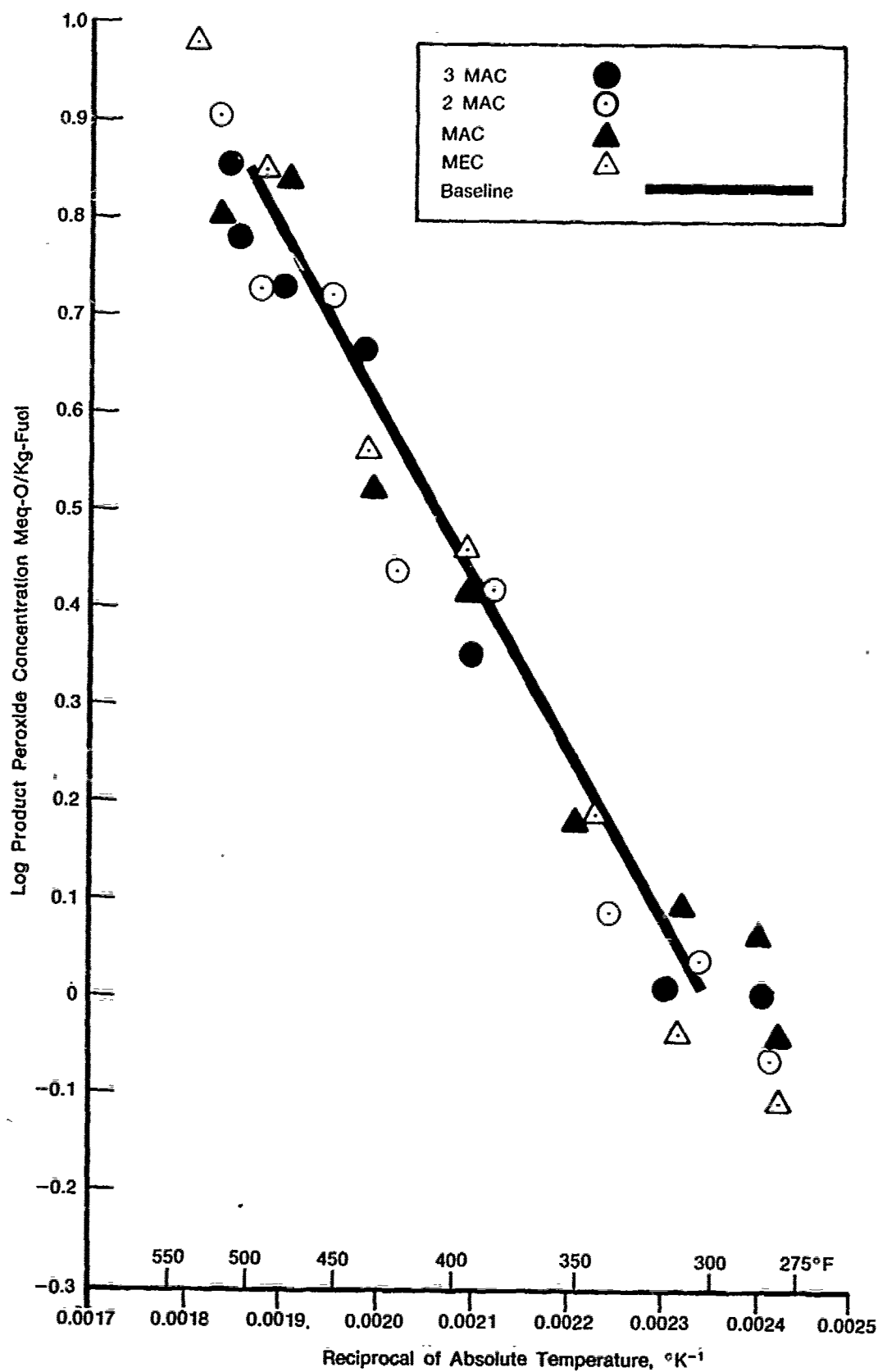
Figure D-5. Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature, Effect of Conductivity Additive on a Clay Treated JP-8 Fuel
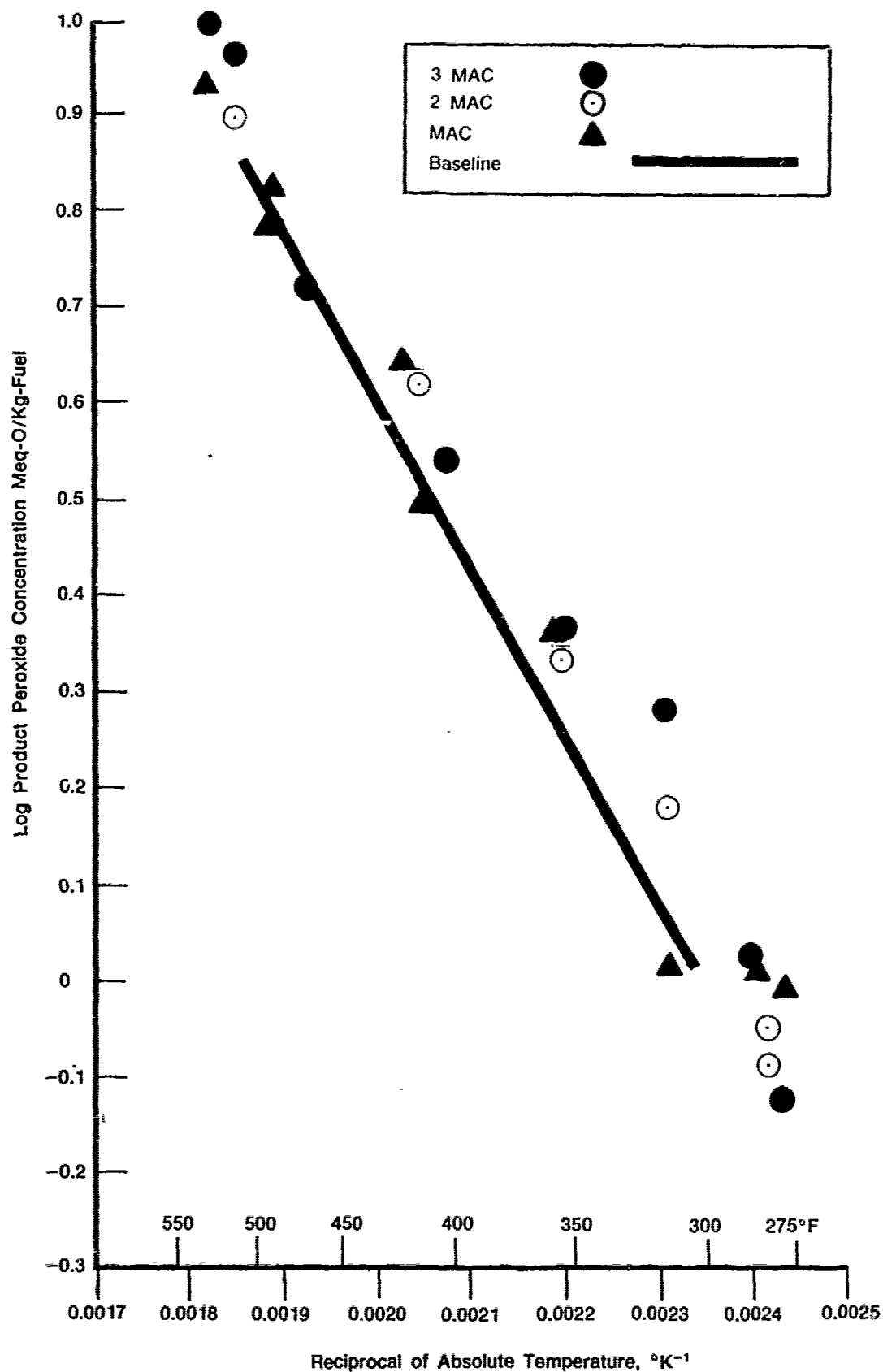
Figure D-6. Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature, Effect of Metal Deactivator on a Clay Treated JP-8 Fuel
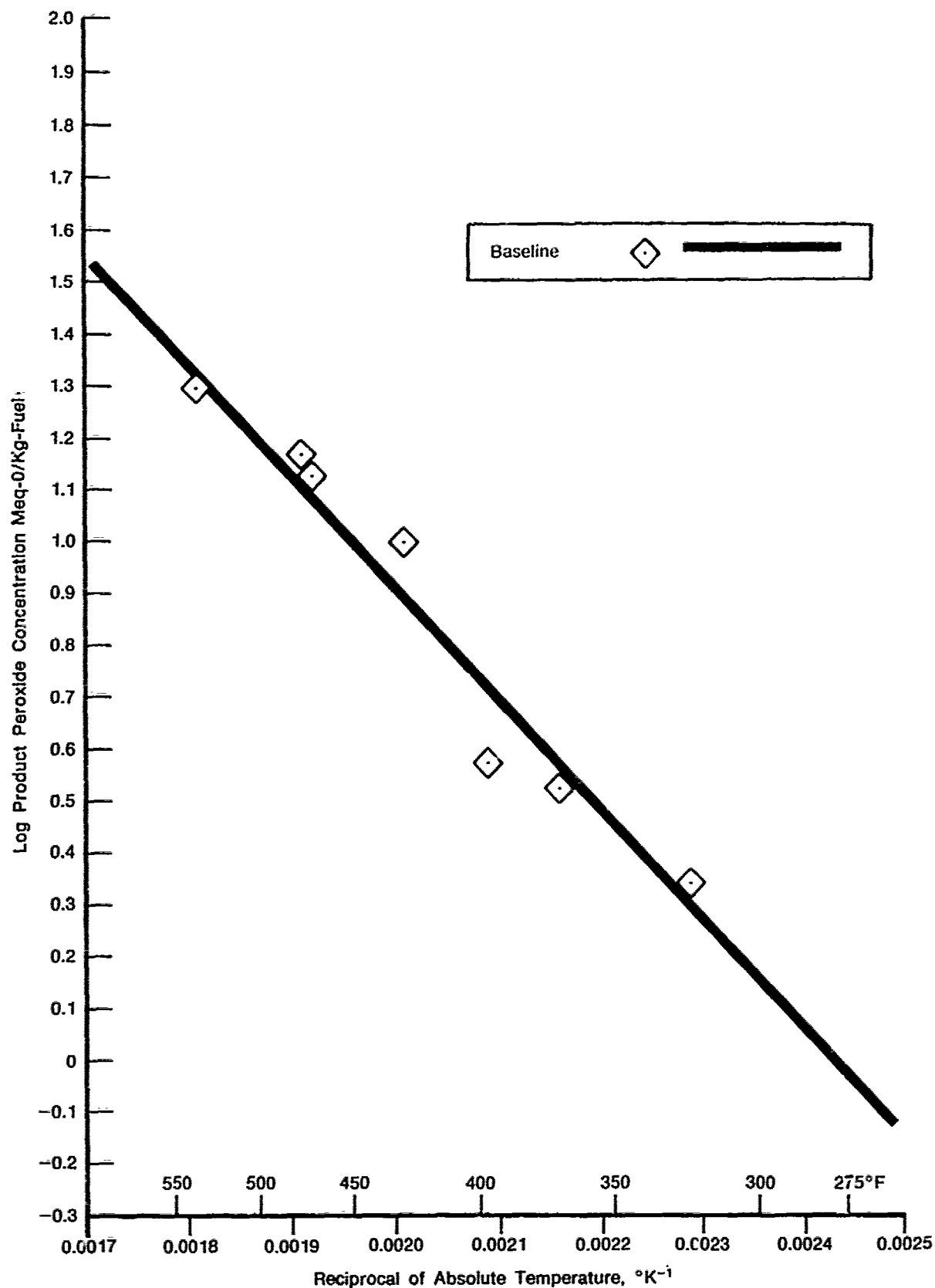
Figure D-7. Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature of a Clay Treated JP-4 Fuel, Baseline Data
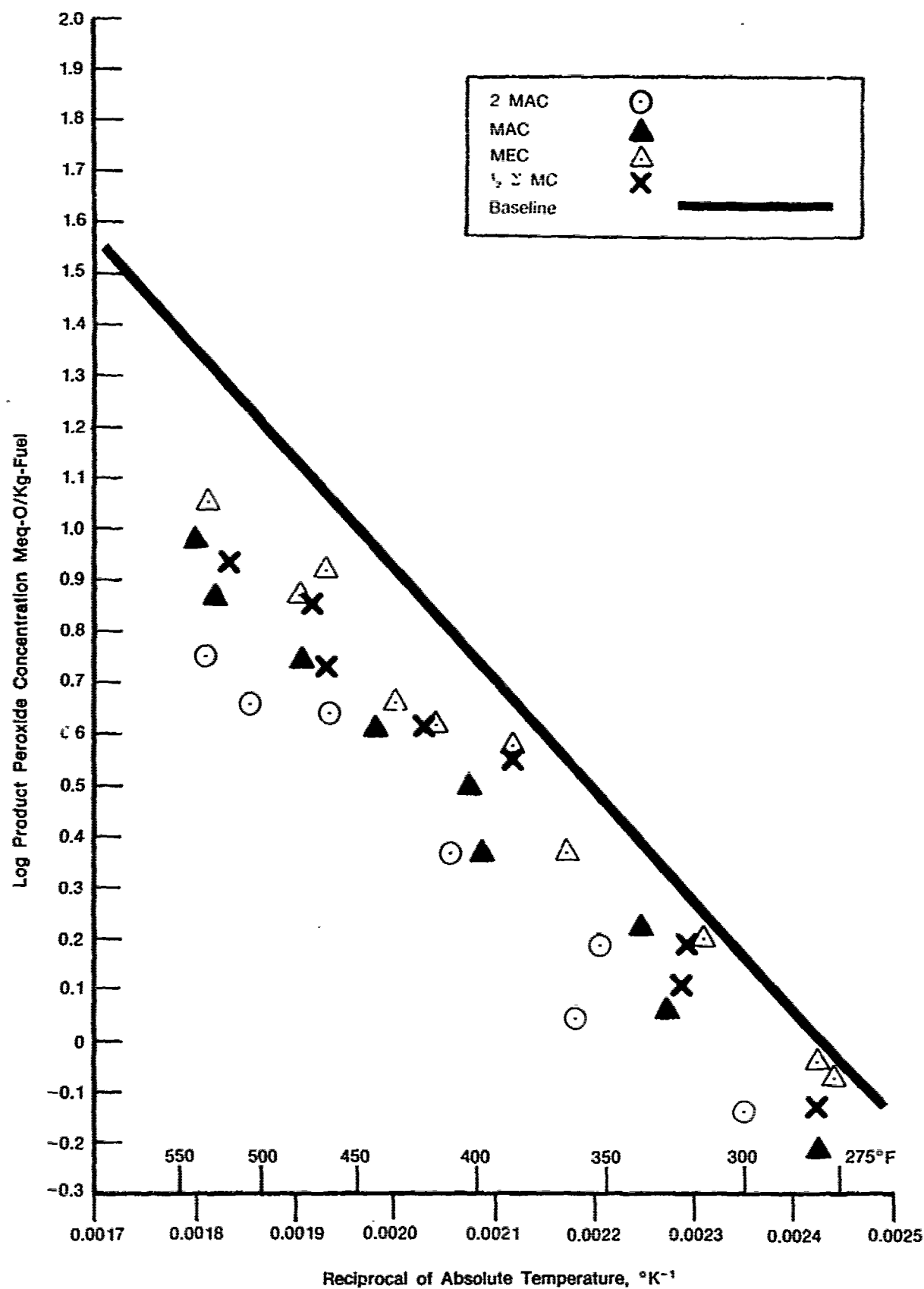
Figure D-8. *Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature. Effect of Antioxidant on a Clay Treated JP-4 Fuel*
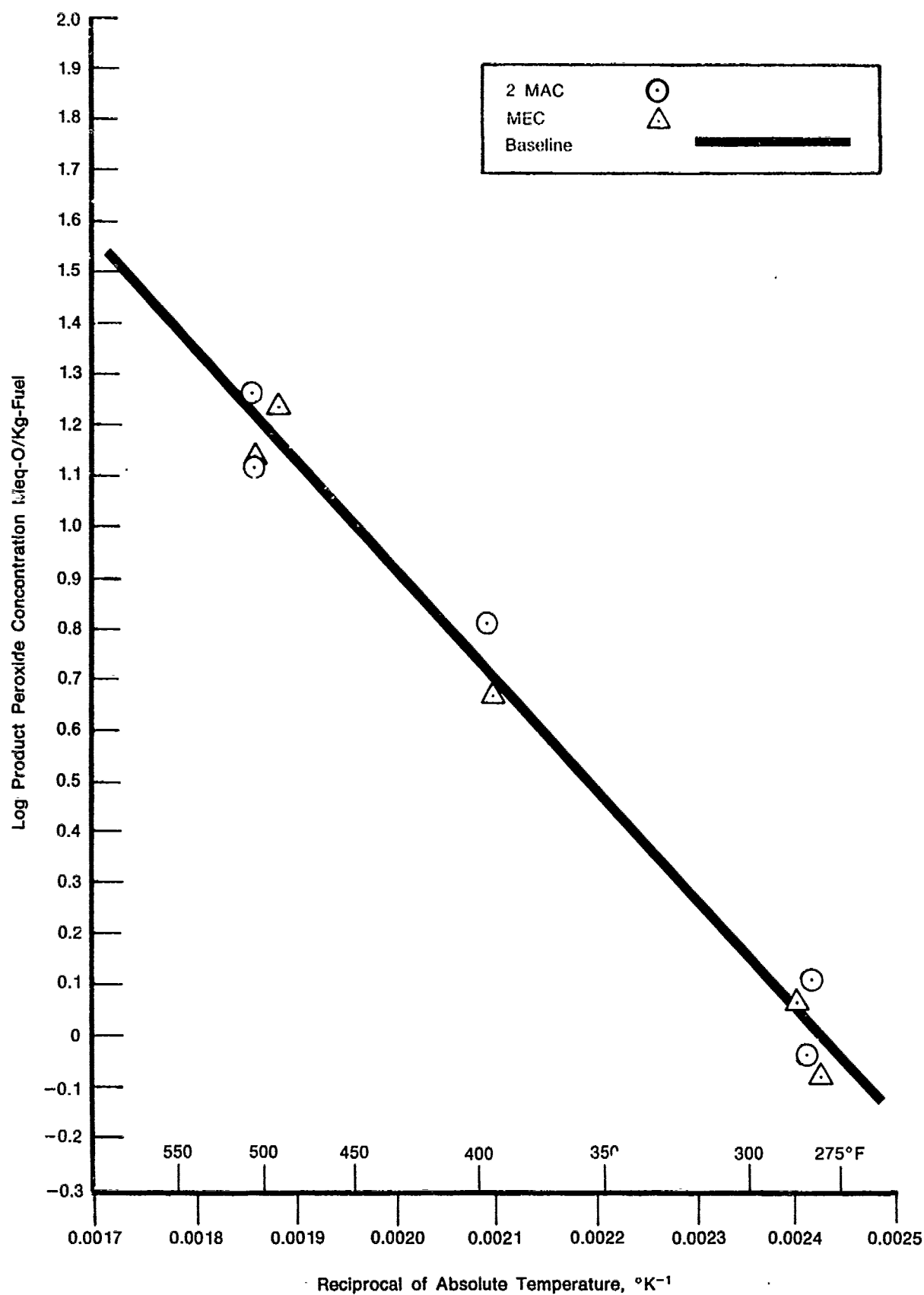
Figure D-9. Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature, Effect of Corrosion Inhibitor on a Clay Treated JP-4 Fuel

90
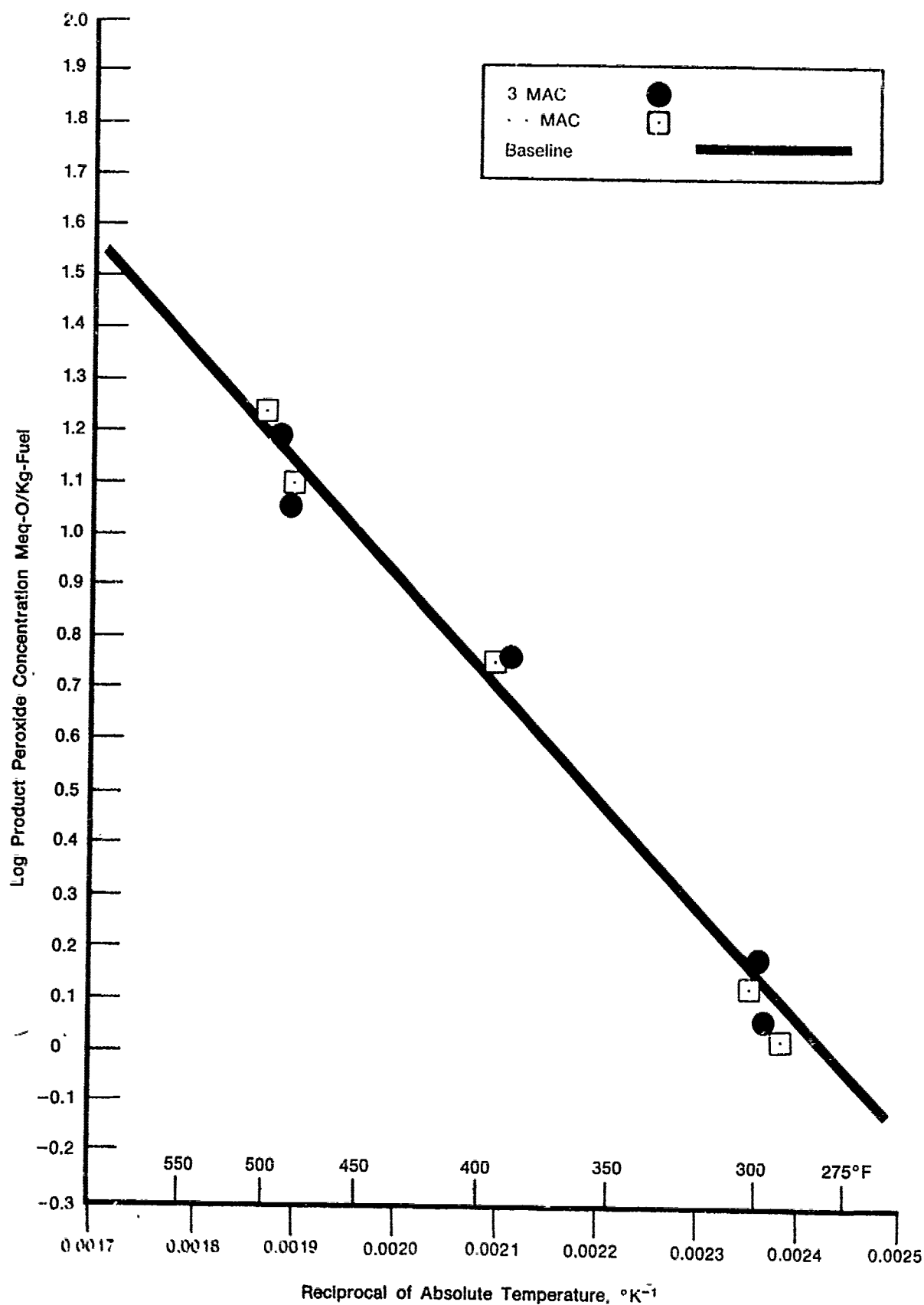
Figure D-10. Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature, Effect of Icing Inhibitor on a Clay Treated JP-4 Fuel
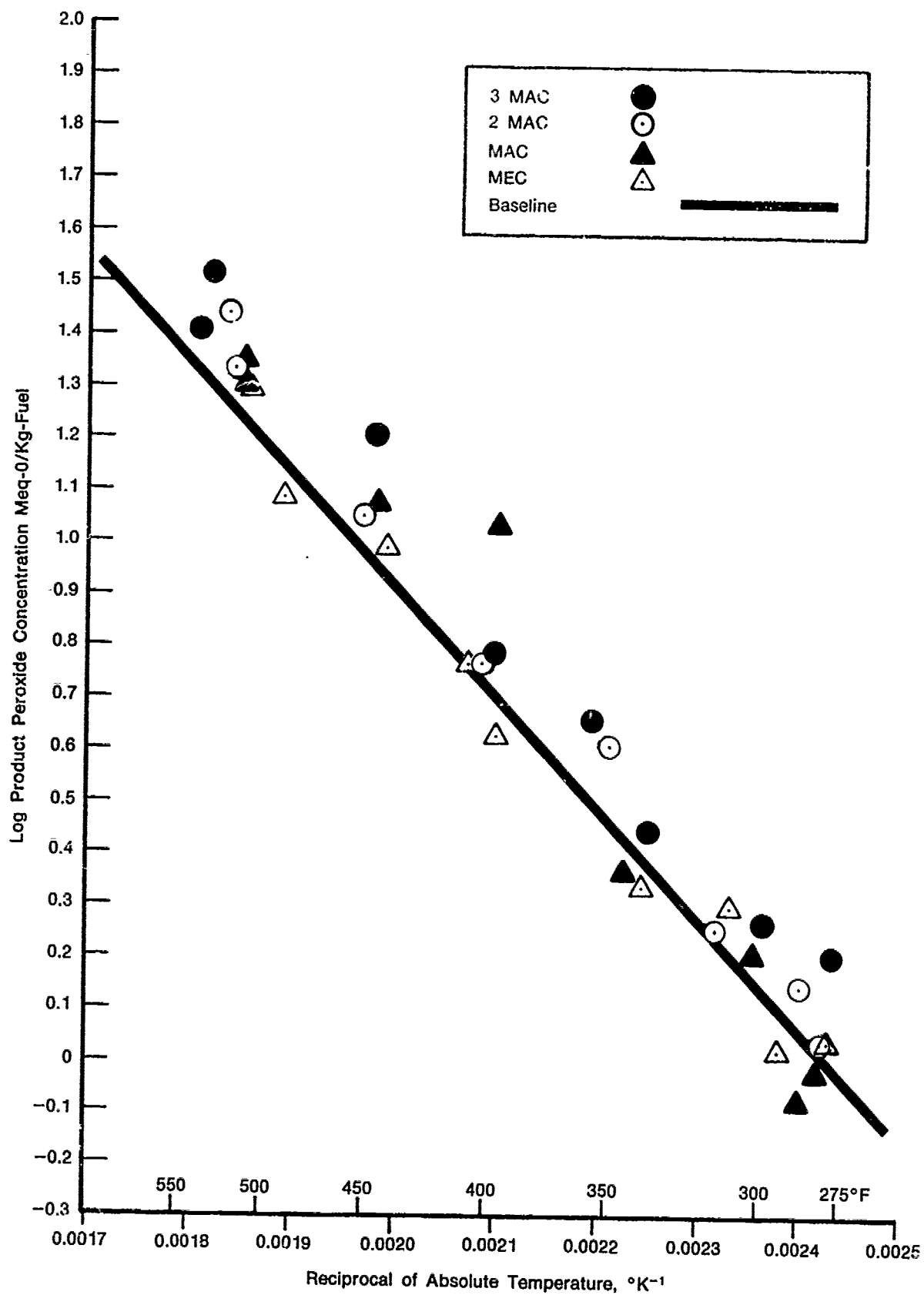
Figure D-11. Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature, Effect of Conductivity Additive on a Clay Treated JP-4 Fuel
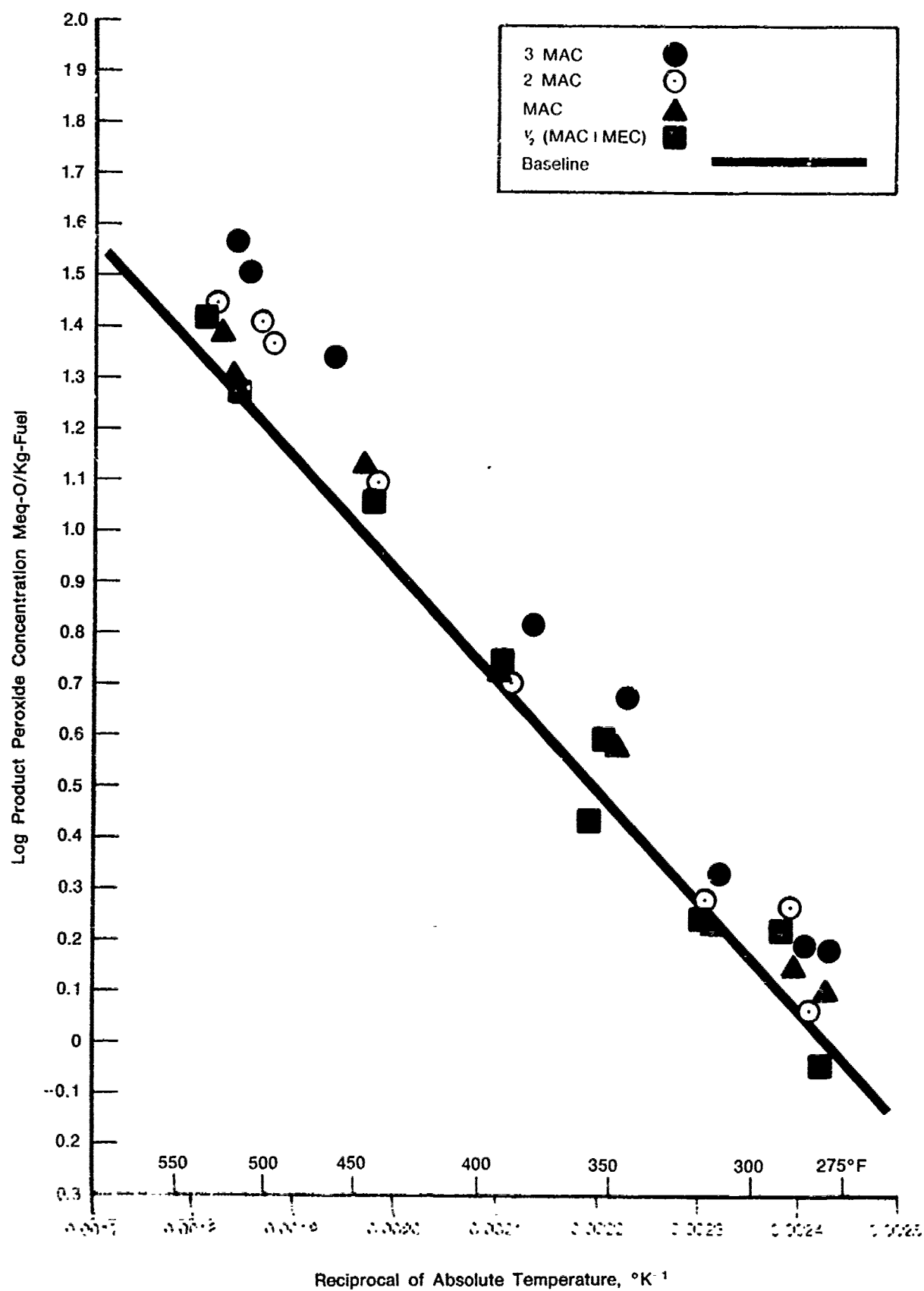
Figure D-12. *Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature, Effect of Metal Deactivator on a Clay Treated JP-4 Fuel*
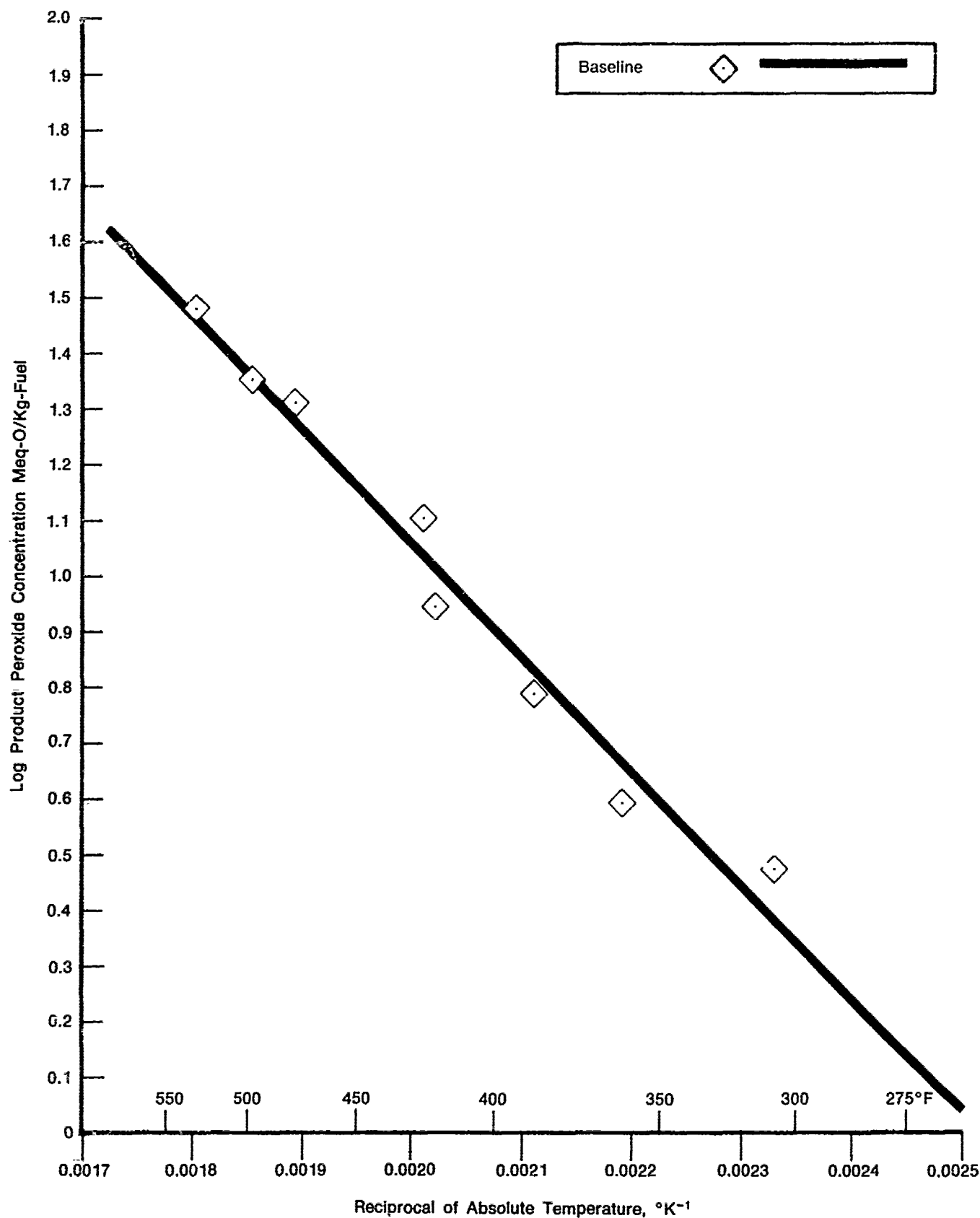
Figure D-13. Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature of a Clay Treated JP-4 Fuel with 25% Aromatics, Baseline Data

94
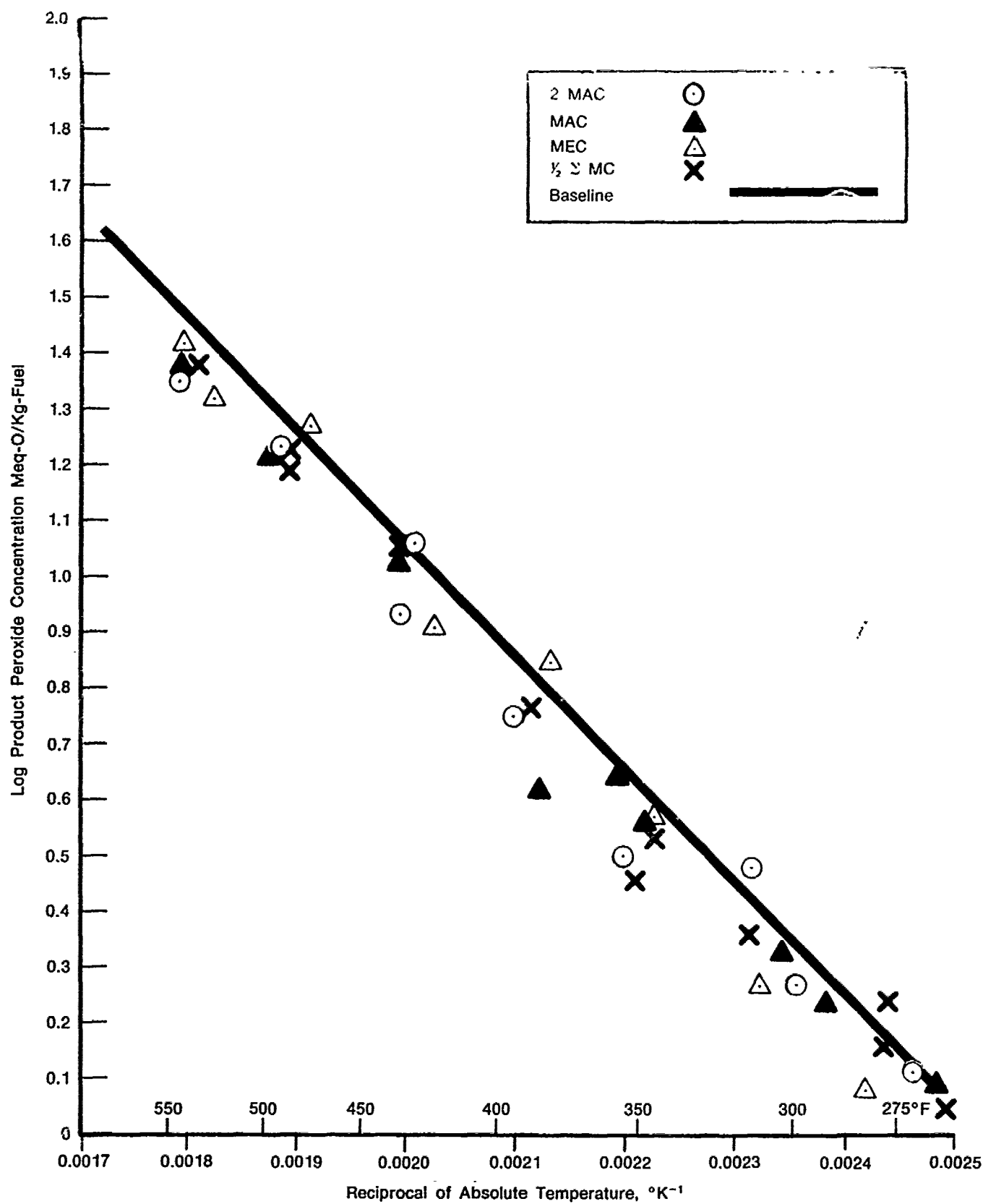
Figure D-14. *Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature, Effect of Antioxidant on a Clay Treated JP-4 Fuel with 25% Aromatics*

95
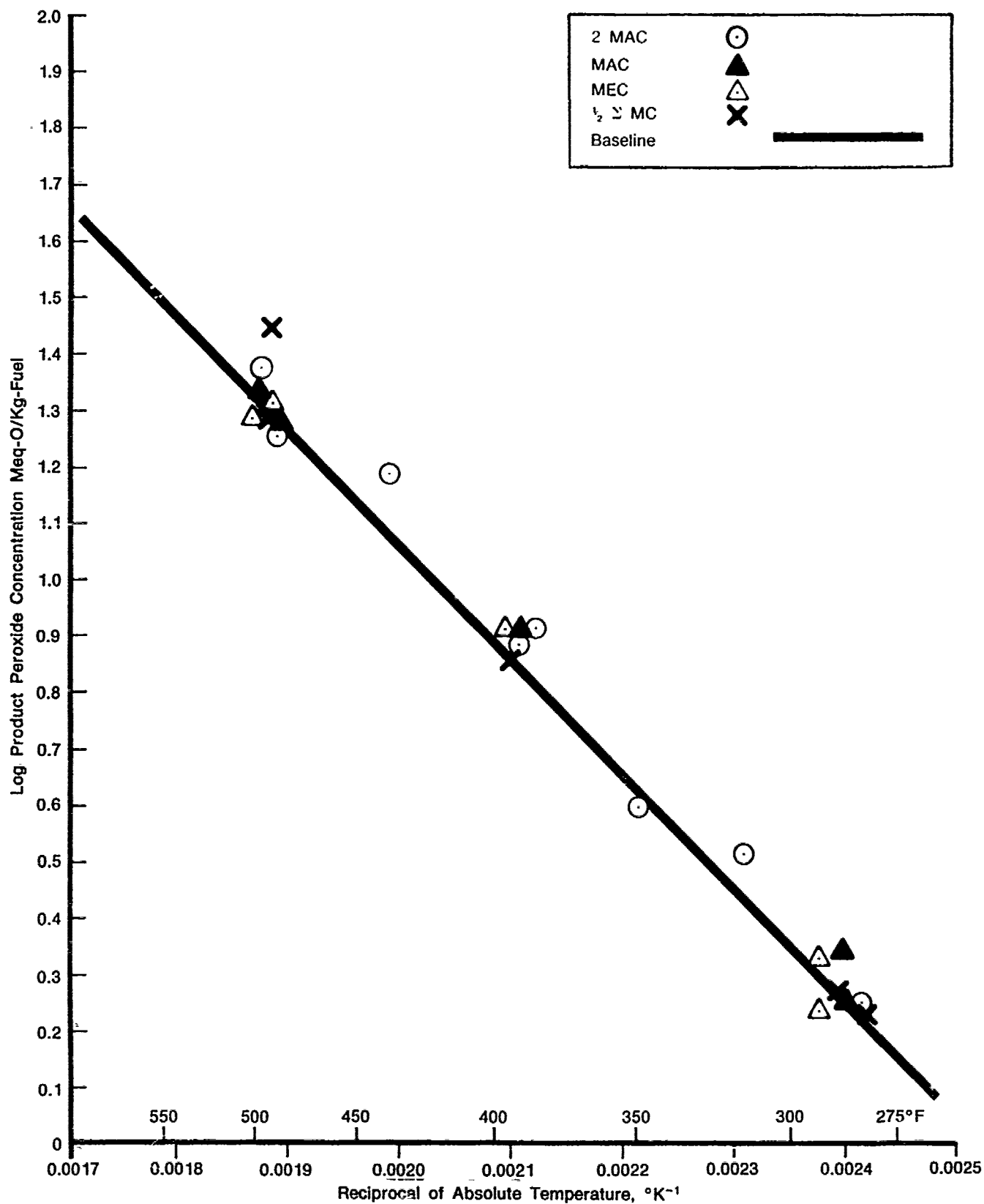
Figure D-15. *Variation of Active Oxygen Expressed es Peroxide as a Function of Fuel Temperature, Effect of Corrosion Inhibitor on a Clay Treated JP-4 Fuel with 25% Aromatics*
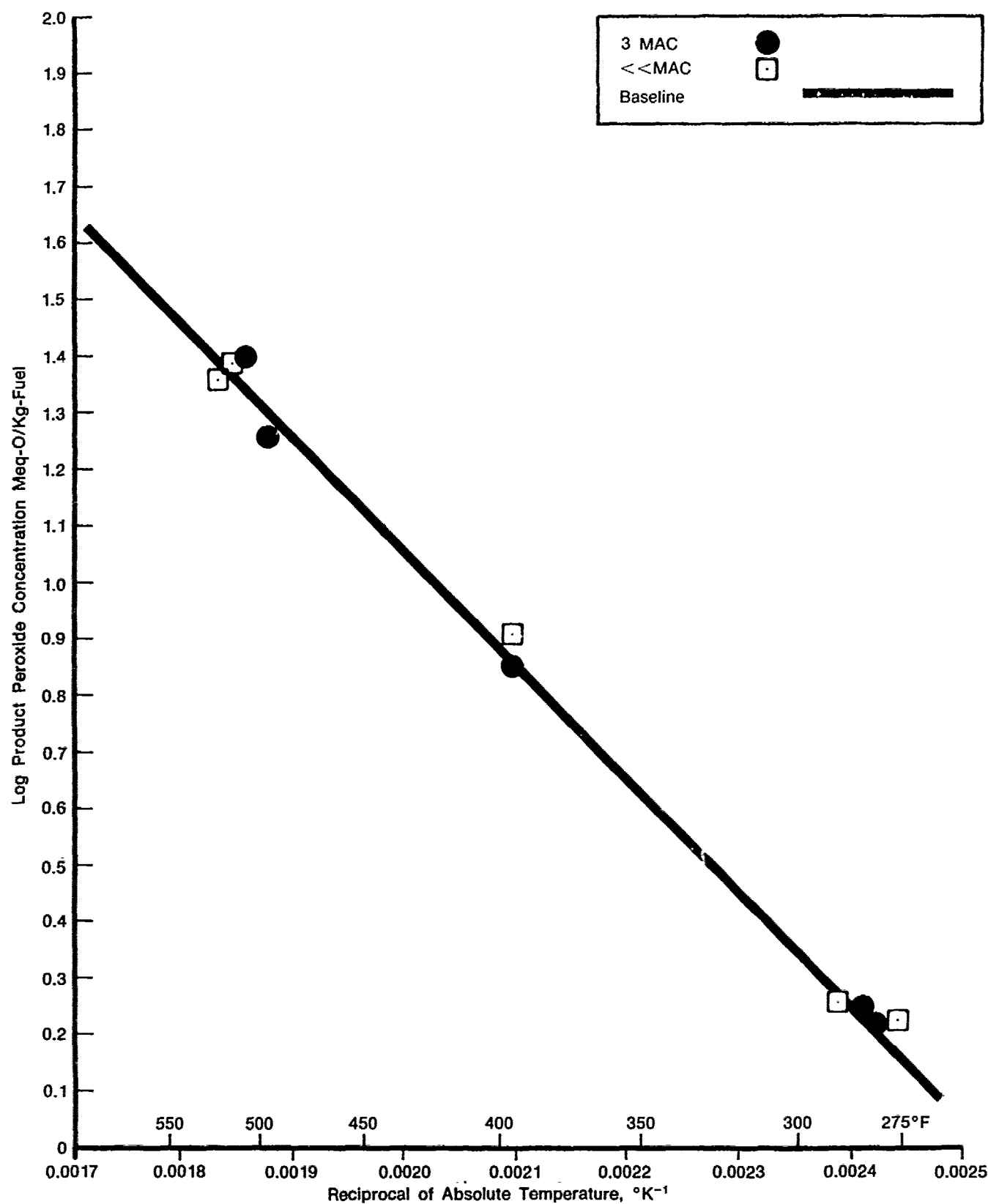
Figure D-16. Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature, Effect of Icing Inhibitor on a Clay Treated JP-4 Fuel with 25% Aromatics

97
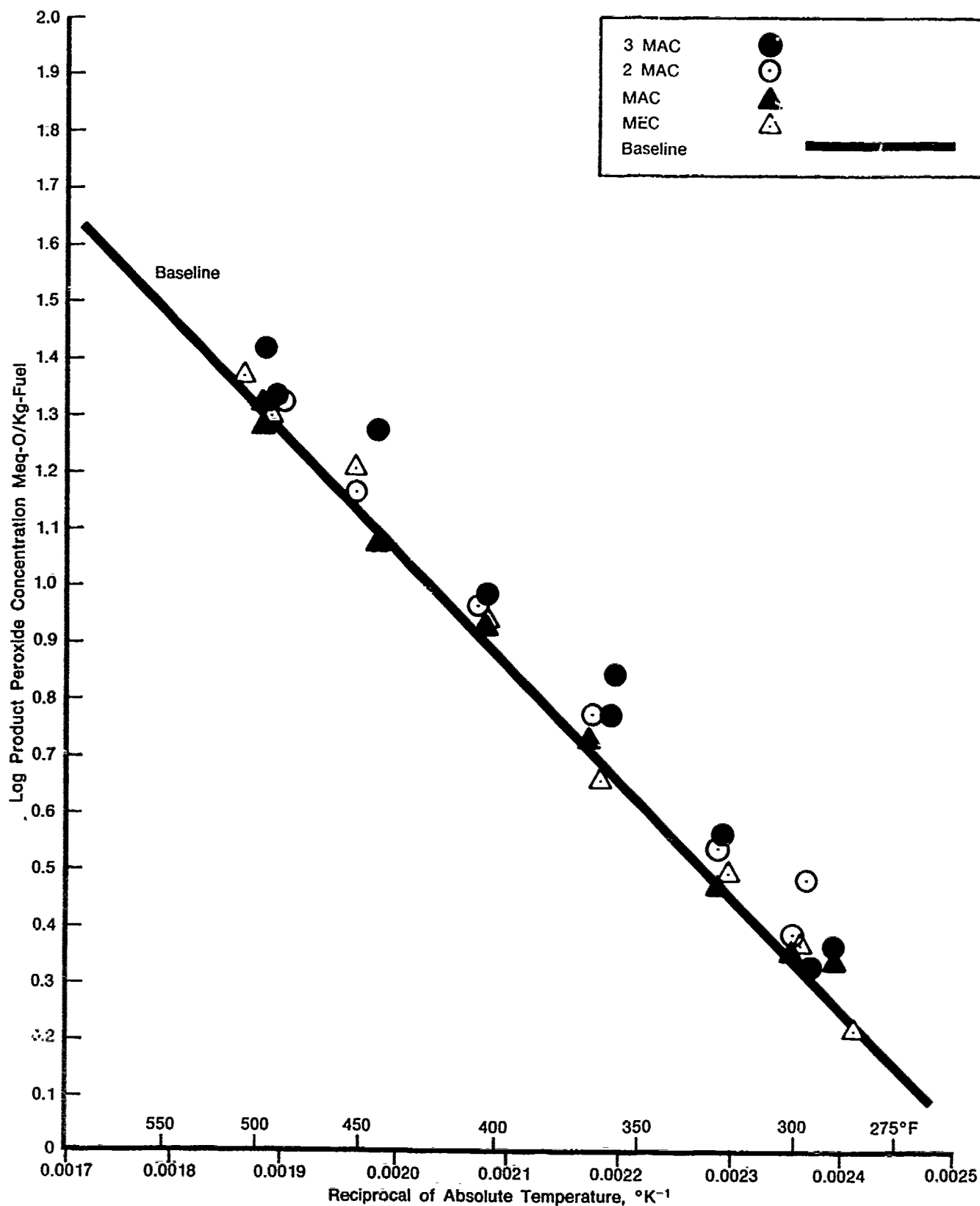
Figure D-17. *Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature, Effect of Conductivity Additive on a Clay Treated JP-4 Fuel with 25% Aromatics*
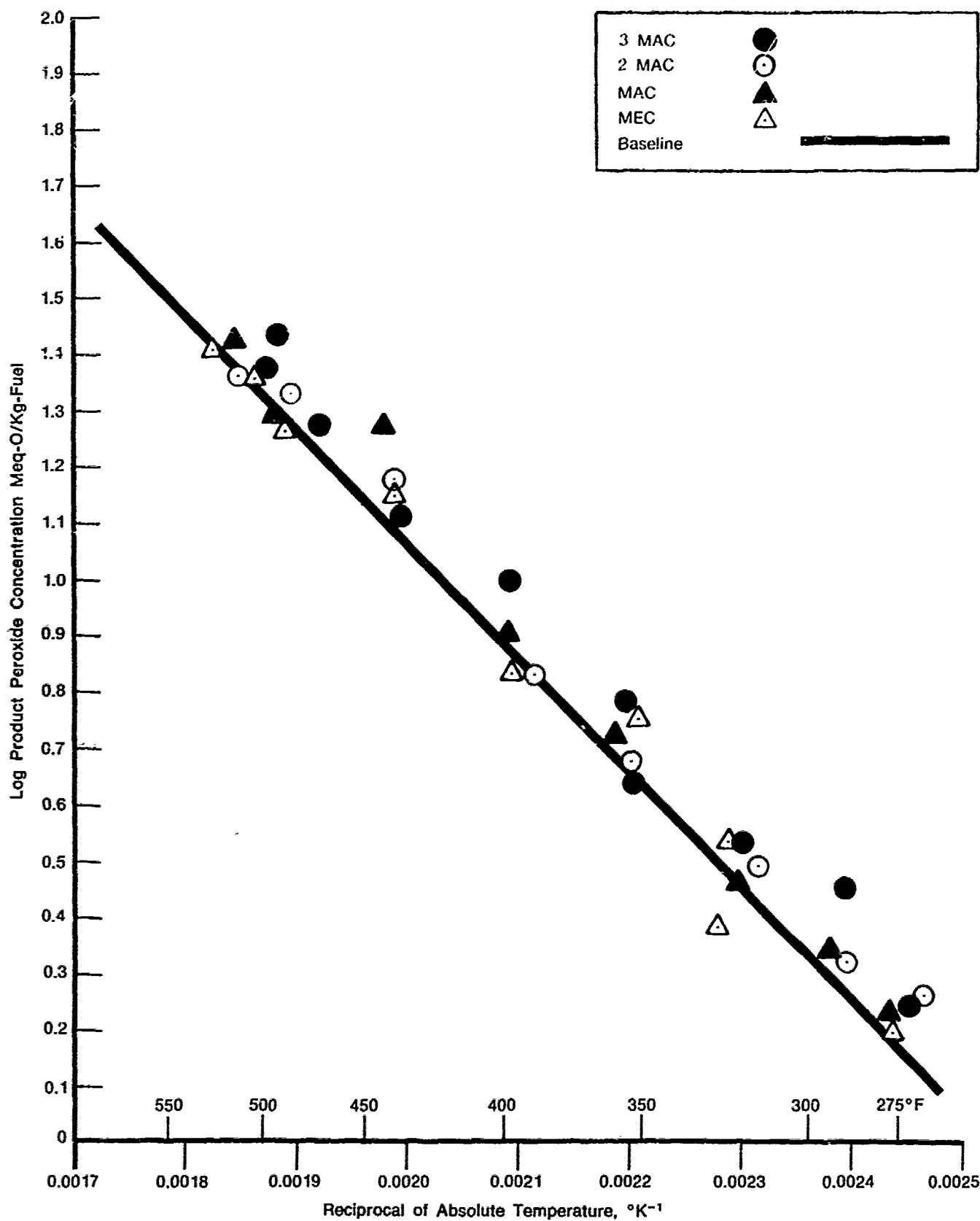
Figure D-18. Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel
Temperature, Effect of Metal Deactivator on a Clay Treated JP-4 Fuel
with 25% Aromatics

99
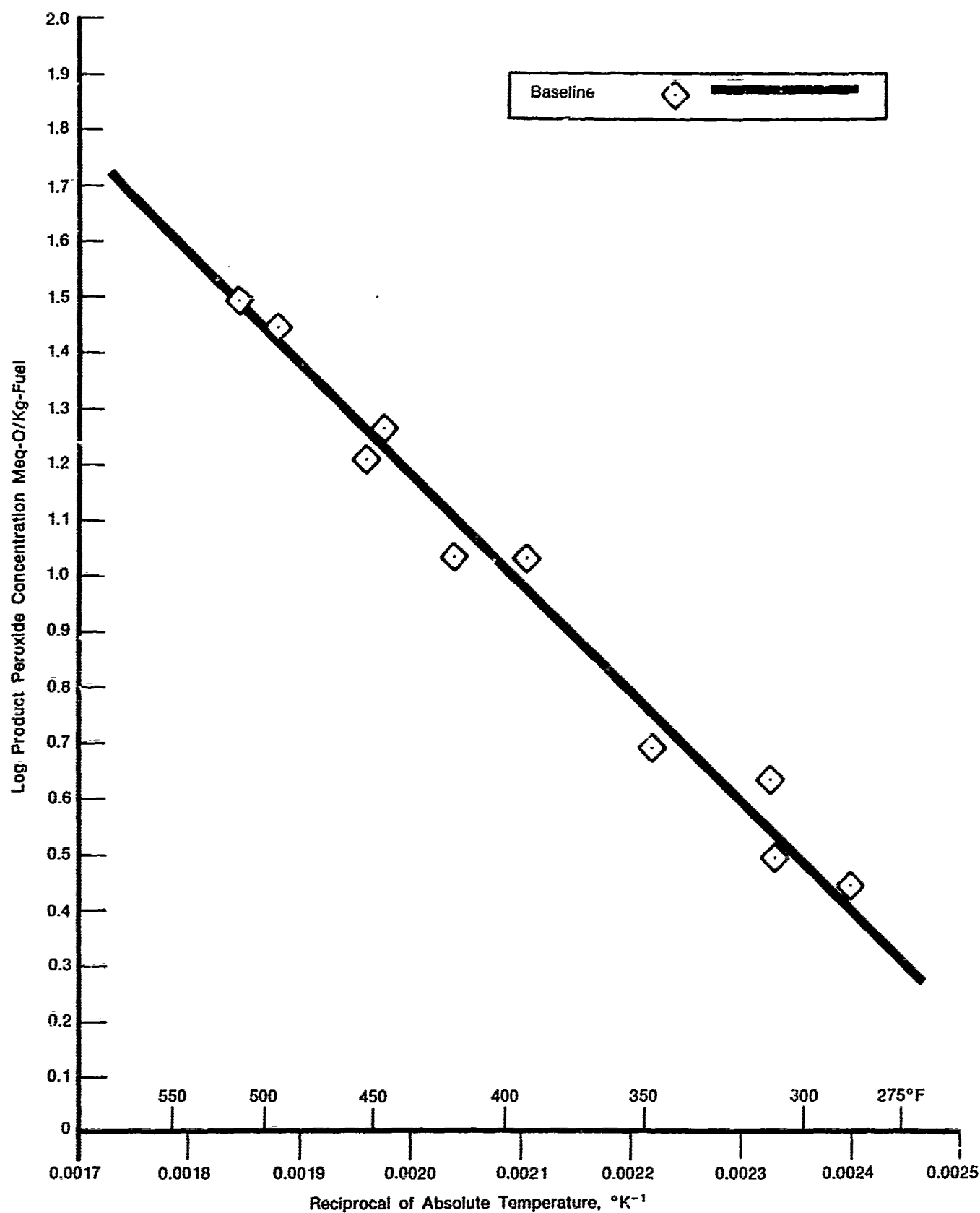
Figure D-19. Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature of a Clay Treated JP-4 Fuel with 35% Aromatics, Baseline Data

100
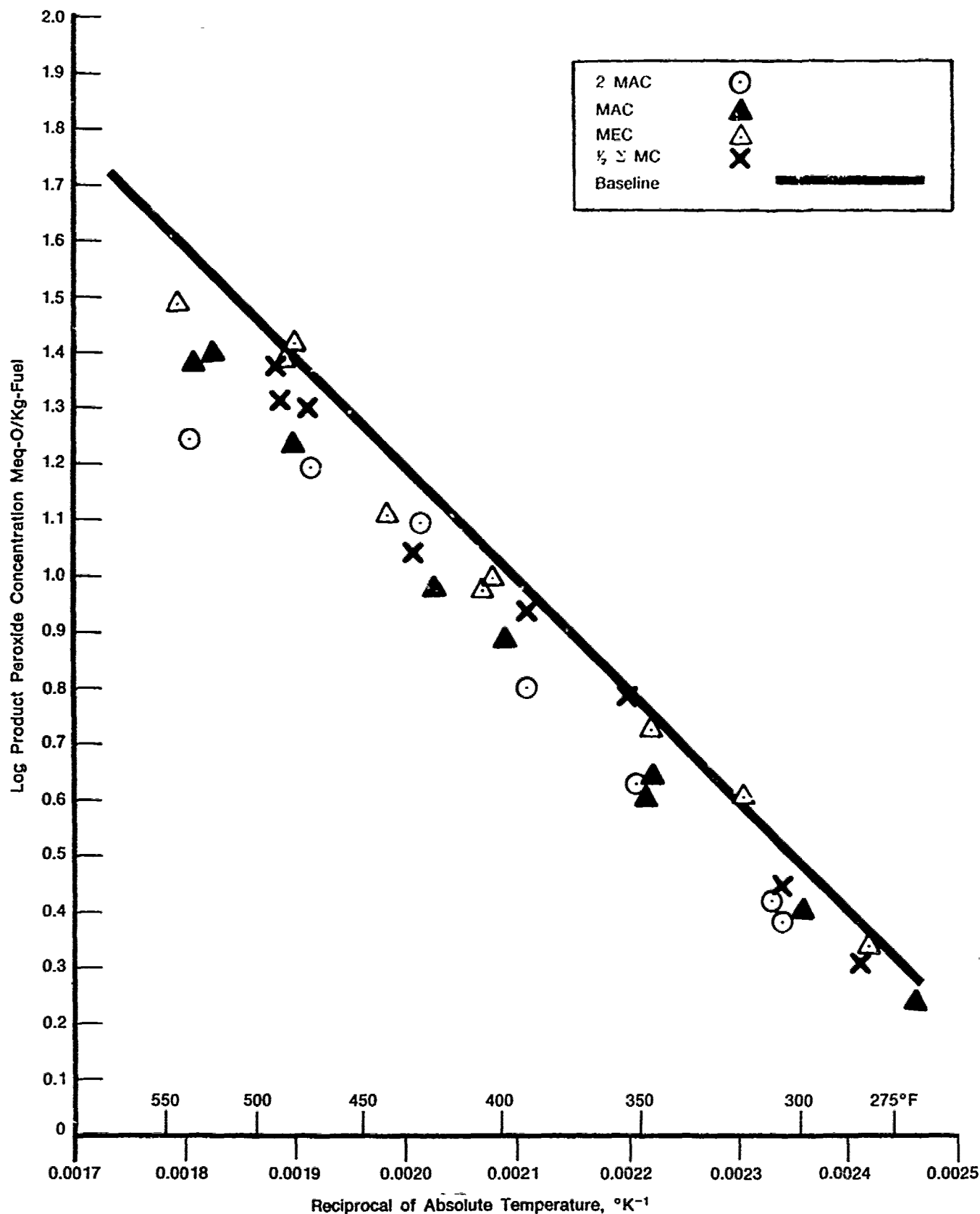
Figure D-20. *Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature, Effect of Antioxidant on a Clay Treated JP-4 Fuel with 35% Aromatics*

101
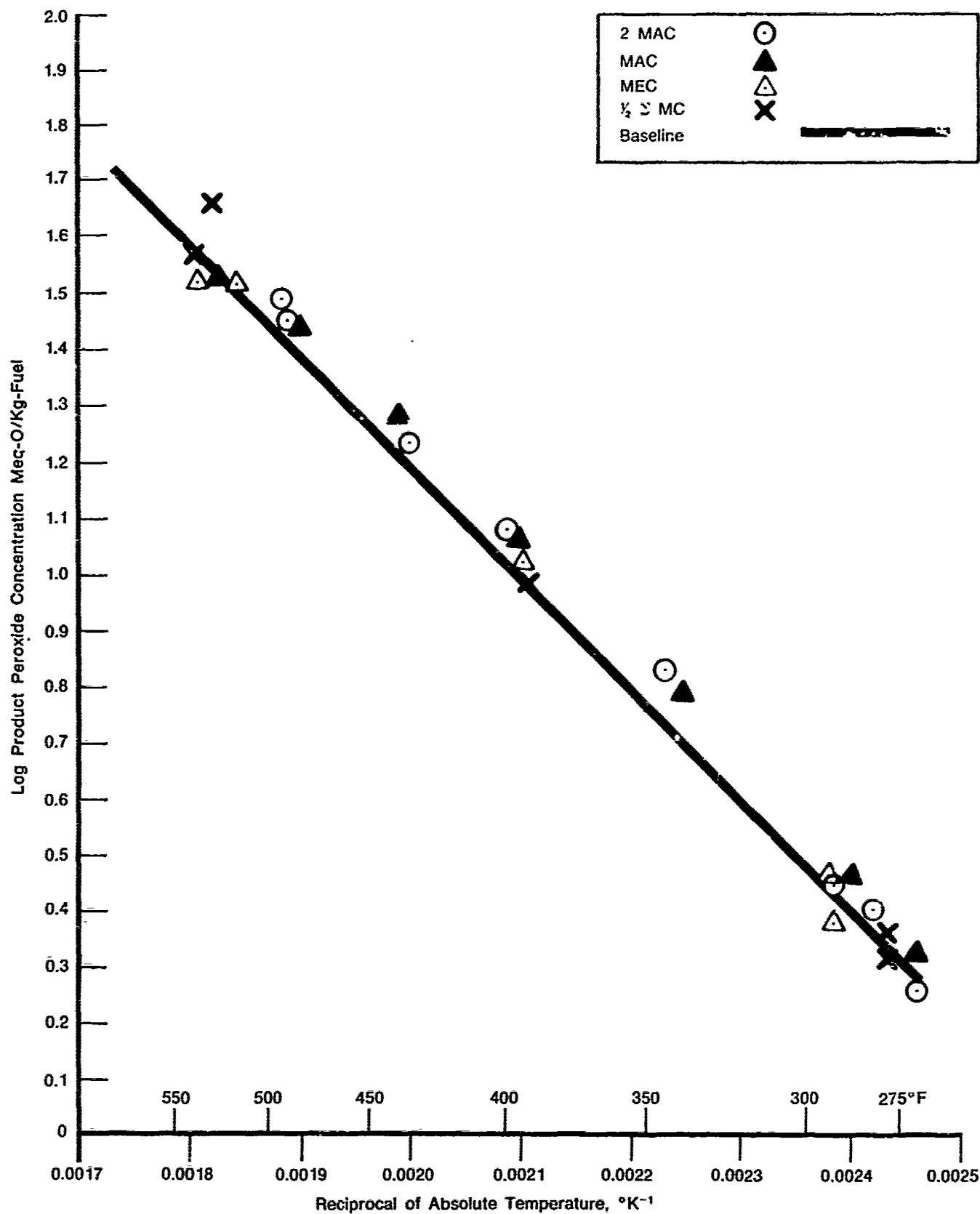
Figure D-21. *Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature, Effect of Corrosion Inhibitor on a Clay Treated JP-4 Fuel with 35% Aromatics*
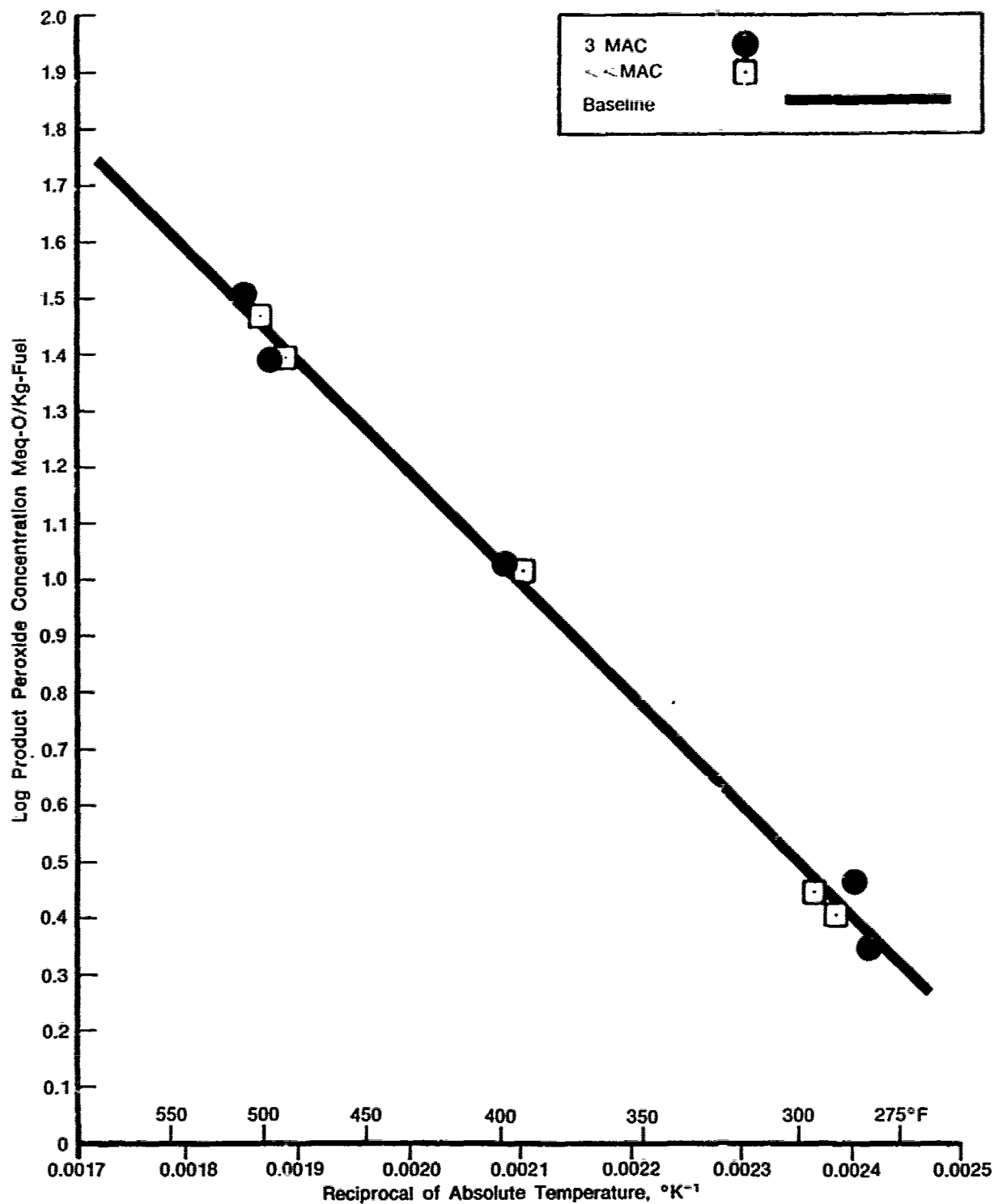
Figure D-22. Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature, Effect of Icing Inhibitor on a Clay Treated JP-4 Fuel with 35% Aromatics

103
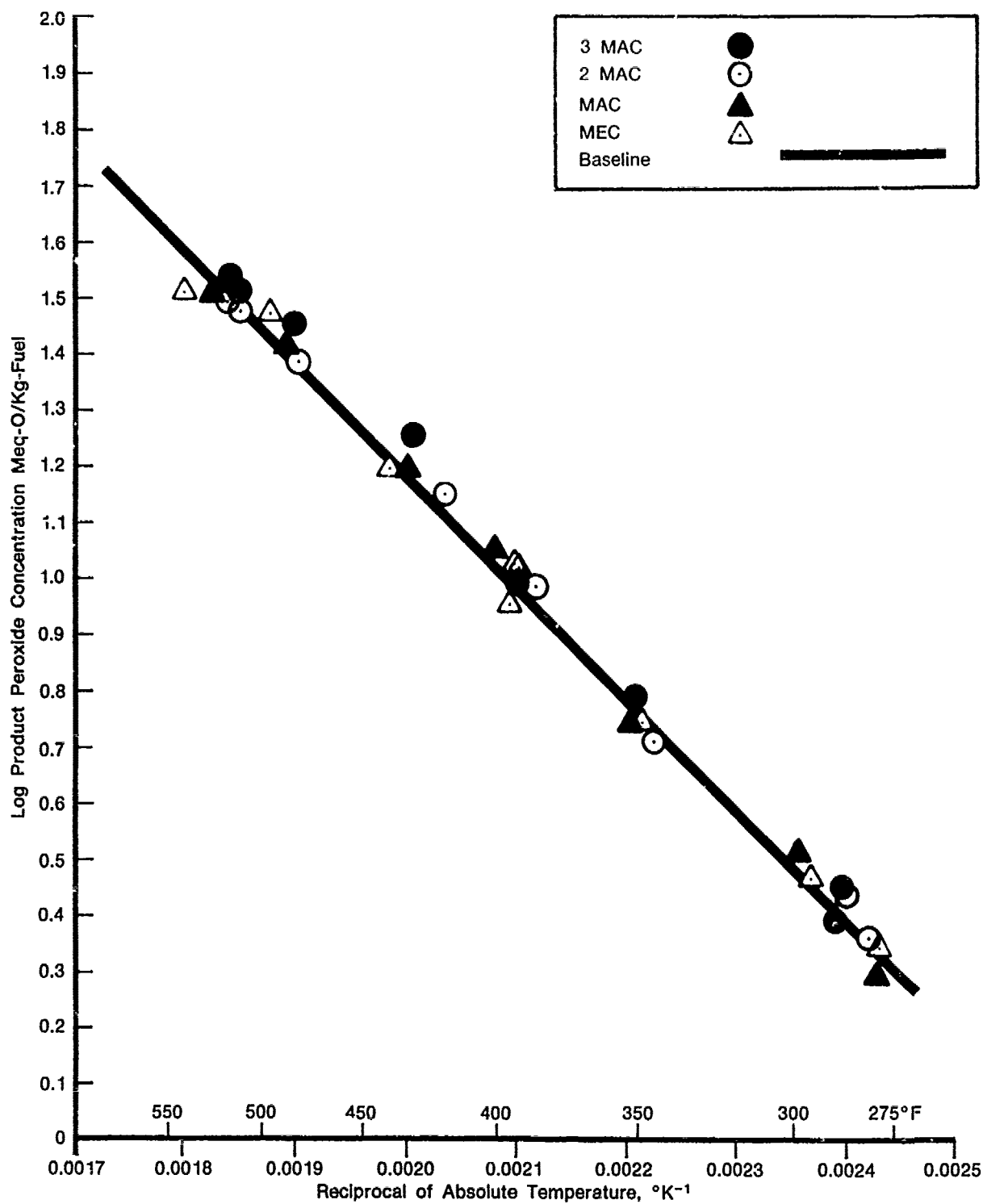
Figure D-23. *Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature, Effect of Conductivity Additive on a Clay Treated JP-4 Fuel 35% Aromatics*

104
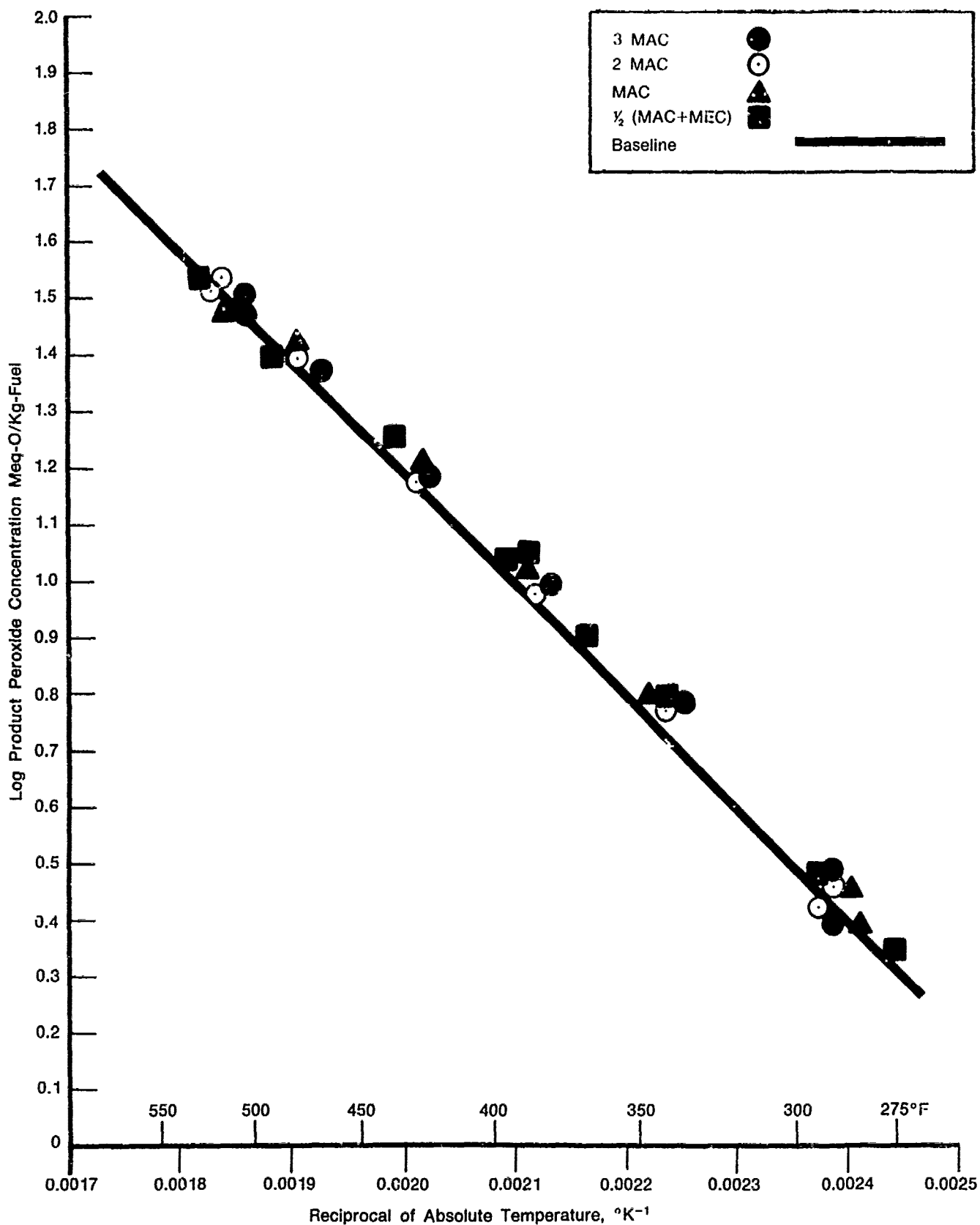
Figure D-24. Variation of Active Oxygen Expressed as Peroxide as a Function of Fuel Temperature, Effect of Metal Deactivator on a Clay Treated JP-4 Fuel with 35% Aromatics

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TABLE D-1
CLAY TREATED JP-8 BASELINE

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
260	0	0
275	0	0
315	8.6	1.1
359	13.3	1.7
362	15.9	2.0
393	23.3	2.8
440	31.0	3.9
441	32.4	4.0
483	50.5	6.3
539	68.4	8.5

Linear Regression Data:

0.002369/300°F =	−0.0426
0.002096/400°F =	0.4392
0.001876/500°F =	0.8276
0.001697/600°F =	1.1423

Activation Energy = 8077 cal/mole
Pre-exponential Factor = 1.373×10^4

TABLE D-2
CLAY TREATED JP-8, ANTIOXIDANT AT
TWICE MAXIMUM ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
512	47.2	5.9
501	40.3	5.0
466	25.4	3.2
458	27.0	3.4
390	15.0	1.9
382	13.6	1.7
351	9.9	1.2
333	9.4	1.2
299	BDL	—
276	BDL	—

Linear Regression Data:

0.002369/300°F =	−0.1379
0.002096/400°F =	0.3160
0.001876/500°F =	0.6819
0.001697/600°F =	0.9784

Activation Energy = 7609 cal/mole
Pre-exponential Factor = 6.316×10^7

TABLE D-3
CLAY TREATED JP-8, ANTIOXIDANT AT
THE MAXIMUM ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
531	50.0	6.3
497	36.8	4.6
472	35.2	4.4
423	20.5	2.6
381	14.2	1.8
350	10.6	1.3
302	8.4	1.0
281	BDL	—
276	BDL	—

Linear Regression Data:

0.002369/300°F =	−0.0508
0.002096/400°F =	0.3564
0.001876/500°F =	0.6847
0.001697/600°F =	0.9506

Activation Energy = 6826 cal/mole
Pre-exponential Factor = 3.034×10^3

TABLE D-4 ✦
CLAY TREATED JP-8, ANTIOXIDANT AT
MIDSPECIFICATION CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
516	53.2	6.7
491	48.1	6.0
473	38.4	4.8
469	32.0	4.0
431	25.8	3.2
388	16.2	2.0
376	11.1	1.4
330	9.7	1.2
291	BDL	—

Linear Regression Data:

0.002369/300°F =	−0.151
0.002096/400°F =	0.356
0.001876/500°F =	0.764
0.001697/600°F =	1.096

Activation Energy = 8507 cal/mole
Pre-exponential Factor = 1.7808×10^4

TABLE D-5 *
CLAY TREATED JP-8, ANTIOXIDANT AT
MINIMUM EFFECTIVE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
536	62.8	7.9
502	51.6	5.1
457	29.6	3.7
433	26.4	2.6
393	21.2	2.6
341	11.2	1.4
300	8.2	1.0
278	BDL	—
261	BDL	—

Linear Regression Data:

0.002369/300°F =	−0.0167
0.002096/400°F =	0.4179
0.001876/500°F =	0.7682
0.001697/600°F =	1.0521

Activation Energy = 7285 cal/mole
Pre-exponential Factor = 5.673×10^3

TABLE D-6
CLAY TREATED JP-8, CORROSION
INHIBITOR AT TWICE MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
281	BDL	—
284	8.5	1.1
394	18.2	2.3
407	18.6	2.3
512	55.6	6.9
514	59.0	7.4

Linear Regression Data:

0.002369/300°F =	−0.031
0.002096/400°F =	0.439
0.001876/500°F =	0.768
0.001697/600°F =	1.034

Activation Energy = 6840 cal/mole
Pre-exponential Factor = 3.723×10^3

TABLE D-7
CLAY TREATED JP-8, CORROSION
INHIBITOR AT MINIMUM
EFFECTIVE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
279	8.2	1.0
291	—	—
40ʌ	22.9	2.9
415	21.9	2.7
515	52.8	6.6
511	47.5	5.9

Linear Regression Data:

$0.002369/300°F =$	0.083
$0.002096/400°F =$	0.449
$0.001876/500°F =$	0.745
$0.001697/600°F =$	0.984

Activation Energy = 6146 cal/mole
Pre-exponential Factor = 1.836×10^3

TABLE D-8
CLAY TREATED JP-8, ICING
INHIBITOR AT LOW RELATIVE
CONCENTRATION RELATIVE TO MAXIMUM

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
273	BDL	—
284	1.6	0.2
396	21.8	2.7
402	21.1	2.6
521	55.0	6.9
520	50.9	6.4

Linear Regression Data:

$0.002369/300°F =$	−0.428
$0.002096/400°F =$	0.261
$0.001876/500°F =$	0.816
$0.001697/600°F =$	1.265

Activation Energy = 11,540 cal/mole
Pre-exponential Factor = 3.509×10^5

TABLE D-9
CLAY TREATED JP-8, ICING
INHIBITOR AT THREE TIMES
MAXIMUM ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
280	8.1	1.0
289	7.9	1.0
394	16.7	2.1
396	19.8	2.5
526	47.5	5.9
513	61.8	7.7

Linear Regression Data:

0.002369/300°F =	0.044
0.002096/400°F =	0.432
0.001876/500°F =	0.744
0.001697/600°F =	0.997

Activation Energy = 6,490 cal/mole
Pre-exponential Factor = 2.533×10^3

TABLE D-10
CLAY TREATED JP-8, CONDUCTIVITY
ADDITIVE AT THREE TIMES MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
289	7.9	1.0
322	7.8	1.0
348	12.3	1.5
398	17.9	2.2
447	36.8	4.6
488	42.8	5.3
511	48.0	6.0
516	57.0	7.1

Linear Regression Data:

0.002369/300°F =	−0.031
0.002096/400°F =	0.413
0.001876/500°F =	0.772
0.001697/600°F =	1.062

Activation Energy = 7,455 cal/mole
Pre-exponential Factor = 6.717×10^3

TABLE D-11
CLAY TREATED JP-8, CONDUCTIVITY
ADDITIVE AT TWICE MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
286	6.8	0.9
310	8.6	1.1
343	10.0	1.2
389	20.9	2.6
431	22.0	2.7
463	41.4	5.2
497	42.7	5.3
523	64.3	8.0

Linear Regression Data:

0.002369/300°F =	−0.036
0.002096/400°F =	0.414
0.001876/500°F =	0.777
0.001697/600°F =	1.072

Activation Energy = 7,552 cal/mole
Pre-exponential Factor = 7.456×10^3

TABLE D-12
CLAY TREATED JP-8, CONDUCTIVITY
ADDITIVE AT THE MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
283	BDL	—
289	9.2	1.2
316	9.9	1.2
355	12.0	1.5
400	20.7	2.6
443	26.1	3.3
485	55.7	7.0
521	50.8	6.4

Linear Regression Data:

0.002369/300°F =	0.031
0.002096/400°F =	0.434
0.001876/500°F =	0.759
0.001697/600°F =	1.023

Activation Energy = 6,757 cal/mole
Pre-exponential Factor = 3.377×10^3

TABLE D-13
CLAY TREATED JP-8, CONDUCTIVITY
ADDITIVE AT MINIMUM
EFFECTIVE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
283	6.2	0.8
317	7.3	0.9
400	23.0	2.9
446	29.0	3.6
497	56.2	7.0
535	76.0	9.5

Linear Regression Data:

0.002369/300°F =	-0.070
0.002096/400°F =	0.430
0.001876/500°F =	0.833
0.001697/600°F =	1.159

Activation Energy = 8,378 cal/mole
Pre-exponential Factor = 1.846×10^4

TABLE D-14
CLAY TREATED JP-8, METAL
DEACTIVATOR AT MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
528	67.8	8.5
494	48.3	6.0
424	34.8	4.3
362	18.2	2.3
319	8.2	1.0
289	8.1	1.0
289	7.8	1.0

Linear Regression Data:

0.002369/300°F =	0.0446
0.002096/400°F =	0.4828
0.001876/500°F =	0.8360
0.001697/600°F =	1.1222

Activation Energy = 7,345 cal/mole
Pre-exponential Factor = 7.0177×10^3

TABLE D-15
CLAY TREATED JP-8, METAL
DEACTIVATOR AT TWICE MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
511	63.0	7.9
492	53.1	6.6
419	33.1	4.1
418	24.8	3.1
358	17.1	2.1
319	12.0	1.5
285	6.5	0.8
284	7.1	0.9

Linear Regression Data:

0.002369/300°F =	0.0337
0.002096/400°F =	0.4885
0.001876/500°F =	0.8552
0.001697/600°F =	1.1523

Activation Energy = 7,625 cal/mole
Pre-exponential Factor = 9.551×10^3

TABLE D-16
CLAY TREATED JP-8, METAL
DEACTIVATOR AT THREE TIMES
MAXIMUM ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
527	78.5	9.8
511	73.1	9.1
474	41.7	5.2
408	27.4	3.4
358	18.5	2.3
321	15.1	1.9
291	8.4	1.1
281	6.0	0.7

Linear Regression Data:

0.002369/300°F =	0.0636
0.002096/400°F =	0.5205
0.001876/500°F =	0.8888
0.001697/600°F =	1.1872

Activation Energy = 7,659 cal/mole
Pre-exponential Factor = 1.0656×10^4

TABLE D-17
CLAY TREATED JP-4 BASELINE

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
257	6.5	0.8
279	6.8	9.8
329	17.5	2.2
374	26.6	3.3
401	30.1	3.8
435	79.9	10.0
480	105.6	13.2
482	116.8	14.6
535	158.8	19.9

Linear Regression Data:

0.002369/300°F =	0.133
0.002096/400°F =	0.715
0.001876/500°F =	1.184
0.001697/600°F =	1.564

Activation Energy = 9,758 cal/mole
Pre-exponential Factor = 1.524×10^5

TABLE D-18
CLAY TREATED JP-4, ANTIOXIDANT
AT TWICE MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
258	4.2	0.5
307	5.8	0.7
357	12.2	1.5
366	8.8	1.1
416	18.5	2.3
471	34.8	4.3
509	36.1	4.5
533	44.8	5.6

Linear Regression Data:

0.002369/300°F =	−0.125
0.002096/400°F =	0.303
0.001876/500°F =	0.648
0.001697/600°F =	0.928

Activation Energy = 7,175 cal/mole
Pre-exponential Factor = 3.879×10^3

TABLE D-19
CLAY TREATED JP-4, ANTIOXIDANT
AT THE MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
253	4.8	0.6
283	4.9	0.6
333	9.1	1.1
342	13.1	1.6
403	18.6	2.3
408	24.8	3.1
449	32.5	4.1
483	43.8	5.5
527	58.1	7.3
533	74.8	9.3

Linear Regression Data:

0.002369/300°F =	−0.015
0.002096/400°F =	0.419
0.001873/500°F =	0.794
0.001697/600°F =	1.097

Activation Energy = 7,788 cal/mole
Pre-exponential Factor = 9.672×10^3

TABLE D-20
CLAY TREATED JP-4, ANTIOXIDANT
AT MIDSPECIFICATION CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
252	5.6	0.7
283	5.9	0.73
325	12.2	1.52
327	10.2	1.3
391	27.9	3.5
428	30.6	4.1
472	42.1	5.3
480	56.7	7.1
519	67.6	8.5

Linear Regression Data:

0.002369/300°F =	0.040
0.002096/400°F =	0.500
0.001876/500°F =	0.871
0.001697/600°F =	1.171

Activation Energy = 7,710 cal/mole
Pre-exponential Factor = 1.074×10^4

TABLE D-21
CLAY TREATED JP-4, ANTIOXIDANT
AT MINIMUM EFFECTIVE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
283	7.2	0.9
278	6.7	0.8
321	12.6	1.6
369	18.4	2.3
391	29.5	3.7
421	33.2	4.1
440	36.3	4.5
472	66.4	8.3
485	58.4	7.3
532	89.3	11.2

Linear Regression Data:

0.002369/300°F =	0.056
0.002096/400°F =	0.546
0.001876/500°F =	0.942
0.001697/600°F =	1.262

Activation Energy = 8,218 cal/mole
Pre-exponential Factor = 2.040×10^4

TABLE D-22
CLAY TREATED JP-4, CORROSION
INHIBITOR AT MINIMUM
EFFECTIVE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
283	6.7	0.8
290	9.3	1.2
399	37.2	4.6
497	131.3	16.4
506	105.6	13.6

Linear Regression Data:

0.002369/300°F =	0.087
0.002096/400°F =	0.683
0.001876/500°F =	1.164
0.001697/600°F =	1.553

Activation Energy = 9,995 cal/mole
Pre-exponential Factor = 1.82×10^5

TABLE D-23
CLAY TREATED JP-4, CORROSION
INHIBITOR AT TWICE MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
285	10.2	1.3
287	7.4	0.9
400	52.1	6.5
509	107.2	13.4
510	144.4	18.1

Linear Regression Data:

$0.002369/300°F =$	0.150
$0.002096/400°F =$	0.720
$0.001876/500°F =$	1.179
$0.001697/600°F =$	1.551

Activation Energy = 9,553 cal/mole
Pre-exponential Factor = 1.243×10^5

TABLE D-24
CLAY TREATED JP-4, ICING
INHIBITOR AT THREE TIMES
MAXIMUM ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
300	9.2	1.2
302	12.1	1.5
393	46.3	5.8
491	90.4	11.3
497	124.9	15.6

Linear Regression Data:

$0.002369/300°F =$	0.134
$0.002096/400°F =$	0.709
$0.001876/500°F =$	1.172
$0.001697/600°F =$	1.548

Activation Energy = 9,634 cal/mole
Pre-exponential Factor = 1.319×10^5

TABLE D-25
CLAY TREATED JP-4, ICING INHIBITOR AT LOW RELATIVE CONCENTRATION TO MAXIMUM

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
296	8.4	1.0
306	10.7	1.3
399	45.3	5.7
490	98.7	12.3
540	138.3	17.3

Linear Regression Data:

0.002369/300°F =	0.092
0.002096/400°F =	0.665
0.001876/500°F =	1.128
0.001697/600°F =	1.502

Activation Energy = 9,613 cal/mole
Pre-exponential Factor = 1.168×10^5

TABLE D-26
CLAY TREATED JP-4, CONDUCTIVITY AT MINIMUM EFFECTIVE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
280	8.6	1.1
296	8.3	1.0
312	15.7	2.0
342	17.4	2.2
396	33.7	4.2
444	77.6	9.7
492	97.7	12.2
508	157.6	19.7
409	46.3	5.8

Linear Regression Data:

0.002369/300°F =	0.122
0.002096/400°F =	0.712
0.001876/500°F =	1.188
0.001697/600°F =	1.574

Activation Energy = 9,897 cal/mole
Pre-exponential Factor = 1.755×10^5

TABLE D-27
CLAY TREATED JP-4, CONDUCTIVITY
ADDITIVE AT TWICE MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
282	8.6	1.1
289	11.1	1.4
317	14.3	1.8
354	32.5	4.1
404	46.2	5.8
454	110.8	13.9
516	172.2	21.5
521	222.3	27.8

Linear Regression Data:

0.002369/300°F =	0.184
0.002096/400°F =	0.809
0.001876/500°F =	1.312
0.001697/600°F =	1.720

Activation Energy = 10,741 cal/mole
Pre-exponential Factor = 4.016×10^5

TABLE D-28
CLAY TREATED JP-4, CONDUCTIVITY
ADDITIVE AT THE MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
284	7.8	1.0
290	6.7	0.8
304	12.8	1.6
349	18.4	2.3
396	86.7	10.8
449	94.4	11.8
509	158.8	19.9
512	176.6	22.1

Linear Regression Data:

0.002369/300°F =	0.114
0.002096/400°F =	0.787
0.001876/500°F =	1.330
0.001697/600°F =	1.770

Activation Energy = 11,290 cal/mole
Pre-exponential Factor = 9.062×10^5

TABLE D-29
CLAY TREATED JP-4, CONDUCTIVITY
ADDITIVE AT THREE TIMES MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Pa. per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
279	27.7	1.6
300	14.8	1.8
340	22.1	2.8
360	36.3	4.5
398	48.4	6.0
449	129.2	15.2
529	264.4	33.1
533	201.9	25.2

Linear Regression Data:

0.002369/300°F =	0.276
0.002096/400°F =	0.864
0.001876/500°F =	1.337
0.001697/600°F =	1.721

Activation Energy = 9,847 cal/mole
Pre-exponential Factor = 2.631×10^5

TABLE D-30
CLAY TREATED JP-4, METAL
DEACTIVATOR AT THREE TIMES
MAXIMUM ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
383	51.9	6.5
280	12.1	1.5
288	12.4	1.6
316	17.1	2.1
469	174.6	21.8
511	255.4	31.9
518	293.6	36.7
347	37.6	4.7

Linear Regression Data:

0.002369/300°F =	0.290
0.002096/400°F =	0.943
0.001876/500°F =	1.469
0.001697/600°F =	1.896

Activation Energy = 10,951 cal/mole
Pre-exponential Factor = 9.066×10^5

TABLE D-31
CLAY TREATED JP-4, METAL
DEACTIVATOR AT TWICE MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
286	9.3	1.2
293	14.9	1.9
321	15.3	1.9
352	33.6	4.2
391	40.3	5.0
449	98.8	12.4
499	186.8	23.4
505	203.3	25.4
528	222.3	27.8

Linear Regression Data:

0.002369/300°F =	0.213
0.002096/400°F =	0.839
0.001876/500°F =	1.344
0.001697/600°F =	1.752

Activation Energy = 10,492 cal/mole
Pre-exponential Factor = 4.401×10^5

TABLE D-32
CLAY TREATED JP-4, METAL
DEACTIVATOR AT THE MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
282	10.2	1.3
292	11.3	1.4
317	13.6	1.7
351	30.8	3.8
396	42.7	5.3
456	107.8	13.5
519	162.4	20.3
526	195.5	24.4

Linear Regression Data:

0.002369/300°F =	0.201
0.002096/400°F =	0.792
0.001876/500°F =	1.268
0.001697/600°F =	1.654

Activation Energy = 9,899 cal/mole
Pre-exponential Factor = 2.114×10^5

TABLE D-33
CLAY TREATED JP-4, METAL
DEACTIVATOR AT
MIDSPECIFICATION CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
283	7.3	0.9
296	13.3	1.7
322	14.1	1.8
356	31.6	3.9
361	21.9	2.7
395	44.7	5.6
450	91.8	11.5
518	148.9	18.6
534	209.8	26.2

Linear Regression Data:

0.002369/300°F =	0.148
0.002096/400°F =	0.757
0.001876/500°F =	1.249
0.001697/600°F =	1.647

Activation Energy = 10,221 cal/mole
Pre-exponential Factor = 2.41×10^5

TABLE D-34
CLAY TREATED JP-4 WITH 25%
AROMATICS BASELINE

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
393	49.7	6.2
260	11.3	1.4
263	7.3	0.9
313	23.8	3.0
362	31.6	3.9
431	71.2	8.9
436	100.8	12.6
492	165.3	20.7
513	179.8	22.5
540	239.4	29.9

Linear Regression Data:

0.002369/300°F =	0.314
0.002096/400°F =	0.865
0.001876/500°F =	1.309
0.001697/600°F =	1.669

Activation Energy = 9,239 cal/mole
Pre-exponential Factor = 1.247×10^5

TABLE D-35
CLAY TREATED JP-4 WITH 25%
AROMATICS, ANTIOXIDANT AT TWICE
MAXIMUM ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
271	10.3	1.3
304	14.8	1.8
318	23.6	2.9
359	25.2	3.1
399	44.8	5.6
437	91.3	11.4
443	68.2	8.5
496	138.4	17.3
544	176.2	22.0

Linear Regression Data:

0.002369/300°F =	0.276
0.002096/400°F =	0.792
0.001876/500°F =	1.208
0.001697/600°F =	1.545

Activation Energy = 8,652 cal/mole
Pre-exponential Factor = 5.678×10^4

TABLE D-36
CLAY TREATED JP-4 WITH 25%
AROMATICS, ANTIOXIDANT AT
MAXIMUM ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
265	9.8	1.2
296	13.6	1.7
309	16.8	2.1
362	34.8	4.3
352	28.6	3.6
389	32.6	4.1
444	83.7	10.5
504	129.6	16.2
545	181.3	22.7

Linear Regression Data:

0.002369/300°F =	0.270
0.002096/400°F =	0.779
0.001876/500°F =	1.189
0.001697/600°F =	1.521

Activation Energy = 8,526 cal/mole
Pre-exponential Factor = 4.821×10^4

TABLE D-37
CLAY TREATED JP-4 WITH 25% AROMATICS, ANTIOXIDANT AT THE MIDSPECIFICATION CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
275	13.8	1.7
261	8.8	1.1
319	18.3	2.3
280	11.4	1.4
349	27.4	3.4
355	22.9	2.9
392	46.3	5.8
443	88.6	11.1
495	133.6	16.7
492	124.4	15.5
537	188.6	23.6

Linear Regression Data:

0.002369/300°F =	0.283
0.002096/400°F =	0.803
0.001876/500°F =	1.223
0.001697/600°F =	1.562

Activation Energy = 8,720 cal/mole
Pre-exponential Factor = 6.257×10^4

TABLE D-38
CLAY TREATED JP-4 WITH 25% AROMATICS, ANTIOXIDANT AT MINIMUM EFFECTIVE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
256	9.5	1.2
285	14.2	1.8
315	14.7	1.8
350	29.4	3.7
385	55.6	7.0
429	64.8	8.1
482	148.6	18.6
527	166.5	20.8
543	208.6	26.1

Linear Regression Data:

0.002369/300°F =	0.307
0.002096/400°F =	0.833
0.001876/500°F =	1.256
0.001697/600°F =	1.600

Activation Energy = 8,810 cal/mole
Pre-exponential Factor = 7.366×10^4

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TABLE D-39
CLAY TREATED JP-4 WITH 25%
AROMATICS, CORROSION INHIBITOR
AT TWICE MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
286	14.3	1.8
320	26.2	3.3
354	31.7	4.0
389	66.3	8.3
395	60.8	7.6
446	122.4	15.3
493	142.3	17.8
501	190.8	23.9

Linear Regression Data:

0.002369/300°F =	0.359
0.002096/400°F =	0.909
0.001876/500°F =	1.353
0.001697/600°F =	1.713

Activation Energy = 9,229 cal/mole
Pre-exponential Factor = 1.366×10^5

TABLE D-40
CLAY TREATED JP-4 WITH 25%
AROMATICS, CORROSION INHIBITOR
AT MAXIMUM ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
289	14.3	1.8
291	17.7	2.2
394	64.6	8.1
491	152.7	19.1
501	173.3	21.1

Linear Regression Data:

0.002369/300°F =	0.368
0.002096/400°F =	0.902
0.001876/500°F =	1.333
0.001697/600°F =	1.682

Activation Energy = 8,953 cal/mole
Pre-exponential Factor = 1.005×10^5

TABLE D-41
CLAY TREATED JP-4 WITH 25%
AROMATICS, CORROSION INHIBITOR
AT MIDSPECIFICATION CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
285	13.6	1.7
292	14.8	1.8
398	56.8	7.1
496	221.3	27.7
497	155.5	19.4

Linear Regression Data:

0.002369/300°F =	0.320
0.002096/400°F =	0.900
0.001876/500°F =	1.367
0.001697/600°F =	1.746

Activation Energy = 9,725 cal/mole
Pre-exponential Factor = 2.255×10^5

TABLE D-42
CLAY TREATED JP-4 WITH 25%
AROMATICS, CORROSION INHIBITOR
AT MINIMUM EFFECTIVE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
298	17.1	2.1
298	13.8	1.7
399	65.2	8.1
496	163.5	20.4
504	155.1	19.4

Linear Regression Data:

0.002369/300°F =	0.309
0.002096/400°F =	0.864
0.001876/500°F =	1.312
0.001697/600°F =	1.675

Activation Energy = 9,314 cal/mole
Pre-exponential Factor = 1.346×10^5

TABLE D-43
CLAY TREATED JP-4 WITH 25%
AROMATICS, ICING INHIBITOR AT
THREE TIMES ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
283	13.2	1.6
285	14.1	1.8
398	56.2	7.0
499	142.3	17.8
509	198.3	24.8

Linear Regression Data:

0.002369/300°F =	0.330
0.002096/400°F =	0.869
0.001876/500°F =	1.303
0.001697/600°F =	1.655

Activation Energy = 9,037 cal/mole
Pre-exponential Factor = 1.016×10^5

TABLE D-44
CLAY TREATED JP-4 WITH 25%
AROMATICS, ICING INHIBITOR AT
LOW RELATIVE CONCENTRATION
RELATIVE TO MAXIMUM

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
277	13.3	1.7
294	14.4	1.8
399	64.2	8.0
522	182.2	22.8
516	193.8	24.2

Linear Regression Data:

0.002369/300°F =	0.339
0.002096/400°F =	0.875
0.001876/500°F =	1.306
0.001697/600°F =	1.556

Activation Energy = 8,973 cal/mole
Pre-exponential Factor = 9.627×10^4

TABLE D-45
CLAY TREATED JP-4 WITH 25%
AROMATICS, CONDUCTIVITY ADDITIVE
AT THREE TIMES MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
292	18.6	2.3
299	17.1	2.1
325	29.3	3.7
361	56.2	7.0
362	47.6	6.0
405	77.3	9.7
448	149.7	18.7
491	172.7	21.6
497	208.9	26.1

Linear Regression Data:

0.002369/300°F =	0.406
0.002096/400°F =	0.975
0.001876/500°F =	1.434
0.001697/600°F =	1.805

Activation Energy = 9,539 cal/mole
Pre-exponential Factor = 2.203×10^5

TABLE D-46
CLAY TREATED JP-4 WITH 25%
AROMATICS, CONDUCTIVITY ADDITIVE
AT TWICE MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
300	24.2	3.0
296	19.6	2.4
327	28.1	3.5
368	47.3	5.9
409	73.2	9.1
457	116.3	14.5
490	171.2	21.4
492	162.2	20.3

Linear Regression Data:

0.002369/300°F =	0.428
0.002096/400°F =	0.931
0.001876/500°F =	1.337
0.001697/600°F =	1.666

Activation Energy = 8,439 cal/mole
Pre-exponential Factor = 6.245×10^4

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TABLE D-47
CLAY TREATED JP-4 WITH 25%
AROMATICS, CONDUCTIVITY ADDITIVE
AT MAXIMUM ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
292	17.6	2.2
304	18.1	2.3
327	23.7	3.0
369	43.4	5.4
407	68.2	8.5
449	94.3	11.8
497	156.1	19.5
498	164.6	20.6

Linear Regression Data:

0.002369/300°F =	0.351
0.002096/400°F =	0.878
0.001876/500°F =	1.302
0.001697/600°F =	1.646

Activation Energy = 8,828 cal/mole
Pre-exponential Factor = 8.321×10^4

TABLE D-48
CLAY TREATED JP-4 WITH 25%
AROMATICS, CONDUCTIVITY ADDITIVE
AT MINIMUM EFFECTIVE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
287	13.1	1.6
304	18.6	2.3
324	24.7	3.1
365	36.2	4.5
407	68.3	8.5
455	128.4	16.1
494	159.3	19.9
507	183.4	22.9

Linear Regression Data:

0.002369/300°F =	0.320
0.002096/400°F =	0.887
0.001876/500°F =	1.344
0.001697/600°F =	1.715

Activation Energy = 9,580 cal/mole
Pre-exponential Factor = 1.741×10^5

TABLE D-49
CLAY TREATED JP-4 WITH 25%
AROMATICS, METAL DEACTIVATOR
AT MINIMUM EFFECTIVE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
327	27.4	3.4
279	12.6	1.6
297	19.4	2.4
356	45.7	5.7
400	54.7	6.8
446	113.9	14.2
493	145.6	18.2
510	182.3	22.8
528	204.4	25.6

Linear Regression Data:

0.002369/300°F =	0.378
0.002096/400°F =	0.897
0.001876/500°F =	1.316
0.001697/600°F =	1.654

Activation Energy = 8,698 cal/mole
Pre-exponential Factor = 7.593×10^4

TABLE D-50
CLAY TREATED JP-4 WITH 25%
AROMATICS, METAL DEACTIVATOR
AT MAXIMUM ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
280	13.7	1.7
297	17.6	2.2
324	23.4	2.9
363	42.6	5.3
402	64.4	8.0
451	151.3	18.9
499	156.2	19.5
517	211.3	26.4

Linear Regression Data:

0.002369/300°F =	0.357
0.002096/400°F =	0.914
0.001876/500°F =	1.363
0.001697/600°F =	1.727

Activation Energy = 9,337 cal/mole
Pre-exponential Factor = 1.547×10^5

TABLE D-51
CLAY TREATED JP-4 WITH 25%
AROMATICS, METAL DEACTIVATOR
AT TWICE MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
271	14.8	1.8
292	16.9	2.1
318	24.9	3.1
358	38.2	4.8
393	54.2	6.8
447	120.2	15.0
491	172.3	21.5
516	183.2	22.9

Linear Regression Data:

0.002369/300°F =	0.396
0.002096/400°F =	0.913
0.001876/500°F =	1.329
0.001697/600°F =	1.667

Activation Energy = 8,667 cal/mole
Pre-exponential Factor = 7.616×10^4

TABLE D-52.
CLAY TREATED JP-4 WITH 25%
AROMATICS, METAL DEACTIVATOR
AT THREE TIMES MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
274	14.1	1.8
292	22.8	2.9
322	27.3	3.4
357	35.5	4.4
360	48.2	6.0
401	80.3	10.0
433	103.2	12.9
478	151.3	18.9
498	213.7	27.3
501	191.3	23.9

Linear Regression Data:

0.002369/300°F =	0.427
0.002096/400°F =	0.960
0.001876/500°F =	1.389
0.001697/600°F =	1.737

Activation Energy = 8,931 cal/mole
Pre-exponential Factor = 1.120×10^5

TABLE D-53
CLAY TREATED JP-4 WITH 35%
AROMATICS BASELINE

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
257	11.2	1.4
291	22.4	2.8
313	24.9	3.1
315	34.2	4.3
351	39.2	4.9
395	86.0	10.7
422	87.3	10.9
451	146.2	18.3
459	129.4	16.2
498	224.7	28.0
516	248.4	31.0

Linear Regression Data:

0.002369/300°F =	0.460
0.002096/400°F =	0.995
0.001876/500°F =	1.426
0.001697/600°F =	1.776

Activation Energy = 8,969 cal/mole
Pre-exponential Factor = 1.265×10^5

TABLE D-54
CLAY TREATED JP-4 WITH 35%
AROMATICS, ANTIOXIDANT AT
MINIMUM EFFECTIVE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
262	13.6	1.7
284	17.3	2.2
321	32.2	4.0
351	42.4	5.3
406	79.6	9.9
410	76.0	9.5
448	102.5	12.8
488	206.6	25.8
494	194.3	24.3
546	245.7	30.7

Linear Regression Data:

0.002369/300°F =	0.454
0.002096/400°F =	0.962
0.001876/500°F =	1.372
0.001697/600°F =	1.703

Activation Energy = 8,515 cal/mole
Pre-exponential Factor = 7.263×10^4

TABLE D-55
CLAY TREATED JP-4 WITH 35%
AROMATICS, ANTIOXIDANT AT
MIDSPECIFICATION CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
256	11.9	1.5
287	16.3	2.0
311	22.4	2.8
359	48.4	6.0
394	68.8	8.6
438	88.2	11.0
483	159.3	19.9
498	191.0	23.9
529	164.7	20.6

Linear Regression Data:

0.002369/300°F =	0.423
0.002096/400°F =	0.918
0.001876/500°F =	1.317
0.001697/600°F =	1.640

Activation Energy = 8,292 cal/mole
Pre-exponential Factor = 5.189×10^4

TABLE D-56
CLAY TREATED JP-4 WITH 35%
AROMATICS, ANTIOXIDANT AT
MAXIMUM ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
271	13.7	1.7
304	20.1	2.5
351	34.8	4.3
353	32.1	4.0
402	61.1	7.6
429	76.1	9.5
490	136.2	17.0
529	198.4	24.8
538	191.3	23.9

Linear Regression Data:

0.002369/300°F =	0.375
0.002096/400°F =	0.866
0.001876/500°F =	1.262
0.001697/600°F =	1.583

Activation Energy = 8,234 cal/mole
Pre-exponential Factor = 4.329×10^4

TABLE D-57
CLAY TREATED JP-4 WITH 35%
AROMATICS, ANTIOXIDANT AT TWICE
MAXIMUM ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
262	12.2	1.5
310	19.2	2.4
313	21.3	2.7
356	33.8	4.2
394	50.4	6.3
434	100.3	12.5
482	124.3	15.5
538	141.7	17.7

Linear Regression Data:

0.002369/300°F =	0.373
0.002096/400°F =	0.838
0.001876/500°F =	1.213
0.001697/600°F =	1.516

Activation Energy = 7,787 cal/mole
Pre-exponential Factor = 2.534×10^4

TABLE D-58
CLAY TREATED JP-4 WITH 35%
AROMATICS, CORROSION INHIBITOR
AT TWICE MAXIMUM ALLOWABLE
CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
273	14.3	1.8
285	19.9	2.5
296	22.3	2.8
349	53.4	6.7
404	94.4	11.8
443	133.6	16.7
496	224.7	28.1
499	241.6	30.2

Linear Regression Data:

0.002369/300°F =	0.478
0.002096/400°F =	1.034
0.001876/500°F =	1.483
0.001697/600°F =	1.846

Activation Energy = 9,330 cal/mole
Pre-exponential Factor = 2.026×10^5

TABLE D-59
CLAY TREATED JP-4 WITH 35%
AROMATICS, CORROSION INHIBITOR
AT MAXIMUM ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
273	16.7	2 1
291	23.2	2.9
343	48.3	6.0
400	89.8	11.2
446	149.2	18.7
493	218.7	27.3
527	265.3	33.2

Linear Regression Data:

0.002369/300°F =	0.516
0.002096/400°F =	1.038
0.001876/500°F =	1.459
0.001697/600°F =	1.800

Activation Energy = 8,749 cal/mole
Pre-exponential Factor = 1.108×10^5

TABLE D-60
CLAY TREATED JP-4 WITH 35%
AROMATICS, CORROSION INHIBITOR
AT MIDSPECIFICATION CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
280	16.2	2.0
281	18.1	2.3
396	76.3	9.5
531	264.7	45.6
540	291.5	36.4

Linear Regression Data:

0.002369/300°F =	0.456
0.002096/400°F =	1.016
0.001876/500°F =	1.467
0.001697/600°F =	1.833

Activation Energy = 9,383 cal/mole
Pre-exponential Factor = 2.054×10^5

TABLE D-61
CLAY TREATED JP-4 WITH 35%
AROMATICS, CORROSION INHIBITOR
AT MINIMUM EFFECTIVE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
296	18.9	2.4
297	22.6	2.7
399	82.7	10.3
520	258.6	32.3
539	262.2	32.8

Linear Regression Data:

0.002369/300°F =	0.440
0.002096/400°F =	0.978
0.001876/500°F =	1.411
0.001697/600°F =	1.763

Activation Energy = 9,019 cal/mole
Pre-exponential Factor = 1.281×10^5

TABLE D-62
CLAY TREATED JP-4 WITH 35%
AROMATICS, ICING INHIBITOR
AT THREE TIMES MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
287	17.8	2.2
292	23.4	2.9
405	85.3	10.7
502	194.6	24.3
513	254.3	31.8

Linear Regression Data:

0.002369/300°F =	0.472
0.002096/400°F =	0.992
0.001876/500°F =	1.419
0.001697/600°F =	1.762

Activation Energy = 8,795 cal/mole
Pre-exponential Factor = 1.056×10^5

TABLE D-63
CLAY TREATED JP-4 WITH 35%
AROMATICS, ICING INHIBITOR AT
LOW RELATIVE CONCENTRATION
RELATIVE TO MAXIMUM

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel by
296	20.3	2.5
302	22.4	2.8
398	83.4	10.4
494	197.3	24.7
507	233.7	29.2

Linear Regression Data:

0.002369/300°F =	0.441
0.002096/400°F =	0.992
0.001876/500°F =	1.436
0.001697/600°F =	1.796

Activation Energy = 9,241 cal/mole
Pre-exponential Factor = 1.674×10^5

TABLE D-64
CLAY TREATED JP-4 WITH 35%
AROMATICS, CONDUCTIVITY ADDITIVE
AT THREE TIMES MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
294	19.7	2.5
292	22.6	2.8
356	49.8	6.2
396	79.6	9.9
438	140.6	17.6
488	228.6	28.6
514	258.6	32.3
517	271.4	33.9

Linear Regression Data:

0.002369/300°F =	0.469
0.002096/400°F =	1.027
0.001876/500°F =	1.478
0.001697/600°F =	1.843

Activation Energy = 9,365 cal/mole
Pre-exponential Factor = 2.069×10^5

TABLE D-65
CLAY TREATED JP-4 WITH 35%
AROMATICS, CONDUCTIVITY ADDITIVE
AT TWICE MAXIMUM ALLOWABLE
CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
290	21.8	2.7
284	18.6	2.3
349	47.2	5.9
391	77.2	9.6
425	113.5	14.2
486	194.3	24.3
513	239.8	30.0
516	241.5	30.2

Linear Regression Data:

0.002369/300°F =	0.490
0.002096/400°F =	1.014
0.001876/500°F =	1.437
0.001697/600°F =	1.779

Activation Energy = 8,790 cal/mole
Pre-exponential Factor = 1.094×10^5

TABLE D-66
CLAY TREATED JP-4 WITH 35%
AROMATICS, CONDUCTIVITY ADDITIVE
AT MAXIMUM ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
281	15.9	2.0
304	26.2	3.3
357	44.3	5.5
400	84.3	10.5
405	89.9	11.2
440	124.3	15.5
492	208.7	26.1
526	256.4	32.1

Linear Regression Data:

0.002369/300°F =	0.453
0.002096/400°F =	0.998
0.001876/500°F =	1.437
0.001697/600°F =	1.792

Activation Energy = 9,127 cal/mole
Pre-exponential Factor = 1.504×10^5

TABLE D-67
CLAY TREATED JP-4 WITH 35%
AROMATICS, CONDUCTIVITY ADDITIVE
AT MINIMUM EFFECTIVE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
281	17.7	2.2
301	23.4	2.9
354	44.8	5.6
400	72.4	9.0
399	83.7	10.5
447	126.3	15.8
499	236.4	29.6
540	258.3	32.3

Linear Regression Data:

0.002369/300°F =	0.461
0.002096/400°F =	0.988
0.001876/500°F =	1.412
0.001697/600°F =	1.756

Activation Energy = 8,825 cal/mole
Pre-exponential Factor = 1.069×10^5

TABLE D-68
CLAY TREATED JP-4 WITH 35%
AROMATICS, CONDUCTIVITY ADDITIVE
AT THREE TIMES MAXIMUM
ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
294	19.7	2.5
296	24.6	3.1
339	48.7	6.1
384	79.6	9.9
430	121.7	15.2
475	187.8	23.5
508	257.7	32.2
509	239.6	30.0

Linear Regression Data:

0.002369/300°F =	0.501
0.002096/400°F =	1.039
0.001876/500°F =	1.473
0.001697/600°F =	1.825

Activation Energy = 9,021 cal/mole
Pre-exponential Factor = 1.481×10^5

TABLE D-69
CLAY TREATED JP-4 WITH 35%
AROMATICS, METAL DEACTIVATOR
AT TWICE MAXIMUM ALLOWABLE
CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
294	23.6	2.9
298	21.2	2.6
345	47.2	5.9
390	76.3	9.5
435	119.3	14.9
485	197.9	27.7
520	274.8	34.4
423	269.4	33.7

Linear Regression Data:

0.002369/300°F =	0.483
0.002096/400°F =	1.020
0.001876/500°F =	1.452
0.001697/600°F =	1.802

Activation Energy = 8,990 cal/mole
Pre-exponential Factor = 1.369×10^5

TABLE D-70
CLAY TREATED JP-4 WITH 35%
AROMATICS, METAL DEACTIVATOR
AT MAXIMUM ALLOWABLE CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
286	19.8	2.5
288	22.6	2.8
350	49.6	6.2
394	85.3	10.7
433	127.8	16.0
485	209.8	26.2
518	238.4	29.8

Linear Regression Data:

0.002369/300°F =	0.512
0.002096/400°F =	1.033
0.001876/500°F =	1.453
0.001697/600°F =	1.793

Activation Energy = 8,734 cal/mole
Pre-exponential Factor = 1.078×10^5

TABLE D-71
CLAY TREATED JP-4 WITH 35%
AROMATICS, METAL DEACTIVATOR
AT MIDSPECIFICATION CONCENTRATION

ECA Test Temperature (°F)	Parts per Million of Peroxide	Milliequivalents of Oxygen per Kilogram of Fuel
277	17.8	2.2
296	23.9	3.0
345	48.3	6.0
371	63.5	7.9
394	85.6	10.7
399	86.3	10.8
444	142.7	17.8
496	197.6	24.7
529	269.5	33.7

Linear Regression Data:

0.002369/300°F =	0.513
0.002096/400°F =	1.027
0.001876/500°F =	1.441
0.001697/600°F =	1.777

Activation Energy = 8,613 cal/mole
Pre-exponential Factor = 9.354×10^4