AFWAL-TR-85-2045

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AD-A161 667

# F100 FUEL SAMPLING ANALYSIS

L. Q. Maurice
Fuels Branch
Fuels and Lubrication Division

September 1985

Final Report for Period May 1983 - April 1984

Approved for Public Release; Distribution Unlimited.

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AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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Lourdes Q Maurice
LOURDES Q. MAURICE
Fuels Branch
Fuels and Lubrication Division
Aero Propulsion Laboratory

Arthur V. Churchill
ARTHUR V. CHURCHILL, Chief
Fuels Branch
Fuels and Lubrication Division
Aero Propulsion Laboratory

FOR THE COMMANDER

Robert D. Sherrill
ROBERT D. SHERRILL, Chief
Fuels and Lubrication Division
Aero Propulsion Laboratory

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

AD-A161 669

## REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE

3. DISTRIBUTION/AVAILABILITY OF REPORT
Approved for Public Release;
Distribution Unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)

5. MONITORING ORGANIZATION REPORT NUMBER(S)
AFWAL-TR-85-2045

6a. NAME OF PERFORMING ORGANIZATION
Aero Propulsion Laboratory
USAF

6b. OFFICE SYMBOL *(If applicable)*
AFWAL/POSF

7a. NAME OF MONITORING ORGANIZATION
Aero Propulsion Laboratory (AFWAL/POS)
Air Force Wright Aeronautical Laboratories (AFSC)

6c. ADDRESS *(City, State and ZIP Code)*
Wright-Patterson Air Force Base OH 45433-6563

7b. ADDRESS *(City, State and ZIP Code)*
Wright-Patterson Air Force Base OH 45433-6563

8a. NAME OF FUNDING/SPONSORING ORGANIZATION

8b. OFFICE SYMBOL *(If applicable)*

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS *(City, State and ZIP Code)*

10. SOURCE OF FUNDING NOS.

| PROGRAM ELEMENT NO. | PROJECT NO. | TASK NO. | WORK UNIT NO. |
|---|---|---|---|
| 62203F | 3048 | 05 | 91 |

11. TITLE *(Include Security Classification)*
F100 Fuel Sampling Analysis

12. PERSONAL AUTHOR(S)
L.Q. Maurice

13a. TYPE OF REPORT
Final Technical Rpt.

13b. TIME COVERED
FROM May 83 TO Apr 84

14. DATE OF REPORT *(Yr., Mo., Day)*
September 1985

15. PAGE COUNT
136

16. SUPPLEMENTARY NOTATION
(American Society of Testing and Materials)

17. COSATI CODES

| FIELD | GROUP | SUB. GR. |
|---|---|---|
| 21 | 04 | |
| 21 | 05 | |

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
~~Fuel~~s ~~F100 Engine~~ MIL-T-5624L Fuel Specification.
Fuel Properties, ~~JP-4 Fuel~~
ASTM Test Methods; Petroleum Fuel; ~~Cavitation~~

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Fuel pump cavitation problems experienced with the F100 engine used in the F-15/F-16 aircraft have led to an extensive fuel analysis program to identify fuel properties that might be contributing to fuel pump failures. This report analyzes the chemical and physical properties of twenty-one JP-4 fuel samples obtained from United States Air Force Bases. The fuels analyzed met specifications in all but a few isolated cases, and had no unusual properties. If the fuel used is causing fuel pump failure, it must be the result of a fuel property not being measured. The fuels are as good or better than the specification prescribes. It is concluded that the F100 fuel pump cavitation problems are most likely associated with the mechanical complexity built into the design, rather than the result of the fuel used. Keywords:

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT
UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS ☒

21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL
LOURDES Q. MAURICE

22b. TELEPHONE NUMBER *(Include Area Code)*
(513) 255-3138

22c. OFFICE SYMBOL
AFWAL/POSF

**DD FORM 1473, 83 APR** EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

# FOREWORD

This F100 Fuel Samples Analyses program was conducted by the Fuels Branch of the Aero Propulsion Laboratory, Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. The work was performed under Work Unit 30480591. Ms Lourdes Q. Maurice was the project engineer.

This report presents physical and chemical analyses of aviation turbine fuel used in F100 engines at United States Air Force Bases. Attempts are made to correlate fuel properties to fuel pump cavitation problems.

The author wishes to extend gratitude to Ms Tina Allen and Ms Carole Carter for their assistance in preparing portions of this report. Mr Tim Dues' valuable technical advice is also appreciated. The efforts of the Air Force Quality Control Laboratory, SA-ALC/SFTLA, in providing fuel analysis are also gratefully acknowledged.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| AB | Air Base |
| AFB | Air Force Base |
| AFWAL/POSF | Aero Propulsion Laboratory's Fuels Branch |
| API | American Petroleum Institute |
| ASD/YZF | Tactical Engines Program Office |
| ASTM | American Society for Testing and Materials |
| BOC | Ball-on-Cylinder |
| $^oC$ | degrees Celsius |
| cm | centimeter |
| CONUS | Continental United States |
| DFSC | Defense Fuel Supply Center |
| $\Delta$ | Delta, mathematical change |
| $^oF$ | degrees Fahrenheit |
| FIA | Fluorescent Indicator Adsorption |
| FSII | fuel system icing inhibitor |
| $ft^3$ | cubic feet |
| g | grams |
| GC | gas chromatography |
| $H_2SO_4$ | sulfuric acid |
| Hg | mercury |
| JFTOT | Jet Fuel Thermal Oxidation Tester |
| kPa | kilo pascal |
| max | maximum |
| min | minute |
| mm | millimeter |
| $NO_x$ | nitrogen oxides |

## LIST OF ABBREVIATIONS (Concluded)

| | |
|---|---|
| P | pressure |
| PDC | preheater deposit code |
| % | percent |
| ppm | part per million |
| psi | pounds per square inch |
| rpm | revolution per minute |
| SA-ALC/SFTLA | Quality Control Laboratory |
| sec | second |
| $SO_2$ | sulfur dioxide |
| $SO_3$ | sulfur trioxide |
| vol % | volume percent |
| WSD | wear scar diameter |
| wt % | weight percent |

## SUMMARY

Fuel pump cavitation problems experienced in the F-15/F-16 aircraft led to the initiation of an intensive effort to analyze fuels used in these aircraft. Twenty-one fuel samples were collected from United States F-15/F-16 Air Force Bases in order to identify any fuel characteristics that could contribute to increased fuel pump cavitation.

The analyses included specification tests, as well as lubricity and special chemical and physical characterization tests.

Only a few fuels failed to meet specifications prescribed by Military Specification MIL-T-5624L. Fuels from Langley Air Force Base and Aviano Air Base did not meet thermal stability specifications. Fuels from Hill Air Force Base and Luke Air Force Base failed Reid vapor pressure tests. The fuel from Tyndall Air Force Base failed the fuel system icing inhibitor (FSII) content test. In addition, seven fuels (Eglin Air Force Base, Camp New Amsterdam Air Base, Zaragoza Air Base, Torrejon Air Base, Osan Air Base, Clark Air Base, and Anderson Air Base) did not meet simulated distillation specifications, although these results were not repeatable.

Thermal stability and FSII failures are not indicative of fuels likely to contribute to fuel pump failure. Simulated distillation and vapor pressure failures are indicative of the volatility of fuels. According to Perry's "Chemical Engineers' Handbook," (Reference 1), a fuel with lower volatility would be theoretically more likely to cause fuel pump cavitation at sea level conditions. However, both tests were conducted in two laboratories, and in no case did a fuel fail twice. Since the failures were not repeatable, for identical samples drawn from different containers, it is reasonable to presume that poor fuel handling techniques resulted in the loss of fuel front end, light boiling constituents. This in turn would lower vapor pressure and increase simulated distillation temperatures, as noted.

One of the most critical tests of this program was the lubricity test. Poor lubricity is often associated with fuel pump failure. However, all the fuels analyzed had excellent lubricating qualities.

Chemical and physical characterization test results showed no indication of properties likely to cause fuel pump failure.

Overall, all the fuels analyzed met specifications in all but a few isolated cases, and had no unusual properties. The fuels are as good or better than the specification prescribes. If the fuel is causing a fuel pump problem on the F100 fuel pump, it must be the result of a fuel property not limited by the specification, such as surface tension or viscosity.

It is therefore concluded that the F100 fuel pump cavitation problems are most likely associated with the mechanical complexity built into the design, rather than the result of the fuel used.

# SECTION I

# INTRODUCTION

This report summarizes the analyses performed on twenty-one fuel samples from F-15 and F-16 bases, and bases that often refuel this aircraft to identify any fuel characteristics that might be contributing to increased fuel pump cavitation and fuel pump failure. The data was collected between May 1983 and May 1984. The report contains five sections.

Section I is the introduction.

Section II is a discussion of the fuel pump cavitation problem and a summary of the samples involved in the analyses.

Section III describes tests performed, and discusses test results.

Section IV summarizes conclusions.

Section V offers recommendations.

# SECTION II

# BACKGROUND

As a result of fuel pump cavitation problems experienced in the F-15/F-16 aircraft, the Tactical Engines Program Office (ASD/YZF) and the Aero Propulsion Laboratory's Fuels Branch (AFWAL/POSF) jointly initiated a program to analyze aviation fuels used in those aircraft. The objective of the Fuel Analysis Program was to thoroughly analyze fuel samples from all F-16 and F-15 bases, as well as bases that often refuel these aircraft, in order to identify any fuel characteristics that might induce fuel pump cavitation.

The Fuel Analysis Program was divided into two phases. During Phase I, fuel samples provided by 21 Air Force Bases were analyzed, and the results are presented in this report. A list of the bases participating in this phase of the program is shown in Table 1. During Phase II of this program, 16 fuel samples provided by Foreign National bases will be analyzed, and the results will be published under a separate cover.

In order to obtain reliable data from which sound conclusions could be derived, it was necessary to minimize any contamination of the fuel samples, thus several measures were taken to ensure sample purity. AFWAL/POSF provided each Air Force Base with special shipping containers, along with detailed sampling procedures. Each base was also asked to complete a questionnaire providing additional information regarding fuel suppliers, additives, and sampling techniques. This information was requested to possibly provide explanations for any unusual characteristics noted in any of the fuel samples. The results of the questionnaire are tabulated in Table 2.

Each of the participating bases provided two gallons and one pint of fuel sample. The fuel was distributed by AFWAL/POSF to various organizations for detailed analyses. The Quality Control Laboratory, SA-ALC/SFTLA, performed a series of specification tests, Monsanto Research Corporation under Air Force contract was responsible for several characterization tests, and AFWAL/POSF performed lubricity as well as characterization tests.

TABLE 1

UNITED STATES BASES PARTICIPATING IN FUEL SAMPLING PROGRAM

| BASE | FUEL TYPE | SAMPLE CODE |
|---|---|---|
| West | | |
| Hill AFB (UT) | JP-4 | 83-POSF-1006 |
| Luke AFB (AZ) | JP-4 | 83-POSF-1073 |
| Holloman AFB (NM) | JP-4 | 83-POSF-1084 |
| Elmendorf AFB (AK) | JP-4 | 83-POSF-1085 |
| Edwards AFB (CA) | JP-4 | 83-POSF-1086 |
| Nellis AFB (NV) | JP-4 | 83-POSF-1158 |
| Southeast | | |
| Langley AFB (VA) | JP-4 | 83-POSF-1074, 83-POSF-1350 |
| Tyndall AFB (FL) | JP-4 | 83-POSF-1075 |
| MacDill AFB (FL) | JP-4 | 83-POSF-1076 |
| Shaw AFB (SC) | JP-4 | 83-POSF-1077 |
| Eglin AFB (FL) | JP-4 | 83-POSF-1273 |
| Europe | | |
| Hahn AB (Germany) | JP-4 | 83-POSF-1157 |
| Bitburg AB (Germany) | JP-4 | 83-POSF-1159 |
| Aviano AB (Italy) | JP-4 | 83-POSF-1253, 83-POSF-1298 |
| Zaragoza AB (Spain) | JP-4 | 83-POSF-1259 |
| Camp New Amsterdam (The Netherlands) | JP-4 | 83-POSF-1283 |
| Torrejon AB (Spain) | JP-4 | 83-POSF-1287 |
| Far East | | |
| Osan AB (Korea) | JP-4 | 83-POSF-1181 |
| Clark AB (Philippines) | JP-4 | 83-POSF-1272 |
| Anderson AB (Guam) | JP-4 | 83-POSF-1284 |
| Kadena AB (Japan) | JP-4 | 83-POSF-1297 |

TABLE 2

RESULTS OF QUESTIONNAIRE

| BASE | SAMPLING PROCEDURE | SUPPLIERS | ADDITIVES USED |
|---|---|---|---|
| Hill | Samples drawn from a sampling point between a truck fillstand and a filter separator. | American Oil Co.<br>Chevron Oil Co.<br>Phillips Oil Co. | No information available |
| Luke | Samples drawn from quick disconnect with metal flex hose. | Southern Pacific Pipeline Co. | No information available |
| Hollomar | Samples drawn from sample connection downstream of truck fillstand underflow. | Standard Transpipe Corp. | FSII<br>ASA-3<br>STADIS 450 conductivity additive<br>Corrosion inhibitor |
| Elmendorf | Rotated 4,000 gallons thru bottom loader and samples were taken on single point nozzle under full flow conditions thru the bypass line on the in-line sampler. | DFSC Anchorage Terminal,<br>DIO 172nd INF BDE<br>Petroleum Division | No information available |
| Edwards | Samples drawn from sampling point downstream of a filter separator. | Mobil Oil Co., CA<br>Powine Oil Co., CA | FSII<br>Conductivity |
| Nellis | Samples drawn from R-9 refueler thru manhole cover. | Calnev Pipeline Co. | STADIS 450<br>FSII |
| Langley (1074) | Rotated 500 gallons, then sample drawn from regular in-line sampling point. | Government owned stock | No information available |
| (1350) | Used in-line sampler at sampling point on R-9 refueler. | Government owned stock | No information available |

TABLE 2 (Cont'd)
RESULTS OF QUESTIONNAIRE

| BASE | SAMPLING PROCEDURE | SUPPLIERS | ADDITIVES USED |
|---|---|---|---|
| Tyndall | Samples drawn from an R-9 refueler by using sip nozzle hooked to bottom loader at full flow conditions. | No information available | No information available |
| MacDill | Samples drawn through quick disconnect coupler on filter separator #4 in pumphouse W. | Spartan Oil Co. | ASA-3<br>STADIS 450 |
| Shaw | Samples drawn from R-9 refueler while the unit was being recirculated through the in-line sampler connection in the can box. | Continental Service Co. | No information available |
| Eglin | Samples drawn from refueling unit using in-line sampler with contινous flow. | Chevron USA, Inc. | ASA-3 Conductivity Additive<br>FSII |
| Hahn | Samples drawn with top half of in-line sampler, downstream on a hydrant filter separator. | NATO Pipeline | No information available |
| Bitburg | Samples drawn from Type IV hydrant downstream of filter separator. | NATO Pipeline | No information available |
| Aviano (1253) | Samples drawn from fillstand #1, area F bulk storage. Sample was obtained from a 1/2 inch pipe welded to the side of the fillstand pipe. | NATO Pipeline | FSII |
| (1298) | Samples drawn from fillstand #2, area F bulk storage. Sample was obtained from a 1/2 inch pipe welded to the side of the fillstand pipe. | NATO Pipeline | FSII<br>ASA-3 |

TABLE 2 (Concluded)
RESULTS OF QUESTIONNAIRE

| BASE | SAMPLING PROCEDURE | SUPPLIERS | ADDITIVES USED |
|---|---|---|---|
| Zaragoza | Samples drawn from hydrant cart thru the in-line sampler. | Campas Fuels (National Fuel Co.) | ASA-3 |
| Camp New Amsterdam | Samples drawn from unit 81L-167 using the metal portion of the in-line sampler while the fuel was rotating thru the unit. | Royal Netherlands Air Force | ASA-3 |
| Torrejon | Samples drawn from hydrant section. | Campas | ASA-3 |
| Osan | Samples drawn using the top portion of the in-line sampler with the valve on the test position allowing fuel to flow directly into the can. | United States Army Petroleum Distributions Systems Korea (USA PDSK) | ASA-3<br>FSII |
| Clark | Samples drawn from the sampling stub on unit 81L337 using the top portion of the in-line sampler in the "test" position. | Sea Lift Command through Subic Naval Station | ASA-3<br>STADIS 450 |
| Anderson | Fuel samples drawn from refueler 756-676 sample cock downstream of filter separator using the bypass hose of the in-line sampler. | Naval Supply Depot Guam, M.I. | FSII<br>ASA-3 |
| Kadena | Fuel samples drawn using the in-line sampler downstream of the filter separator on refueling unit 81L-148 R-9. | US Army Petroleum System, Okinawa Japan | STADIS 450 |

# SECTION III

# EXPERIMENTAL/DISCUSSION

## A. SPECIFICATION TESTS

The Air Force Quality Control Laboratory (SA-ALC/SFTLA, Wright-Patterson Air Force Base, Ohio) performed a series of 19 specification tests on all 21 fuel samples. The results of these tests can be found in Appendix A.

All specification tests were performed using American Society of Testing & Materials (ASTM) test methods and applicable Federal Test Methods prescribed by Military Specification MIL-T-5624L for JP-4. These test methods are documented in Reference 2.

Results of these tests were compared to the physical and chemical requirements prescribed by MIL-T-5624L. With a few minor exceptions, all fuel samples analyzed were well within the specification limits.

Two fuel samples showed thermal stability problems. The sample from Langley AFB passed the thermal stability test (Jet Fuel Thermal Oxidation Tester or JFTOT) at the Air Force Quality Control Lab, but failed it at Pratt & Whitney Aircraft with a Preheater Deposit Code (PDC) of 3. The Fuels Branch repeated the analysis and also failed the fuel with a PDC of 3. A second fuel sample was requested from Langley AFB for further testing, and this time the sample passed with $\Delta P=0$ and PDC=1.

The Aviano Air Base sample failed JFTOT at SFTLA and Pratt & Whitney Aircraft. The second Aviano sample requested also failed with a PDC of 4.

It is important to note that the Aviano sample had a worse copper strip corrosion than any of the other samples (1B). Also, both the Langley and Aviano samples had higher than typical existent gum (1.0 mg/100 ml and 1.2 mg/100 ml, respectively). These properties confirm that these two samples could have a thermal stability problem.

It appears that the thermal stability failure of the Langley fuel sample was an isolated incident, since the second fuel sample from that base met specification. The failure might have been caused by poor sampling techniques. However, the Aviano fuel appears to have consistently poor thermal stability qualities.

Two fuel samples failed the Reid Vapor Pressure Test. The fuel from Hill AFB had a vapor pressure of 1.7 psi and the sample from Luke AFB had a vapor pressure of 1.5. The specification limits vapor pressure test failures among a widespread sample of fuels from the field. It is very difficult for a technician in the flight line to follow sampling procedures precisely, thus the loss of light end components is common. Furthermore, the fuel samples analyzed by Monsanto from a different container showed no vapor pressure problems.

The fuel from Tyndall AFB failed the fuel system icing inhibitor (FSII) test. The specification limits FSII to 0.15 vol % and the fuel had an FSII content of 0.17 vol %.

Two fuel samples failed the 90% recovered simulated distillation test at Monsanto Research Corp., those from Eglin AFB, and Camp New Amsterdam AB. Seven fuels also failed the end point specification, those from Eglin AFB, Zaragoza AB, Camp New Amsterdam AB, Torrejon AB, Osan AB, Clark AB and Anderson AB.

However, all these fuels met simulated distillation specifications at the Air Force Quality Control Lab. It is reasonable to assume that the failures were caused by the loss of the fuel's front end components from the field to the laboratory. The Quality Control lab analyzed samples obtained directly from the field. Monsanto's samples were drawn from the container received from the field by the Fuels Branch; thus they had a better chance to lose highly volatile front end components.

A summary of specification test failures is found in Table 3.

Results of specification tests were also compared to the average specification properties of JP-4 determined in 1980/81 (Reference 3). The average properties of the F100 study JP-4s are compared to the 1980/81 average JP-4 in Table 4.

Out of 13 properties, four worsened, five improved, and four remained unchanged. The four worsened properties were aromatic content, vapor pressure, smoke point, and hydrogen content. The average aromatic content of the F100 samples was higher than 1980/81 JP-4. This is a negative trend because aromatics tend to increase visible smoke and contribute to shorter life spans for combustor liners.

The average vapor pressure of the F100 fuels was considerably lower than the average vapor pressure of 1980/81 JP-4. Fuels with low vapor pressure do not vaporize

## TABLE 3
## SUMMARY OF SPECIFICATION TEST FAILURES

| Test | Spec Limit | Sample Code | Value of Property |
|---|---|---|---|
| Thermal Stability (ASTM D 3241) | $\Delta$ P=25mm Hg max<br>PDC < 3 | Langley 1(1) | 1 PDC |
| " | " | Langley 2(2) | 3 PDC |
| " | " | Langley 1(3) | 3 PDC |
| " | " | Langley 2(3) | 1 PDC |
| " | " | Aviano 1(1) | 4 |
| " | " | Aviano 1(2) | 4 |
| " | " | Aviano 2(3) | 4 |
| Reid Vapor Pressure (ASTM D 323) | 2 psi min<br>3 psi max | Hill | 1.7 psi |
| " | " | Luke | 1.5 psi |
| Fuel System Icing Inhibitor (FSID 791 5327) | 0.10 vol % min<br>0.15 vol % max | Tyndall | 0.17 vol % |
| Simulated Distillation ASTM D 2887 End Point 90% Recovered | 245°C | Eglin(4) | 252°C |
| " | " | Zaragoza(4) | 252°C |
| Simulated Distillation ASTM D 2887 | 320°C | Eglin(4) | 333°C |
| " | " | Zaragoza(4) | 370°C |
| " | " | Camp New Amsterdam(4) | 333°C |
| " | " | Torrejon(4) | 330°C |
| " | " | Osan(4) | 330°C |
| " | " | Clark(4) | 342°C |
| " | " | Anderson(4) | 334°C |

(1) Values determined by the Air Force Quality Control Laboratory.
(2) Values determined by Pratt & Whitney Aircraft.
(3) Values determined by the Fuels Branch.
(4) Values determined by Monsanto Research Corporation.

TABLE 4
COMPARISON OF AVERAGE JP-4s

| Property | 1980/81 Study Average JP-4 | F100 Study Average JP-4 |
|---|---|---|
| Total Acid Number | 0.005 mg KOH/g | 0.005 mg KOH/g |
| Vol % Aromatics | 12.6 | 14.0 |
| Vol % Olefins | 0.8 | 0.7 |
| Wt % Mercaptan Sulfur | 0.0004 | 0.0002 |
| Wt % Total Sulfur | 0.04 | 0.02 |
| Vapor Pressure | 2.6 | 2.29 |
| API Gravity | 54.2 | 53.9 |
| Net Heat of Combustion | 43.5 | 43.5 |
| Smoke Point | 27 | 25 |
| Hydrogen Content | 14.3 | 14.2 |
| Thermal Stability, PDC | < 3 | < 2 |
| Thermal Stability, ΔP | 1mm Hg | 2mm Hg |
| Existent Gum | 0.8 mg/100 ml | 0.4 mg/100 ml |
| Vol % FSII | 0.13 | 0.13 |

readily, which could lead to difficult starting at low temperatures. Also, fuel vapor pressure is inversely proportional to fuel pump cavitation. Thus, lower fuel vapor pressures would tend to increase fuel pump cavitation.

Smoke point and hydrogen content are closely related, and they were lower which is an unfavorable trend. High hydrogen content/smoke point fuels have good combustion properties, lead to longer combustor life and result in less smoke emissions.

The five improved properties were: volume percent olefins, weight percent total sulfur and mercaptan sulfur, API gravity and existent gum.

The samples analyzed had lower than 1980/81 average JP-4 olefin content. Lower olefins will reduce thermal stability problems caused by the thermal instability and gum forming tendencies of olefins.

The mercaptan sulfur of the F100 samples was considerably lower. This is a favorable trend because some sulfur compounds attack elastomers, and solubilize trace metals such as copper, which can cause thermal stability problems.

The lower sulfur content of the F100 fuels is also favorable because when sulfur is combusted, $SO_2$ and $SO_3$ are formed, which corrode certain fuel system components. Water vapor is also a combustion product, and it may combine with $SO_2$ and $SO_3$ to yield $H_2SO_4$, which attacks the turbine blades of an engine. In addition, sulfur contributes to thermal stability problems.

The increase in API gravity of the F100 fuel samples is a positive trend, because it marks a tendency towards denser fuels. This increases volumetric heat of combustion, and in turn increased volume-limited aircraft range.

Large quantities of gum in a fuel are indicative of contamination of higher boiling oils or particulate matter. Turbine engines that use prevaporizer fuel tubes are known to be sensitive to existent gum. Thus, the lower average existent gum found in the F100 fuels is a definite improvement.

The four properties that remained unchanged were thermal stability, total acid number, net heat of combustion and volume percent FSII.

## B. LUBRICITY TEST

This test evaluates the lubricity characteristics of a fuel sample. In recent years, turbine fuel specifications have become increasingly restrictive, in particular with respect to thermal stability and cleanliness. The demand for turbine fuel has also increased, and new processes have been introduced to satisfy both demand and quality. However, production of cleaner fuels has tended to remove some of the compounds that make fuel a good lubricating agent. Fuel is depended upon to lubricate certain components of the fuel system, particularly fuel pumps and fuel controls. Poor lubricity can affect the life cycle of these components, and even result in fuel pump failure.

The lubricity of the fuel samples was evaluated using the modified Furey Ball-on-Cylinder (BOC) Test Rig (Reference 4). The test consists of contacting a stationary, perpendiculary loaded test ball with a rotating cylinder. The cylinder and ball are located in a rectangular test cell, and the cylinder is immersed approximately 1/3 in the test fluid. The remaining portion of the cylinder and the ball are exposed to a controlled environment which consists of air having a moisture content of less than 20 ppm. The standard operating conditions for the test are: 1000 gm load, 240 rpm cylinder speed, dry air environment with 0.5 $ft^3$/min indirect purging and $77^0$F fuel temperature. The lubricity of the fuel is evaluated by measuring the wear scar on the ball generated by the rotating cylinder. Based on data obtained for fuel samples known to be good lubricating agents, a fuel's lubricity is considered acceptable if the average diameter of the wear scar is less than .45 mm.

The results of lubricity tests for the 21 fuel samples analyzed are presented in Table 5. A fuel lubricity problem would be one of the most likely ways in which a fuel would cause fuel pump failure, thus these data were thoroughly studied.

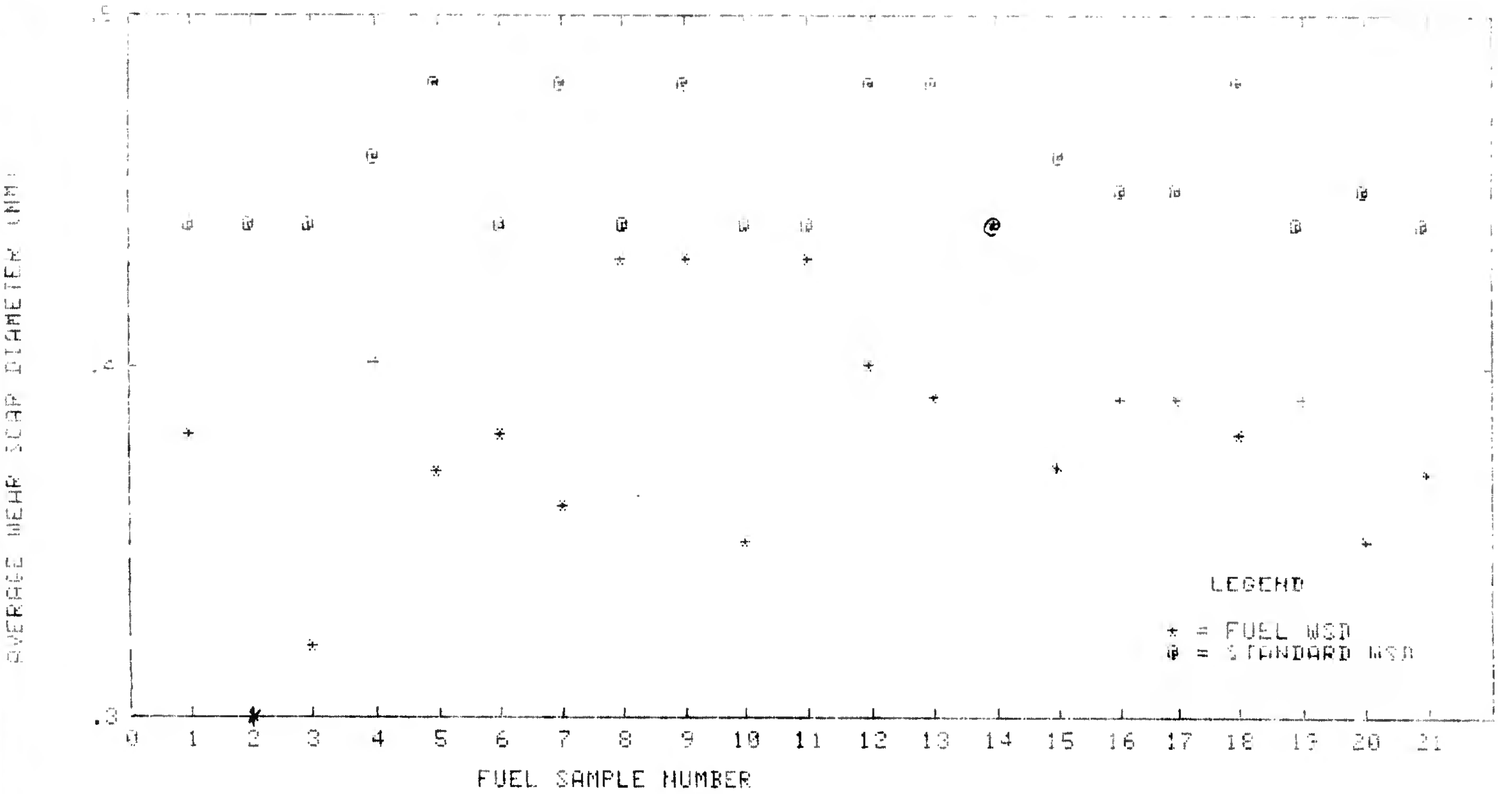
Besides testing each fuel sample in duplicate to ensure accurate results, a "standard" sample known to have good lubricating qualities was tested along with each fuel sample to qualify the acceptability of the test sample.

The wear scars of the 21 F100 fuel samples ranged between 0.29 mm and 0.44 mm, with an average wear scar of 0.38 mm diameter. All wear scars were within the acceptability criteria, as well as smaller than wear scars generated using "standard" samples as illustrated in Figure 1. The fuels from CONUS Western bases had lower wear scar diameters (0.36 mm average). However, no unusual fuel lubricity characteristics that might cause fuel pump problems were observed in any of the samples.

## TABLE 5

## LUBRICITY ANALYSES

| FUEL SAMPLE | AVERAGE WSD (mm) |
|---|---|
| Hill | 0.38 |
| Luke | 0.30 |
| Holloman | 0.32 |
| Elmendorf | 0.40 |
| Edwards | 0.37 |
| Nellis | 0.38 |
| Langley | 0.36 |
| Tyndall | 0.43 |
| MacDill | 0.43 |
| Shaw | 0.35 |
| Eglin | 0.43 |
| Hahn | 0.40 |
| Bitburg | 0.39 |
| Aviano | 0.44 |
| Zaragoza | 0.37 |
| Camp New Amsterdam | 0.39 |
| Torrejon | 0.39 |
| Osan | 0.38 |
| Clark | 0.39 |
| Anderson | 0.35 |
| Kadena | 0.37 |



| FUEL SAMPLE | AVERAGE WSD (mm) |
|---|---|
| HILL | 0.38 |
| LUKE | 0.30 |
| HOLLOMAN | 0.32 |
| ELMENDORF | 0.40 |
| EDWARDS | 0.37 |
| NELLIS | 0.38 |
| LANGLEY | 0.36 |
| TYNDALL | 0.43 |
| MACDILL | 0.43 |
| SHAW | 0.35 |
| EGLIN | 0.43 |
| HAHN | 0.40 |
| BITBURG | 0.39 |
| AVIANO | 0.44 |
| ZARAGOZA | 0.37 |
| CAMP NEW AMSTERDAM | 0.39 |
| TORREJON | 0.39 |
| OSAN | 0.38 |
| CLARK | 0.39 |
| ANDERSON | 0.35 |
| KADENA | 0.37 |

Figure 1. Lubricity Results

## C. CHARACTERIZATION TESTS

1. Description: Monsanto Research Corporation performed a series of characterization tests (Reference 5). These tests were not necessarily specification tests, and tended to provide more information about the fuel samples than simple specification tests. The tests performed were:

- Physical properties as a function of temperature:
  - True Vapor Pressure
  - Kinematic Viscosity
  - Density
  - Surface Tension
- Simulated Distillation by ASTM D 2887
- Hydrocarbon Type by ASTM D 2789-71 and Monsanto 21-PQ-38-36
- Gross Heat of Combustion by ASTM D 240
- Thermal Conductivity
- Specific Heat

a. Physical Properties as a Function of Temperature

The physical properties specification tests performed by the Quality Control Laboratory are generally performed at one specific condition and the results are evaluated according to the pass/fail criteria provided by MIL-T-5624L. The tests show whether fuel samples pass the specification criteria, but they do not show the behavior of the fuel over a wide temperature range. The fuels analyzed for the F100 sampling program were suspected of possibly contributing to pump failure, and this it was desired to study the physical properties of the samples over a wide temperature range to possibly identify any fuel characteristics that might contribute to fuel pump failure.

The true vapor pressure was measured using ASTM D 2551. The method consists of introducing a fuel sample of known volume into an evacuated, temperature controlled vessel. The pressure in the chamber is read with a mercury manometer attached to the apparatus. The pressure read is the sum of the vapor pressure and the partial pressure due to any dissolved air in the sample; therefore, the vapor pressure measurement is preceded by an operation to degas the sample. This operation does not lead to any vapor losses. The vapor pressure was measured at 32, 70, 100 and 140$^0$F and fitted to an equation of the form:

$$\log P = A-B/T$$

where:

P = vapor pressure
T = temperature
A,B = constants

The equation can then be used to determine vapor pressures at various temperatures.

The kinematic viscosity of the various samples was measured at -20, -4, 32, 70, 100 and 140$^0$F using ASTM D 445. The test method has been previously described in Reference 2. Viscosity was measured at the various temperatures and the results were plotted on standard ASTM viscosity temperature charts which serve to determine kinematic viscosities at other temperatures.

The density of the fuel samples was measured at -20, 32, 59, 70, 100 and 140$^0$F using a pyrex dilatometer. The method consists of introducing a fuel sample into a dilatometer, then bringing the sample up to the desired temperature by immersing the dilatometer in a constant temperature bath. After temperature equilibrium was established, the dilatometer scale was read with a cathemometer (Reference 5). The density was then plotted as a function of temperature.

The surface tension was measured at 32, 70, 100 and 140$^0$F using the capillary rise method (Reference 5). The surface tension was calculated using the following expression:

$$\frac{rhdg}{2\cos\Theta}$$

d = density of liquid, g/cm$^3$
h = height of the column of liquid, cm
g = acceleration of gravity, cm/sec$^2$
r = radius of the capillary, cm
$\Theta$ = contact angle, degrees

The data obtained was plotted to obtain a relationship between surface tension and temperature.

### b. Simulated Distillation

The boiling range distribution was determined by Monsanto Research Corporation using ASTM D 2887. The significance of this test was previously discussed in this report. In addition to results for specification temperatures, Monsanto provided detailed analysis of the entire boiling range.

### c. Hydrocarbon Type Analysis

This test identifies hydrocarbon types in fuel samples. Information provided includes weight percent paraffins, cycloparaffins, dicycloparaffins, alkylbenzenes, indans, and tetralins, indenes and dihydronaphthalenes, and naphthalenes. Paraffins are the most chemically inert compounds present in turbine engine fuel, thus they are more stable in storage and under thermal stresses. These compounds also have a minimum solvent and swelling effect on elastomers. Cycloparaffins are similar to straight chained paraffins, although their properties are slightly less desirable. Aromatics do have a high heating content per unit volume, but they do not burn cleanly and have a high solvent and swelling effect on elastomers. Hydrocarbon types were determined by mass spectrometry using both a modification of ASTM 2789 (Reference 2) and Monsanto 21-PQ-38-63 (Reference 6). Both of these analyses are based on summing characteristic mass spectral lines for each compound type, and constructing a matrix of n equations relating each of the n hydrocarbon types to the summed peak values. The simultaneous equations are then solved to provide a quantitative measure of each compound type present in the fuel sample.

### d. Electrical and Thermal Conductivity

Monsanto Research Corporation measured the electrical conductivity of fuel samples. Electrical conductivity is essential to allow any static charge that may build up within the fuel to rapidly bleed to ground. However, electrical conductivity must be controlled because an excessive amount will affect the accuracy of some fuel level indicators.

The thermal conductivity of six of the 21 fuel samples was determined using a transient hot wire apparatus built by Monsanto Research Corporation. The method consists of applying a constant heating current to a resistant wire immersed in fuel. The change in temperature of the wire is obtained from the voltage drop across the wire and known resistance-temperature characteristics (Reference 5). The remaining 15 fuel samples were not analyzed by this method because the procedure is rather lengthy and time consuming and does not provide information that is vital to identify fuel properties that may cause pump cavitation.

#### e. Specific Heat

The specific heat of the samples was measured with a Perkin-Elmer differential scanning calorimeter, Model DSC-1. The calorimeter is used to measure the heat flow into a sample whose temperature is linearly programmed. The specific heat is calculated by comparing the rate of heat from the sample with the rate of heat flow from a standard whose specific heat is known.

The specific heat of the fuel samples was determined by this test. The heat capacity of a fuel is directly proportional to the types of hydrocarbons that make up the fuel. The variations in specific heat between different fuels is usually in the range of ±7%, which could lead to a difference of 30 to 40°C in peak temperature of fuel emerging from the fuel system heat exchangers. Thus, a higher specific heat will result in improved thermal stability (Reference 6).

### 2. Results: Characterization test results can be found in Appendix B.

#### a. Physical Properties

##### (1) Vapor Pressure

Monsanto evaluated vapor pressure as a function of temperature for all 21 fuel samples. The vapor pressure of the samples as a function of temperature was compared to the typical vapor pressure of JP-4 as a function of temperature (Reference 7). Monsanto reported vapor pressure data in units of mm Hg, while the typical JP-4 data was available in KPa. For easy comparison, the typical vapor pressures of JP-4 at the temperatures at which Monsanto determined the vapor pressure of the F100 samples were converted to mm Hg.

Generally, the F100 samples had higher typical vapor pressure at 32°F, and 100°F and lower than normal at 70°F and 40°F. However, the Camp New Amsterdam fuel sample had extremely low vapor pressure. Overall, the data indicate that the F100 samples have higher vapor pressures than typical JP-4. Theoretically, the higher vapor pressures would lead to decreased pump cavitation at sea level conditions. However, this relation may not hold true at higher altitudes. Also, the more volatile fuel would be more difficult to handle.

### (2) Kinematic Viscosity

Monsanto also calculated the kinematic viscosity as a function of temperature of the F100 samples. There are no specifications against which to judge the viscosity of JP-4, but the data obtained was compared to typical JP-4 kinematic viscosity measurements (Reference 7).

The average F100 sample has lower kinematic viscosity at low temperatures than typical JP-4. The samples from Elmendorf, Clark, Anderson, and Kadena have exceptionally low kinematic viscosity, while the sample from Camp New Amsterdam has higher than typical kinematic viscosity at low temperatures. On the other hand, the F100 samples have higher than typical kinematic viscosity at higher temperatures. High kinematic viscosity affects fuel pumpability more at the lower temperature range than at the higher temperature range. Thus, with the exception of the Camp New Amsterdam sample, the F100 examples have better than typical pumpability, which makes them less likely to cause fuel pump failures.

### (3) Density

The average density of the F100 samples is equal to the average density of JP-4. No problems were noted in regards to density with any of the samples.

### (4) Surface Tension

Low surface tension favors the atomization and ignition of fuel droplets (Reference 7). Monsanto measured the surface tension of the F100 samples versus temperature, and results were compared with typical JP-4 surface tension at varying temperatures.

The average surface tension of the 21 F100 samples is higher than the typical surface tension of JP-4. The F100 fuels would tend to negatively impact ignition characteristics as compared to typical JP-4. However, the differences are of such low magnitude that no noticeable loss of performance is likely to occur.

### b. Thermal Properties

#### (1) Thermal Conductivity Analyses

Thermal conductivity analyses were only performed on nine of the 21 fuel samples. The results were compared to the typical thermal conductivity values of JP-4. No unusual characteristics were noted.

#### (2) Specific Heat

The specific heat as a function of temperature of the F100 samples were calculated and compared to typical JP-4 specific heat at various temperatures. The F100 samples had lower specific heat than typical JP-4. The lower specific heat would indicate a tendency towards poorer thermal stability, but no increased fuel pump problems.

### c. Chemical Composition

#### (1) Boiling Point Distribution

The simulated distillation data obtained by Monsanto for the 21 F100 fuel samples were plotted to obtain distillation curves.

No abnormalities are noted in the distillation curves, with the exception of the curves for the Eglin and Camp New Amsterdam fuel samples. These two samples failed the boiling point distribution specifications, and their distillation shows higher than normal JP-4 distillation curves.

#### (2) Hydrocarbon Type Analyses

Hydrocarbon type analyses were performed by both modified ASTM and Monsanto methods. To determine which test method was more applicable to the F100 samples, the average carbon number of the samples was measured by mass spectrometry. The average carbon numbers were in the 7 to 9 range which indicates that the samples are more compatible with the modified ASTM test method.

Hydrocarbon types measured included paraffins, cycloparaffins, dicycloparaffins, alkylbenzenes, indans, and tetralins and naphthalenes.

The average paraffin content was 53.5%, with values ranging from 39.6% for the Nellis sample to 66% for the Tyndall sample. The cycloparaffin content ranged between 39.5% for the Elmendorf sample to 13.7% for the Tyndall sample. The average cycloparaffin content was 27.4%. The dicycloparaffin content was low, ranging from 1.3% for the Elmendorf sample to 8.1% for the Nellis sample. The average dicycloparaffin content was 4.01%. The average sample had an 84.9% average paraffin/cycloparaffin content, and none of the samples deviated from the average by more than three percent.

The average alkybenzene content was 12.8%, with values ranging from 9.8% for the Torrejon sample to 15.9% for the Holloman and Elmendorf samples. The indenes and tetralins content was low, averaging 1.5%. Values ranged from 0.2% for the Hill sample to 2.9% for the Nellis sample. The naphthalene content was also low. The average naphthalene content was 0.8%, with values ranging from 0.3% for the Aviano sample to 1.2% for the Shaw sample. The total aromatic content ranged from 18.3% for the Tyndall sample to 12% for the Torrejon sample. The average total aromatics content was 15%. Again, samples from the CONUS Western bases had higher than average total aromatics content and the samples from European bases had lower than average aromatic content. These deviations are easily explained by processing practices.

No unusual trends were noted in the hydrocarbon type analyses. All the samples fit the description of "typical JP-4" and should not contribute to fuel pump failure.

Attempts were made to correlate hydrocarbon type to final boiling point. Although hydrocarbon types do influence boiling point distribution, no specific correlations were found. The samples that did fail boiling point specifications did have a larger average carbon number than the remaining samples.

### 3. Normal Paraffin Analyses

AFWAL/POSF analyzed the normal paraffin fraction of the 21 F100 fuel samples by Gas Chromatography. A high content of long chained normal paraffins would tend to give the fuels a "waxy", less pumpable character, possibly contributing to fuel pump failure.

The longest normal paraffin found in the F100 samples was normal C-17, and this was only found in the Holloman fuel sample. The longest normal paraffin found in most of the samples was C-16, and seven samples only had normal paraffins as long as C-15. These analyses revealed no abnormalities that would cause the F100 fuels to contribute to increased fuel pump failure.

Attempts were made to correlate total normal paraffin content and long chained normal paraffin content to simulated distillation data, but no correlations were noted.

# SECTION IV

# CONCLUSIONS

Due to fuel pump cavitation problems experienced in the F-15/F-16 aircraft, fuel samples from 21 F-15 and F-16 air bases were thoroughly analyzed to possibly identify fuel properties that might contribute to increased fuel pump cavitation and/or fuel pump failure. The analysis performed did not yield any conclusive results that would indicate that the fuels being presently used in US Air Force Bases have any inherent characteristics that contribute to pump cavitation or failure.

Only four areas resulted in fuels not meeting specification requirements: thermal stability (2 failures), simulated distillation (7 failures), vapor pressure (2 failures) and FSII (1 failure).

Thermal stability and FSII content failures are not indicative of characteristics likely to cause fuel pump failure. The observed failures were isolated cases and generally not repeatable by second laboratories. Simulated distillation and fuel vapor pressure are closely related. The vapor pressure and simulated distillation failures could indicate a tendency for the fuel to increase fuel pump cavitation, since cavitation is inversely proportional to vapor pressure at sea level conditions. However, these failures were not repeatable. It is felt that the failures were the result of poor sampling techniques that led to the loss of light end fuel components, which decreases vapor pressure and increases simulated distillation temperatures.

The characterization tests showed no unusual fuel properties that might lead to fuel pump problems. Vapor pressure, kinematic viscosity, surface tension and density as a function of temperature were comparable to typical JP-4. Hydrocarbon type analyses also revealed no unusual trends.

Lubricity tests indicated that all the samples had adequate lubricating qualities. Poor fuel lubricity is often blamed for fuel pump failures, but all the F100 samples are considered acceptable.

Overall, the JP-4 fuels analyzed for the F100 fuel sampling program were well within specifications. The fuels were also comparable, or generally better than "typical" JP-4.

From this analyses program, it can be concluded that it is unlikely that extensive analyses of fuel samples not directly involved in isolated aircraft fuel pump failures will provide explanations for such incidents. In general, fuel used in the field is of very high quality, and such analyses as the F100 sampling program attest to assurances that specifications used by the Air Force are as viable as they were when the chemical and physical properties of JP-4 for 1980-1981 was published (Reference 3).

## SECTION V

## RECOMMENDATIONS

Since analyzing fuel samples has not offered any clues to the fuel pump cavitation problem, it is recommended that the cavitation problem be studied in a more fundamental level. Fuel pump tests should be conducted to determine if any fuel characteristics, not limited by the specification such as viscosity and surface tension, can be causing fuel pump failures.

This analyses is an excellent survey of operational fuels. However, if the fuel is causing a fuel pump problem on the F100 fuel pump, it must be the result of a fuel property not being measured, or one that has never been related to pump failure before. it is more likely that the F100 fuel pump cavitation problems are associated with the mechanical complexity build into the design, rather than the result of the fuel used. A different approach must be taken to resolve the F100 fuel pump failure problem.

# APPENDIX A

# SPECIFICATION ANALYSES

# APPENDIX A

## SPECIFICATION ANALYSES

## TABLE A1

## SAYBOLT COLOR

Spec Limits: No Limit

| Fuel | Saybolt Color |
|---|---|
| 1. Hill | 27 |
| 2. Luke | 22 |
| 3. Holloman | 28 |
| 4. Elmendorf | 30 |
| 5. Edwards | 12 |
| 6. Nellis | 10 |
| 7. Langley | 17 |
| 8. Tyndall | 10 |
| 9. MacDill | 17 |
| 10. Shaw | 18 |
| 11. Eglin | 14 |
| 12. Hahn | 22 |
| 13. Bitburg | 25 |
| 14. Aviano | 22 |
| 15. Zaragoza | 22 |
| 16. Camp New Amsterdam | 28 |
| 17. Torrejon | 26 |
| 18. Osan | 27 |
| 19. Clark | 22 |
| 20. Anderson | 14 |
| 21. Kadena | 29 |

Mean: 21 ± 6

## TABLE 42

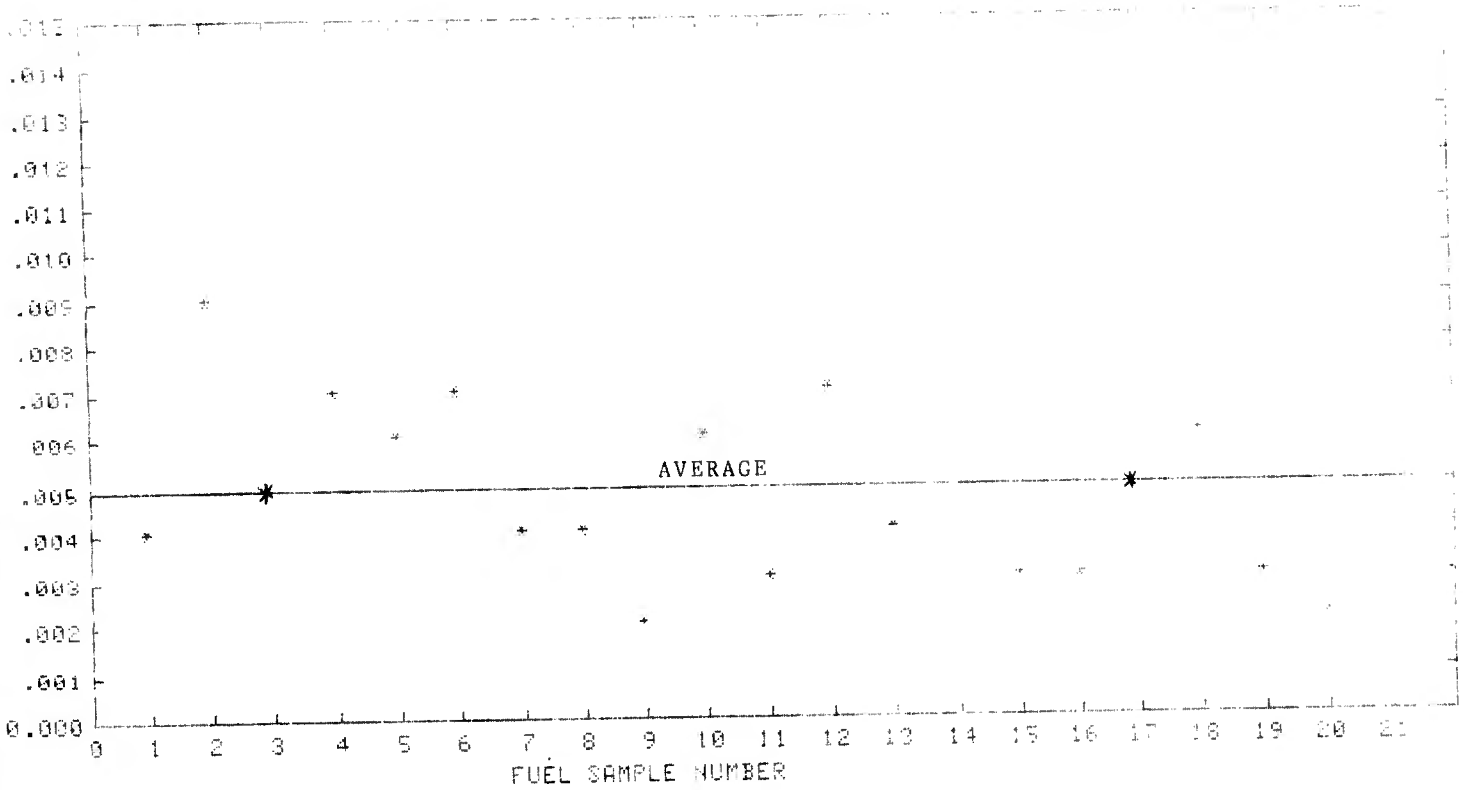
## TOTAL ACID NUMBER ANALYSES

Spec: 0.015 mg KOH/g maximum

"Average" from 1980/81 JP-4 Study: 0.005 mg KOH/g

| Fuel | Total Acid (mg KOH/g) |
|---|---|
| 1. Hill | .004 |
| 2. Luke | .009 |
| 3. Holloman | .005 |
| 4. Elmendorf | .007 |
| 5. Edwards | .006 |
| 6. Nellis | .007 |
| 7. Langley | .004 |
| 8. Tyndall | .004 |
| 9. MacDill | .002 |
| 10. Shaw | .006 |
| 11. Eglin | .003 |
| 12. Hahn | .007 |
| 13. Bitburg | .004 |
| 14. Aviano | .007 |
| 15. Zaragoza | .003 |
| 16. Camp New Amsterdam | .003 |
| 17. Torrejon | .005 |
| 18. Osan | .006 |
| 19. Clark | .003 |
| 20. Anderson | .002 |
| 21. Kadena | .006 |

Mean: .005 ± 0.002



| FUEL SAMPLE | TOTAL ACID (mg KOH/g) |
|---|---|
| HILL | .004 |
| LUKE | .009 |
| HOLLOMAN | .005 |
| ELMENDORF | .007 |
| EDWARDS | .006 |
| NELLIS | .007 |
| LANGLEY | .004 |
| TYNDALL | .004 |
| MACDILL | .002 |
| SHAW | .006 |
| EGLIN | .003 |
| HAHN | .007 |
| BITBURG | .004 |
| AVIANO | .007 |
| ZARAGOZA | .003 |
| CAMP NEW AMSTERDAM | .003 |
| TORREJON | .005 |
| OSAN | .006 |
| CLARK | .002 |
| ANDERSON | .002 |
| KADENA | .006 |

Figure A1. Total Acid Number

## TABLE A3

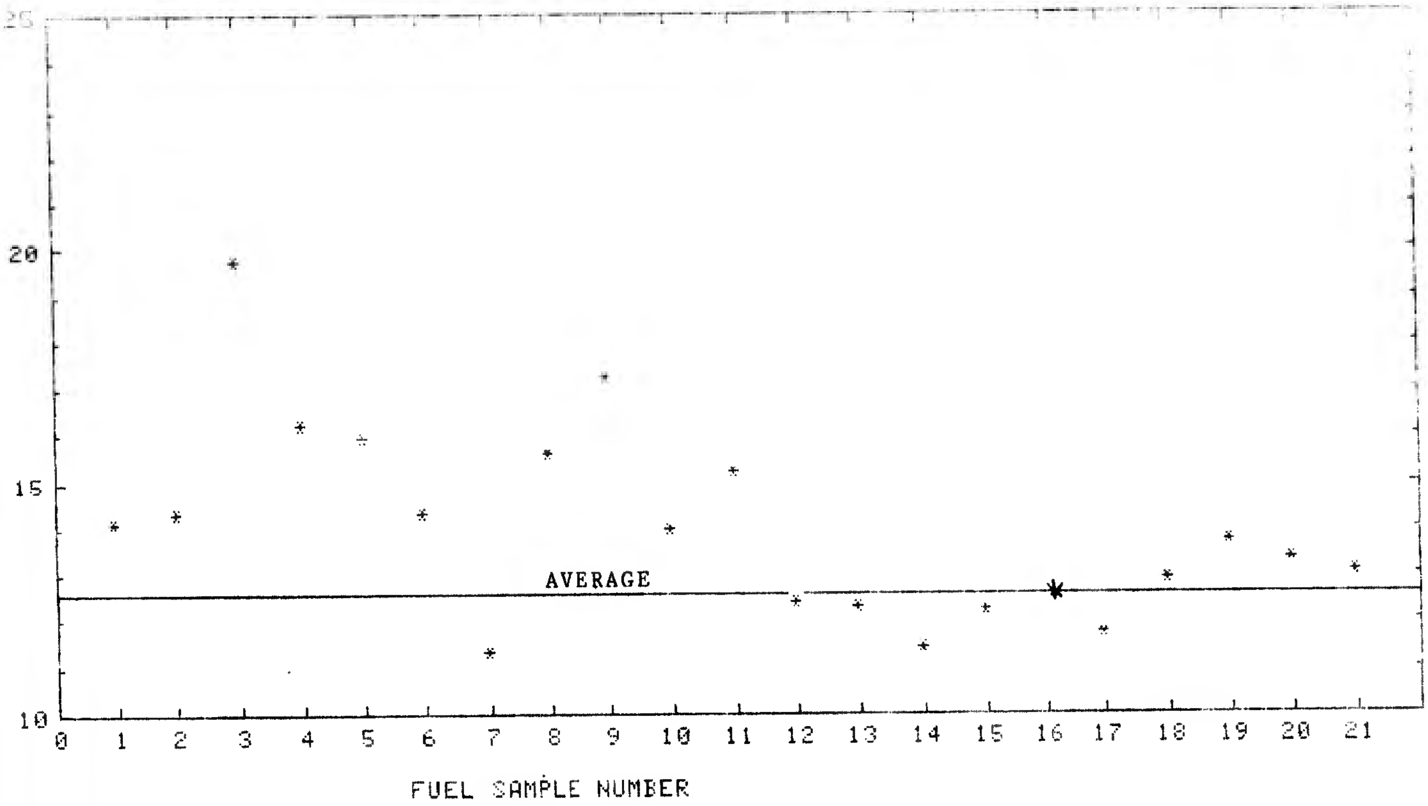
## VOLUME PERCENT AROMATICS ANALYSES

Spec: 25% maximum

"Average" from 1980/81 JP-4 Study: 12.6%

| Fuel | Vol % Aromatics |
|---|---|
| 1. Hill | 14.1 |
| 2. Luke | 14.3 |
| 3. Holloman | 19.7 |
| 4. Elmendorf | 16.2 |
| 5. Edwards | 15.9 |
| 6. Nellis | 14.3 |
| 7. Langley | 11.3 |
| 8. Tyndall | 15.6 |
| 9. MacDill | 17.2 |
| 10. Shaw | 13.9 |
| 11. Eglin | 15.2 |
| 12. Hahn | 12.4 |
| 13. Bitburg | 12.3 |
| 14. Aviano | 11.4 |
| 15. Zaragoza | 12.2 |
| 16. Camp New Amsterdam | 12.6 |
| 17. Torrejon | 11.7 |
| 18. Osan | 12.8 |
| 19. Clark | 13.7 |
| 20. Anderson | 13.3 |
| 21. Kadena | 13.0 |

Mean: 14.0 ± 2.1



| FUEL SAMPLE | VOLUME PERCENT AROMATICS (volume percent) |
|---|---|
| HILL | 14.1 |
| LIKE | 14.3 |
| HOLLOMAN | 19.7 |
| ELMENDORF | 16.2 |
| EDWARDS | 15.9 |
| NELLIS | 14.3 |
| LANGLEY | 11.3 |
| TYNDALL | 15.6 |
| MACDILL | 17.2 |
| SHAW | 13.9 |
| EGLIN | 15.2 |
| HAHN | 12.4 |
| BITBURG | 12.3 |
| AVIANO | 11.4 |
| ZARAGOZA | 12.2 |
| CAMP NEW AMSTERDAM | 12.6 |
| TORREJON | 11.7 |
| OSAN | 12.8 |
| CLARK | 13.7 |
| ANDERSON | 13.3 |
| KADENA | 13.0 |

Figure A2. Volume Percent Aromatics

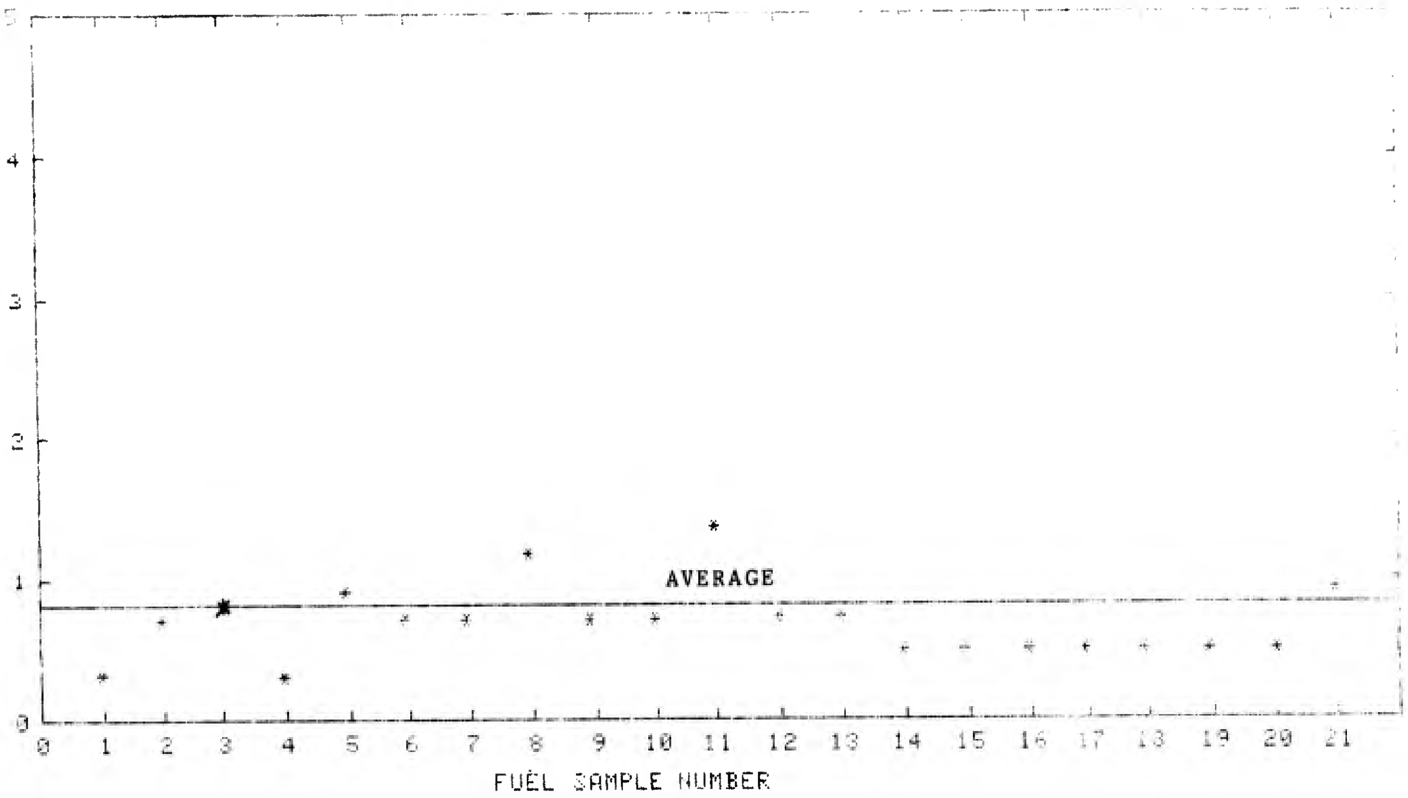
## TABLE A4
## VOLUME PERCENT OLEFINS ANALYSES

Spec: 5% maximum

"Average" from 1980/81 JP-4 Study: 0.8%

| Fuel | Vol % Olefins |
|---|---|
| 1. Hill | 0.3 |
| 2. Luke | 0.7 |
| 3. Holloman | 0.8 |
| 4. Elmendorf | 0.3 |
| 5. Edwards | 0.9 |
| 6. Nellis | 0.7 |
| 7. Langley | 0.7 |
| 8. Tyndall | 1.2 |
| 9. MacDill | 0.7 |
| 10. Shaw | 0.7 |
| 11. Eglin | 1.4 |
| 12. Hahn | 0.7 |
| 13. Bitburg | 0.7 |
| 14. Aviano | 0.5 |
| 15. Zaragoza | 0.5 |
| 16. Camp New Amsterdam | 0.5 |
| 17. Torrejon | 0.5 |
| 18. Osan | 0.5 |
| 19. Clark | 0.5 |
| 20. Anderson | 0.5 |
| 21. Kadena | 0.9 |

Mean: 0.7 ± 0.3



| FUEL SAMPLE | VOLUME PERCENT OLEFINS (vol %) |
|---|---|
| HILL | 0.3 |
| LUKE | 0.7 |
| HOLLOMAN | 0.8 |
| ELMENDORF | 0.3 |
| EDWARDS | 0.9 |
| NELLIS | 0.7 |
| LANGLEY | 0.7 |
| TYNDALL | 1.2 |
| MACDILL | 0.7 |
| SHAW | 0.7 |
| EGLIN | 1.4 |
| HAHN | 0.7 |
| BITBURG | 0.7 |
| AVIANO | 0.5 |
| ZARAGOZA | 0.5 |
| CAMP NEW AMSTERDAM | 0.5 |
| TORREJON | 0.5 |
| OSAN | 0.5 |
| CLARK | 0.5 |
| ANDERSON | 0.5 |
| KADENA | 0.9 |

Figure A3. Volume Percent Olefins

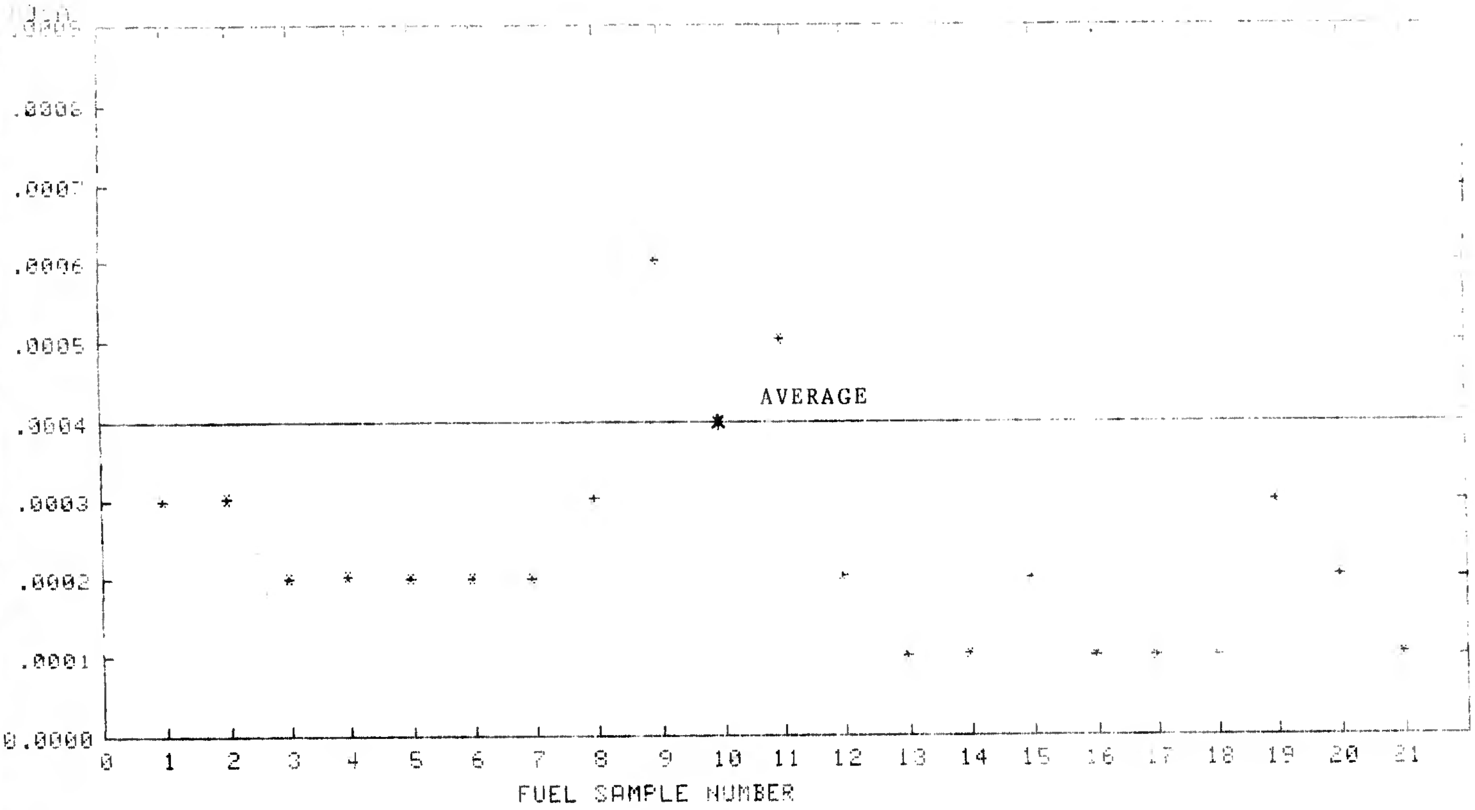
## TABLE A5
## MERCAPTAN SULFUR ANALYSES

Spec: .001 wt% maximum

"Average" from 1980/81 JP-4 Study: 0.0004

| Fuel | Mercaptan Sulfur Wt % |
|---|---|
| 1. Hill | 0.0003 |
| 2. Luke | 0.0003 |
| 3. Holloman | 0.0002 |
| 4. Elmendorf | 0.0002 |
| 5. Edwards | 0.0002 |
| 6. Nellis | 0.0002 |
| 7. Langley | 0.0002 |
| 8. Tyndall | 0.0003 |
| 9. MacDill | 0.0006 |
| 10. Shaw | 0.0004 |
| 11. Eglin | 0.0005 |
| 12. Hahn | 0.0002 |
| 13. Bitburg | 0.0001 |
| 14. Aviano | 0.0001 |
| 15. Zaragoza | 0.0002 |
| 16. Camp New Amsterdam | 0.0001 |
| 17. Torrejon | 0.0001 |
| 18. Osan | 0.0001 |
| 19. Clark | 0.0003 |
| 20. Anderson | 0.0002 |
| 21. Kadena | 0.0002 |

Mean: 0.0002 + .0001



| FUEL SAMPLE | MERCAPTAN SULFUR WT % (WT %) |
|---|---|
| HILL | 0.0003 |
| LUKE | 0.0003 |
| HOLLOMAN | 0.0002 |
| ELMENDORF | 0.0002 |
| EDWARDS | 0.0002 |
| NELLIS | 0.0002 |
| LANGLEY | 0.0002 |
| TYNDALL | 0.0003 |
| MACDILL | 0.0006 |
| SHAW | 0.0004 |
| EGLIN | 0.0005 |
| HAHN | 0.0002 |
| BITBURG | 0.0001 |
| AVIANO | 0.0001 |
| ZARAGOZA | 0.0002 |
| CAMP NEW AMSTERDAM | 0.0001 |
| TORREJON | 0.0000 |
| OSAN | 0.0001 |
| CLARK | 0.0003 |
| ANDERSON | 0.0002 |
| KADENA | 0.0001 |

Figure A4. Mercaptan Sulfur

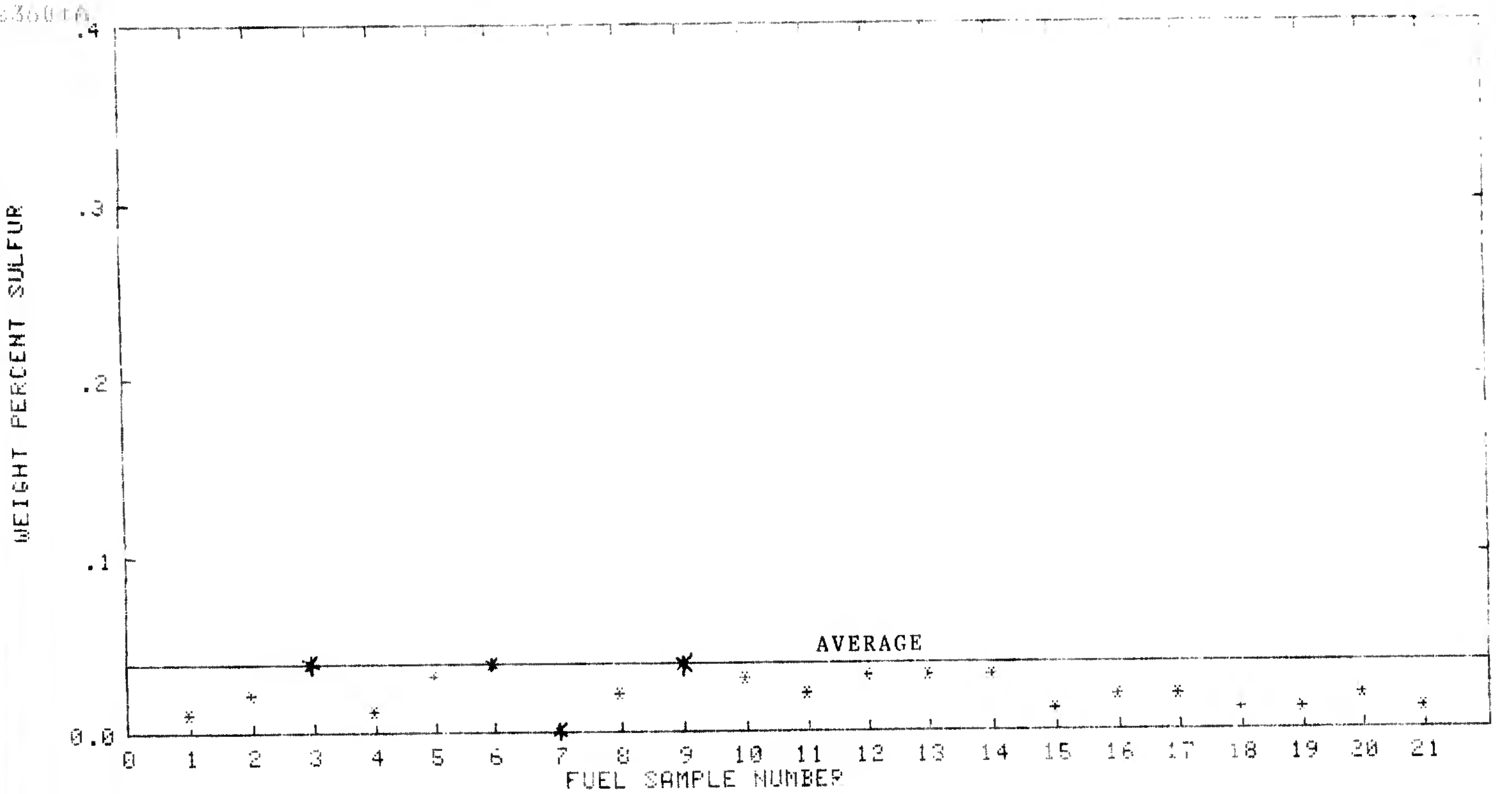
## TABLE A6

## TOTAL WEIGHT PERCENT SULFUR ANALYSES

Spec: 0.40 wt % maximum

"Average" from 1980/81 JP-4 Study: 0.04 wt %

| Fuel | Wt % Sulfur |
|---|---|
| 1. Hill | 0.01 |
| 2. Luke | 0.02 |
| 3. Holloman | 0.04 |
| 4. Elmendorf | 0.01 |
| 5. Edwards | 0.03 |
| 6. Nellis | 0.04 |
| 7. Langley | 0.00 |
| 8. Tyndall | 0.02 |
| 9. MacDill | 0.04 |
| 10. Shaw | 0.03 |
| 11. Eglin | 0.02 |
| 12. Hahn | 0.03 |
| 13. Bitburg | 0.03 |
| 14. Aviano | 0.03 |
| 15. Zaragoza | 0.01 |
| 16. Camp New Amsterdam | 0.02 |
| 17. Torrejon | 0.00 |
| 18. Osan | 0.01 |
| 19. Clark | 0.01 |
| 20. Anderson | 0.02 |
| 21. Kadena | 0.01 |
| | Mean: 0.02 ± 0.01 |



| FUEL SAMPLE | WEIGHT PERCENT SULFUR (WT %) |
|---|---|
| HILL | 0.01 |
| LUKE | 0.02 |
| HOLLOMAN | 0.04 |
| ELMENDORF | 0.01 |
| EDWARDS | 0.03 |
| NELLIS | 0.04 |
| LANGLEY | 0.00 |
| TYNDALL | 0.02 |
| MACDILL | 0.04 |
| SHAW | 0.03 |
| EGLIN | 0.02 |
| HAHN | 0.03 |
| BITGURG | 0.03 |
| AVIANO | 0.03 |
| ZARAGOZA | 0.01 |
| CAMP NEW AMSTERDAM | 0.02 |
| TORREJON | 0.00 |
| OSAN | 0.01 |
| CLARK | 0.01 |
| ANDERSON | 0.02 |
| KADENA | 0.01 |

Figure A5. Total Sulfur

## TABLE A7

## BOILING RANGE DISTRIBUTION SPECS

|  |  | ASTM D 2887 | ASTM D 86 |
|---|---|---|---|
| SPECS: | 20% recovered | - 130°C max | 145°C max |
|  | 50% recovered | - 185°C max | 190°C max |
|  | 90% recovered | - 250°C max | 245°C max |
|  | FBP | - 320°C max | 270°C max |

"AVERAGE" FROM 1980/81 JP-4 STUDY (ASTM D 86)

|  |  |
|---|---|
| IBD | 61°C |
| 10% | 94°C |
| 20% | 107°C |
| 50% | 143°C |
| 90% | 205°C |
| FBP | 238°C |

## TABLE A8
## SIMULATED DISTILLATION ANALYSES

| Fuel | IBP °C |  | 10% °C |  | 20% °C |  |
|---|---|---|---|---|---|---|
|  | SFTLA | MONSANTO | SFTLA | MONSANTO | SFTLA | MONSANTO |
| 1. Hill | 0 | 29 | 73 | 78 | 94 | 99 |
| 2. Luke | 24 | 30 | 70 | 73 | 92 | 91 |
| 3. Holloman | 25 | 27 | 75 | 77 | 98 | 98 |
| 4. Elmendorf | 24 | 34 | 73 | 79 | 89 | 91 |
| 5. Edwards | 24 | 27 | 75 | 74 | 97 | 97 |
| 6. Nellis | 1 | 27 | 76 | 83 | 101 | 101 |
| 7. Langley | 24 | 29 | 66 | 66 | 90 | 89 |
| 8. Tyndall | 2 | 27 | 68 | 87 | 102 | 117 |
| 9. MacDill | 24 | 29 | 68 | 67 | 97 | 95 |
| 10. Shaw | 24 | 29 | 66 | 62 | 90 | 87 |
| 11. Eglin | 23 | 28 | 90 | 92 | 118 | 119 |
| 12. Hahn | 10 | 27 | 69 | 60 | 98 | 96 |
| 13. Bitburg | 23 | 27 | 69 | 71 | 94 | 98 |
| 14. Aviano | 1 | 26 | 76 | 87 | 102 | 107 |
| 15. Zaragoza | 22 | 29 | 68 | 55 | 97 | 93 |
| 16. Camp New Amsterdam | 25 | 29 | 83 | 82 | 99 | 100 |

## TABLE A8 (Continued)
## SIMULATED DISTILLATION ANALYSES

| | IBP °C | | 10% °C | | 20% °C | |
|---|---|---|---|---|---|---|
| Fuel | SFTLA | MONSANTO | SFTLA | MONSANTO | SFTLA | MONSANTO |
| 17. Torrejon | 23 | 28 | 74 | 73 | 99 | 100 |
| 18. Osan | 22 | 10 | 67 | 64 | 96 | 95 |
| 19. Clark | 25 | 28 | 82 | 72 | 99 | 98 |
| 20. Anderson | 25 | 31 | 70 | 73 | 93 | 97 |
| 21. Kadena | 25 | 29 | 85 | 84 | 99 | 99 |
| Mean: | | | | | 97 | 98 |

## TABLE A8 (Continued)
## SIMULATED DISTILLATION ANALYSES

| Fuel | 50% °C |  | 90% °C |  | FBP |  |
|---|---|---|---|---|---|---|
|  | SFTLA | MONSANTO | SFTLA | MONSANTO | SFTLA | MONSANTO |
| 1. Hill | 146 | 141 | 216 | 195 | 278 | 262 |
| 2. Luke | 144 | 135 | 231 | 221 | 284 | 281 |
| 3. Holloman | 149 | 159 | 234 | 245 | 280 | 318 |
| 4. Elmendorf | 120 | 116 | 214 | 215 | 281 | 303 |
| 5. Edwards | 147 | 142 | 238 | 238 | 291 | 305 |
| 6. Nellis | 159 | 159 | 246 | 244 | 297 | 296 |
|  |  |  |  |  |  |  |
| 7. Langley | 147 | 142 | 236 | 233 | 279 | 275 |
| 8. Tyndall | 147 | 147 | 239 | 229 | 284 | 283 |
| 9. MacDill | 166 | 163 | 246 | 244 | 284 | 288 |
| 10. Shaw | 168 | 172 | 244 | 244 | 284 | 304 |
| 11. Eglin | 143 | 145 | 239 | 253 | 291 | 333 |
|  |  |  |  |  |  |  |
| 12. Hahn | 160 | 160 | 229 | 228 | 275 | 288 |
| 13. Bitburg | 162 | 170 | 233 | 235 | 271 | 295 |
| 14. Aviano | 143 | 141 | 219 | 216 | 264 | 257 |
| 15. Zaragoza | 160 | 165 | 226 | 240 | 265 | 370 |
| 16. Camp New Amsterdam | 169 | 173 | 235 | 252 | 285 | 333 |
| 17. Torrejon | 157 | 167 | 229 | 238 | 270 | 330 |

## TABLE A8 (Concluded)
## SIMULATED DISTILLATION ANALYSES

| | | 50% °C | | 90% °C | | FBP | |
|---|---|---|---|---|---|---|---|
| | Fuel | SFTLA | MONSANTO | SFTLA | MONSANTO | SFTLA | MONSANTO |
| 18. | Osan | 160 | 166 | 228 | 234 | 288 | 330 |
| 19. | Clark | 131 | 134 | 204 | 222 | 276 | 342 |
| 20. | Anderson | 132 | 139 | 206 | 246 | 282 | 334 |
| 21. | Kadena | 126 | 126 | 215 | 220 | 300 | 311 |
| | Mean | 149 | 151 | 229 | 233 | 281 | 307 |

## TABLE A9
## VAPOR PRESSURE ANALYSES

Spec: 2 psi minimum; 3 psi maximum

"Average" from 1980/81 JP-4 Study: 2.6 psi

| Fuel | Vapor Pressure (psi)<br>SFTLA |
|---|---|
| 1. Hill | 1.7 |
| 2. Luke | 1.5 |
| 3. Holloman | 2.5 |
| 4. Elmendorf | 2.3 |
| 5. Edwards | 2.5 |
| 6. Nellis | 2.1 |
| 7. Langley | 2.2 |
| 8. Tyndall | 2.1 |
| 9. MacDill | 2.2 |
| 10. Shaw | 2.1 |
| 11. Eglin | 2.9 |
| 12. Hahn | 2.1 |
| 13. Bitburg | 2.4 |
| 14. Aviano | 2.3 |
| 15. Zaragoza | 2.4 |
| 16. Camp New Amsterdam | 2.1 |
| 17. Torrejon | 2.3 |
| 18. Osan | 2.4 |
| 19. Clark | 2.5 |
| 20. Anderson | 2.8 |
| 21. Kadena | 2.6 |
|  | Mean 2.29 ± .38 |

## TABLE A10

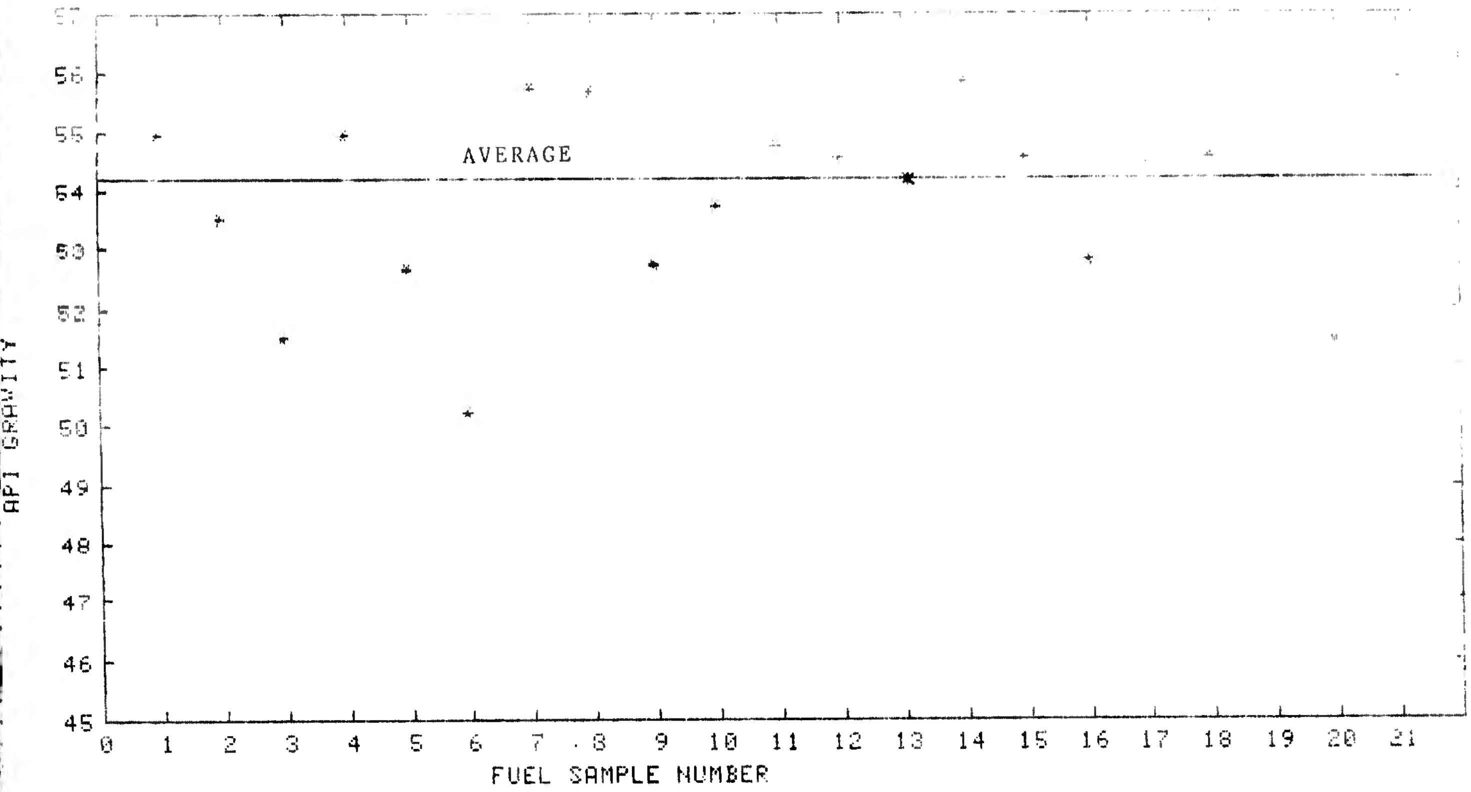
## API GRAVITY ANALYSES

Spec Limits: 45.0 and 57.0

"Average" from 1980/81 JP-4 Study: 54.2

| Fuel | API Gravity |
|---|---|
| 1. Hill | 54.9 |
| 2. Luke | 53.5 |
| 3. Holloman | 51.5 |
| 4. Elmendorf | 54.9 |
| 5. Edwards | 52.6 |
| 6. Nellis | 50.2 |
| 7. Langley | 55.7 |
| 8. Tyndall | 55.7 |
| 9. MacDill | 52.7 |
| 10. Shaw | 53.7 |
| 11. Eglin | 54.7 |
| 12. Hahn | 54.5 |
| 13. Bittburg | 54.2 |
| 14. Aviano | 55.8 |
| 15. Zaragoza | 54.5 |
| 16. Camp New Amsterdam | 52.8 |
| 17. Torrejon | 54.4 |
| 18. Osan | 54.5 |
| 19. Clark | 54.8 |
| 20. Anderson | 51.4 |
| 21. Kadena | 55.9 |

Mean: 53.9 ± 1.6



| FUEL SAMPLE | API GRAVITY |
|---|---|
| HILL | 54.9 |
| LUKE | 53.5 |
| HOLLOMAN | 51.5 |
| ELMENDORF | 54.9 |
| EDWARDS | 52.6 |
| NELLIS | 50.2 |
| LANGLEY | 55.7 |
| TYNDALL | 55.7 |
| MACDILL | 52.7 |
| SHAW | 53.7 |
| EGLIN | 54.7 |
| HAHN | 54.5 |
| BITBURG | 54.2 |
| AVIANO | 55.8 |
| ZARAGOZA | 54.5 |
| CAMP NEW AMSTERDAM | 52.8 |
| TORREJON | 54.4 |
| OSAN | 54.5 |
| CLARK | 54.8 |
| ANDERSON | 54.4 |
| KADENA | 55.9 |

Figure A6. API Gravity

## TABLE A11
## FREEZING POINT ANALYSES

Spec Limit: -58°C maximum

"Near Spec Limit": -60.6°C maximum

| Fuel | Freezing Point (°C) |
|---|---|
| 1. Hill | -73 |
| 2. Luke | -69 |
| 3. Holloman | -66 |
| 4. Elmendorf | -73 |
| 5. Edwards | -66 |
| 6. Nellis | -63 |
| 7. Langley | -66 |
| 8. Tyndall | -67 |
| 9. MacDill | -58 |
| 10. Shaw | -60 |
| 11. Eglin | -59 |
| 12. Hahn | -67 |
| 13. Bitburg | -64 |
| 14. Aviano | -73 |
| 15. Zaragoza | -63 |
| 16. Camp New Amsterdam | -60 |
| 17. Torrejon | -62 |
| 18. Osan | -66 |
| 19. Clark | -73 |
| 20. Anderson | -73 |
| 21. Kadena | -73 |

## TABLE A12
## VISCOSITY ANALYSES

Spec Limits: No limit

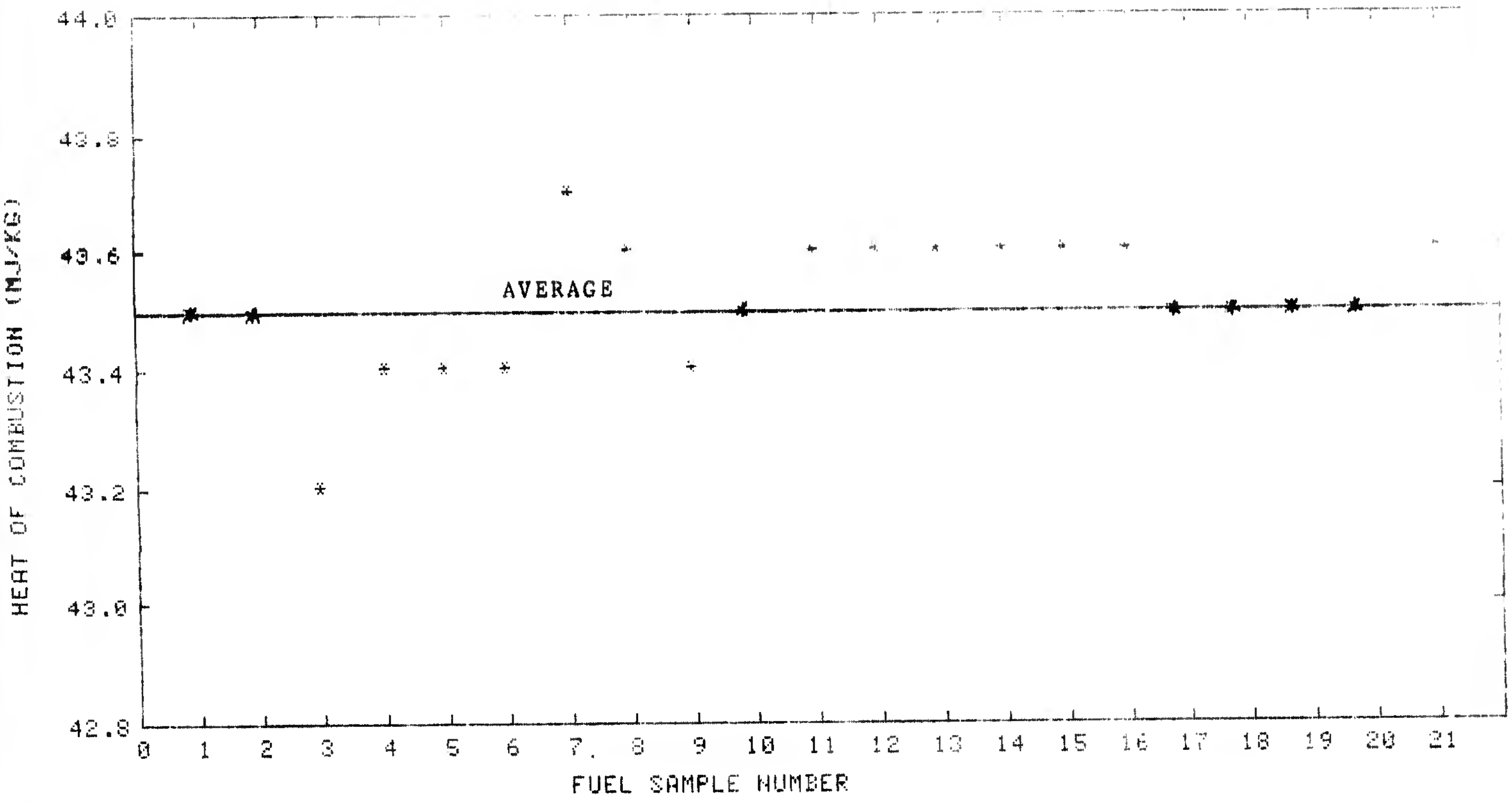
| Fuel | Viscosity (CS) (-20°C) | |
|---|---|---|
| | SFTLA | Monsanto |
| 1. Hill | 1.6 | 1.5 |
| 2. Luke | 1.6 | 1.5 |
| 3. Holloman | 1.8 | 1.8 |
| 4. Elmendorf | 1.3 | 1.3 |
| 5. Edwards | 1.9 | 1.7 |
| 6. Nellis | 2.1 | 1.9 |
| 7. Langley | 1.6 | 1.6 |
| 8. Tyndall | 1.8 | 1.5 |
| 9. MacDill | 1.9 | 1.8 |
| 10. Shaw | 2.0 | 1.8 |
| 11. Eglin | 1.9 | 1.7 |
| 12. Hahn | 1.9 | 1.8 |
| 13. Bitburg | 1.9 | 1.8 |
| 14. Aviano | 1.7 | 1.5 |
| 15. Zaragoza | 1.9 | 1.8 |
| 16. Camp New Amsterdam | 2.2 | 1.9 |
| 17. Torrejon | 2.0 | 1.8 |
| 18. Osan | 1.8 | 1.7 |
| 19. Clark | 1.6 | 1.4 |
| 20. Anderson | 1.5 | 1.4 |
| 21. Kadena | 1.5 | 1.4 |
| Mean: | 1.8 ± .2 | 1.6 ± .2 |

## TABLE A13
## HEAT OF COMBUSTION ANALYSES

Spec: 42.8 MJ/kg minimum

"Average" from 1980/81 JP-4 Study: 43.5 MJ/kg

| Fuel | Heat of Combustion (MJ/kg) | |
|---|---|---|
| | SFTLA | MONSANTO |
| 1. Hill | 43.5 | 43.6 |
| 2. Luke | 43.5 | 43.4 |
| 3. Holloman | 43.2 | 43.2 |
| 4. Elmendorf | 43.4 | 43.5 |
| 5. Edwards | 43.4 | 43.4 |
| 6. Nellis | 43.4 | 43.2 |
| 7. Langley | 43.7 | 43.5 |
| 8. Tyndall | 43.6 | 43.5 |
| 9. MacDill | 43.4 | 43.5 |
| 10. Shaw | 43.5 | 43.5 |
| 11. Eglin | 43.6 | 43.5 |
| 12. Hahn | 43.6 | 43.5 |
| 13. Bitburg | 43.6 | 43.5 |
| 14. Aviano | 43.6 | 43.5 |
| 15. Zaragoza | 43.6 | 43.5 |
| 16. Camp New Amsterdam | 43.6 | 43.6 |
| 17. Torrejon | 43.6 | 43.5 |
| 18. Osan | 43.5 | 43.4 |
| 19. Clark | 43.5 | 43.4 |
| 12. Anderson | 43.5 | 43.4 |
| 21. Kadena | 43.6 | 43.5 |
| | Mean: 43.5 ± .11 | Mean: 43.5 ± .10 |



| FUEL SAMPLE | HEAT OF COMBUSTION (MJ/KG) |
|---|---|
| HILL | 43.5 |
| LUKE | 43.5 |
| HOLLOMAN | 43.2 |
| ELMENDORF | 43.4 |
| EDWARDS | 43.4 |
| NELLIS | 43.4 |
| LANGLEY | 43.7 |
| TYNDALL | 43.6 |
| MACDILL | 43.4 |
| SHAW | 43.5 |
| EGLIN | 43.6 |
| HAHN | 43.6 |
| BITBURG | 43.6 |
| AVIANO | 43.6 |
| ZARAGOZA | 43.6 |
| CAMP NEW AMSTERDAM | 43.5 |
| TORREJON | 43.6 |
| OSAN | 43.6 |
| CLARK | 43.5 |
| ANDERSON | 43.5 |
| KADENA | 43.6 |

Figure A7. Heat of Combustion

## TABLE A14

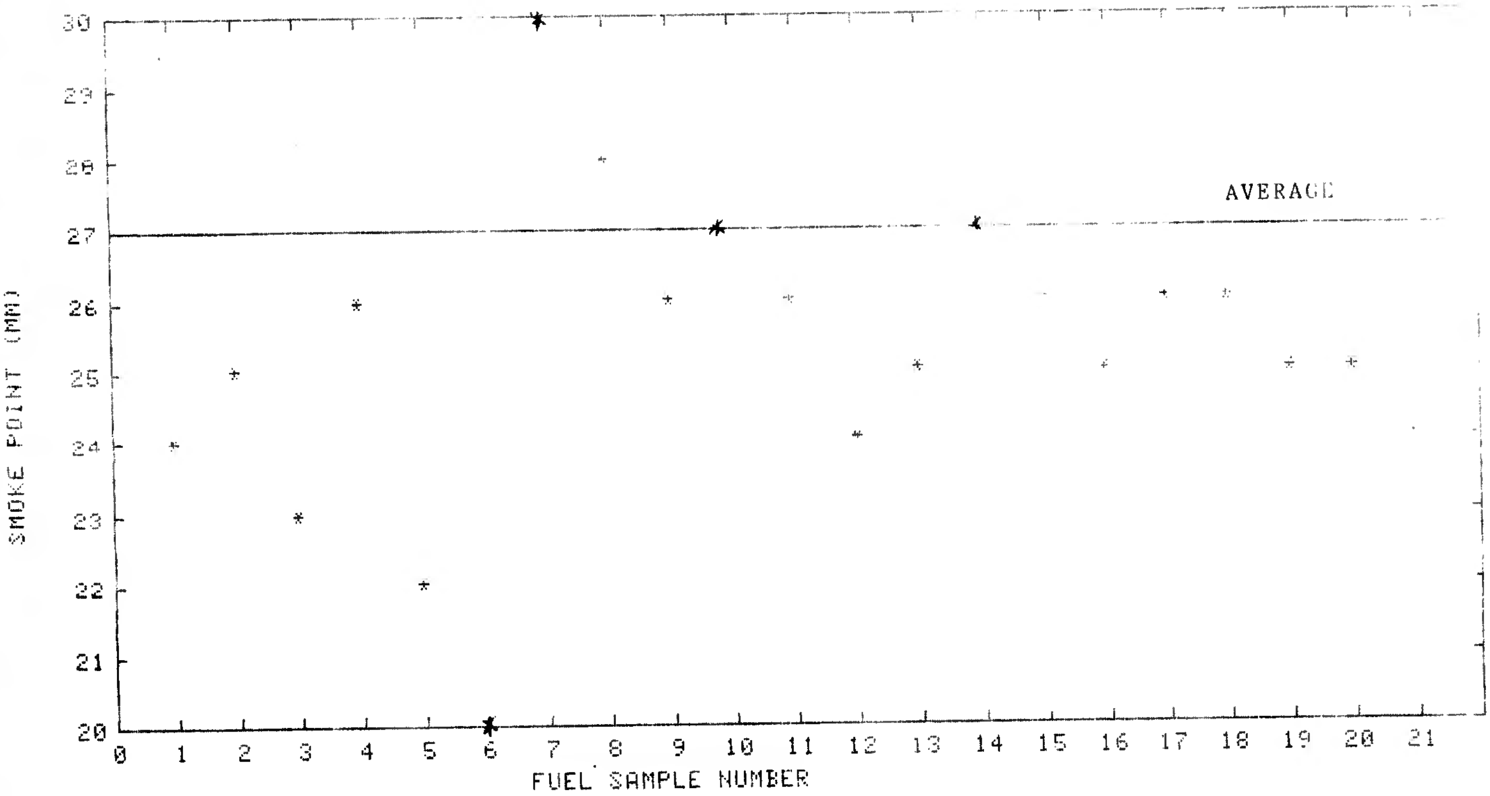
## SMOKE POINT ANALYSES

Spec: 20 mm minimum

"Average" from 1980/81 JP-4 study: [illegible]

| | Fuel | Smoke Point |
|---|---|---|
| 1. | Hill | 24.0 |
| 2. | Luke | 25.0 |
| 3. | Holloman | 23.0 |
| 4. | Elmendorf | 26.0 |
| 5. | Edwards | 22.0 |
| 6. | Nellis | 20.0 |
| 7. | Langley | 30.0 |
| 8. | Tyndall | 28.0 |
| 9. | MacDill | 26.0 |
| 10. | Shaw | 27.0 |
| 11. | Eglin | 26.0 |
| 12. | Hahn | 24.0 |
| 13. | Bitburg | 25.0 |
| 14. | Aviano | 27.0 |
| 15. | Zaragoza | 26.0 |
| 16. | Camp New Amsterdam | 25.0 |
| 17. | Torrejon | 28.0 |
| 18. | Osan | 26.0 |
| 19. | Clark | 25.0 |
| 20. | Anderson | 25.0 |
| 21. | Kadena | 24.0 |

Mean: 25 ± 2



| FUEL SAMPLE | SMOKE POINT (mm) |
|---|---|
| HILL | 24.0 |
| LUKE | 25.0 |
| HOLLOMAN | 23.0 |
| ELMENDORF | 26.0 |
| EDWARDS | 22.0 |
| NELLIS | 20.0 |
| LANGLEY | 30.0 |
| TYNDALL | 28.0 |
| MACDILL | 26.0 |
| SHAW | 27.0 |
| EGLIN | 26.0 |
| HAHN | 24.0 |
| BITGURG | 25.0 |
| AVIANO | 27.0 |
| ZARAGOZA | 26.0 |
| CAMP NEW AMSTERDAM | 25.0 |
| TORREJON | 28.0 |
| OSAN | 26.0 |
| CLARK | 25.0 |
| ANDERSON | 25.0 |
| KADENA | 24.0 |

Figure A8. Smoke Point

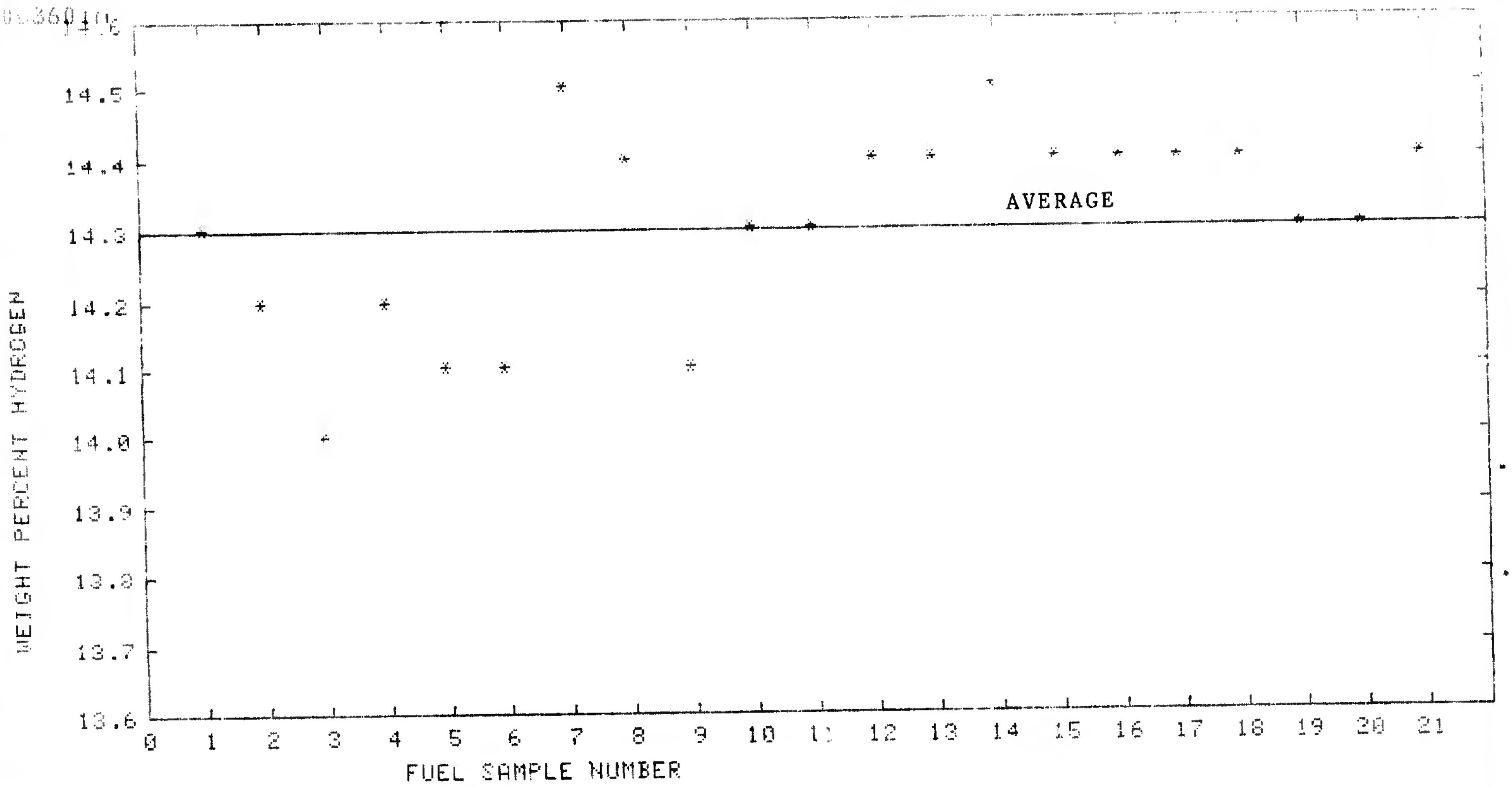
## TABLE A15
## HYDROGEN CONTENT ANALYSES

Spec: 13.6 wt % minimum

"Average" from 1980/81 JP-4 Study: 14.3

| Fuel | SFTLA Wt % $H_2$ | POSF Wt % $H_2$ |
|---|---|---|
| 1. Hill | 14.3 | 14.2 |
| 2. Luke | 14.2 | 14.0 |
| 3. Holloman | 14.0 | 13.9 |
| 4. Elmendorf | 14.2 | 14.0 |
| 5. Edwards | 14.1 | 14.1 |
| 6. Nellis | 14.1 | 13.9 |
| 7. Langley | 14.5 | 14.4 |
| 8. Tyndall | 14.4 | 14.3 |
| 9. MacDill | 14.1 | 14.1 |
| 10. Shaw | 14.3 | 14.3 |
| 11. Eglin | 14.3 | 14.3 |
| 12. Hahn | 14.4 | 14.4 |
| 13. Bitburg | 14.4 | 14.4 |
| 14. Aviano | 14.5 | 14.4 |
| 15. Zaragoza | 14.4 | 14.4 |
| 16. Camp New Amsterdam | 14.4 | 14.2 |
| 17. Torrejon | 14.4 | 14.5 |
| 18. Osan | 14.4 | 14.3 |
| 19. Clark | 14.3 | 14.2 |
| 20. Anderson | 14.3 | 14.1 |
| 21. Kadena | 14.4 | 14.3 |
| | Mean: 14.3 ± .1 | Mean: 14.2 ± .2 |

% Difference over Spec Min 4 %



| FUEL SAMPLE | SFTLA WT % $H_2$ | POSF WT % $H_2$ |
|---|---|---|
| HILL | 14.3 | 14.2 |
| LUKE | 14.2 | 14.0 |
| HOLLOMAN | 14.0 | 13.9 |
| ELMENDORF | 14.2 | 14.0 |
| EDWARDS | 14.1 | 14.1 |
| NELLIS | 14.1 | 13.9 |
| LANGLEY | 14.5 | 14.4 |
| TYNDALL | 14.4 | 14.3 |
| MACDILL | 14.1 | 14.1 |
| SHAW | 14.3 | 14.3 |
| EGLIN | 14.3 | 14.3 |
| HAHN | 14.4 | 14.4 |
| BITBURG | 14.4 | 14.4 |
| AVIANO | 14.5 | 14.4 |
| ZARAGOZA | 14.4 | 14.4 |
| CAMP NEW AMSTERDAM | 14.4 | 14.2 |
| TORREJON | 14.4 | 14.5 |
| OSAN | 14.4 | 14.3 |
| CLARK | 14.3 | 14.2 |
| ANDERSON | 14.3 | 14.1 |
| KADENA | 14.4 | 14.3 |

Figure A9. Hydrogen Content

## TABLE A16
## COPPER STRIP CORROSION ANALYSES

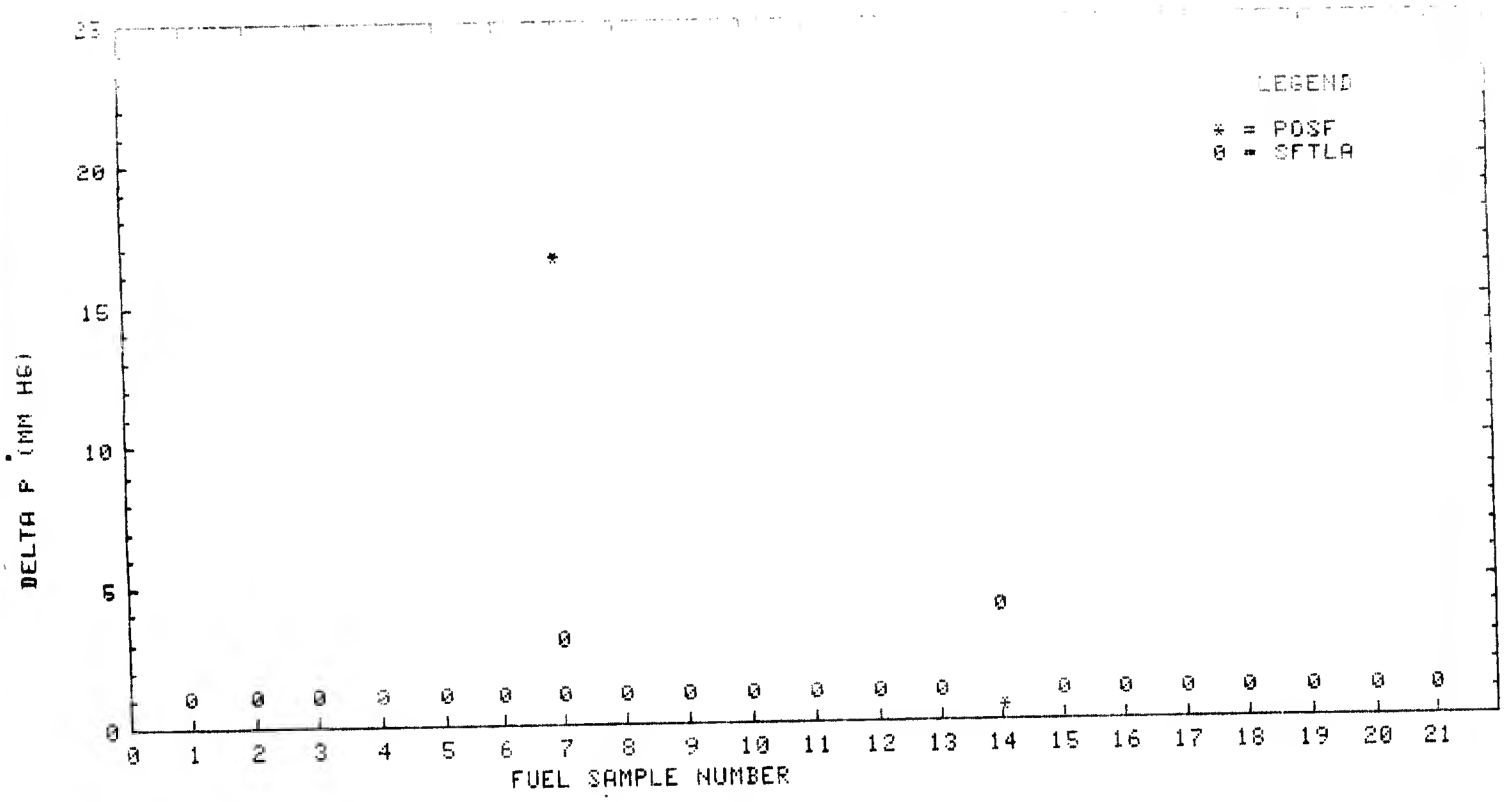
Spec Limit: 1B maximum

| Fuel | Copper Strip Corrosion |
|---|---|
| 1. Hill | 1A |
| 2. Luke | 1A |
| 3. Holloman | 1A |
| 4. Elmendorf | 1A |
| 5. Edwards | 1A |
| 6. Nellis | 1A |
| 7. Langley | 1A |
| 8. Tyndall | 1A |
| 9. MacDill | 1A |
| 10. Shaw | 1A |
| 11. Eglin | 1A |
| 12. Hahn | 1A |
| 13. Bitburg | 1A |
| 14. Aviano | 1B |
| 15. Zaragoza | 1A |
| 16. Camp New Amsterdam | 1A |
| 17. Torrejon | 1A |
| 18. Osan | 1A |
| 19. Clark | 1A |
| 20. Anderson | 1A |
| 21. Kadena | 1A |

## TABLE A17
## THERMAL STABILITY ANALYSES

Spec: $\Delta$ P = 25 mm Hg maximum PDC < 3

| Fuel | P mm Hg | PDC |
|---|---|---|
| 1. Hill | 0 | 1 |
| 2. Luke | 0 | 1 |
| 3. Holloman | 0 | 1 |
| 4. Elmendorf | 0 | 1 |
| 5. Edwards | 0 | 1 |
| 6. Nellis | 0 | 1 |
| 7. Langley | 0, 16.5, 0 | 1, 3, 1 |
| 8. Tyndall | 0 | 1 |
| 9. MacDill | 0 | 1 |
| 10. Shaw | 0 | 1 |
| 11. Eglin | 0 | 1 |
| 12. Hahn | 0 | 1 |
| 13. Bitburg | 0 | 1 |
| 14. Aviano | 0, 0.2 | 4, 4 |
| 15. Zaragoza | 0 | 1 |
| 16. Camp New Amsterdam | 0 | 1 |
| 17. Torrejon | 0 | 1 |
| 18. Osan | 0 | 1 |
| 19. Clark | 0 | 1 |
| 20. Anderson | 0 | 1 |
| 21. Kadena | 0 | 1 |



| FUEL SAMPLE | DELTA P (mm hg) |
|---|---|
| HILL | 0 |
| LUKE | 0 |
| HOLLOMAN | 0 |
| ELMENDORF | 0 |
| EDWARDS | 0 |
| NELLIS | 0 |
| LANGLEY | 0, 16.5 |
| TYNDALL | 0 |
| MACDILL | 0 |
| SHAW | 0 |
| EGLIN | 0 |
| HAHN | 0 |
| BITBURG | 0 |
| AVIANO | 0, 0.2 |
| ZARAGOZA | 0 |
| CAMP NEW AMSTERDAM | 0 |
| TORREJON | 0 |
| OSAN | 0 |
| CLARK | 0 |
| ANDERSON | 0 |
| KADENA | 0 |

Figure A10. Thermal Stability

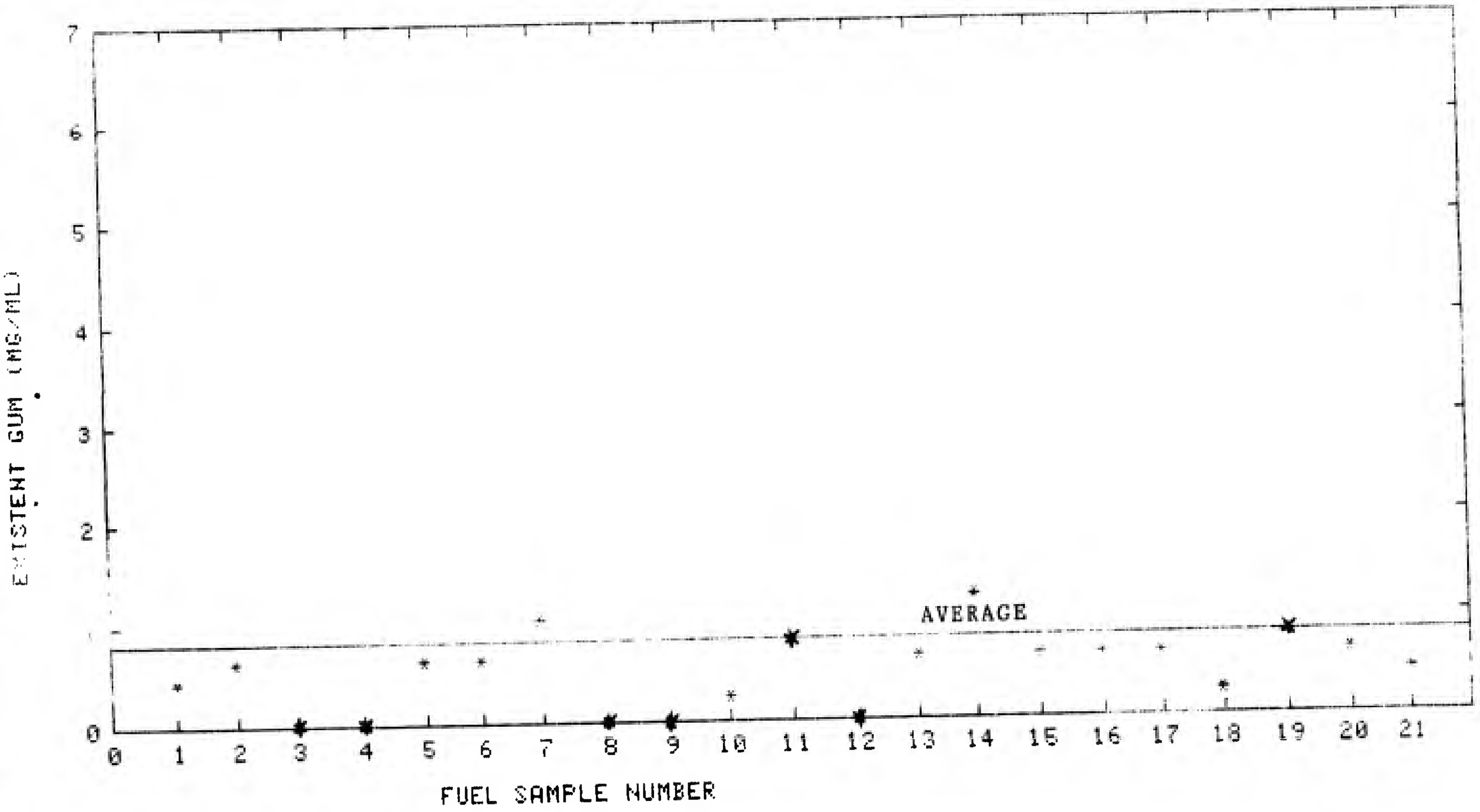
## TABLE A18
## EXISTENT GUM ANALYSES

Spec: 7 mg/100 ml maximum

"Average" from 1980/81 JP-4 Study: 0.8 mg/100 ml

| Fuel | Existent Gum |
|---|---|
| 1. Hill | 0.4 |
| 2. Luke | 0.6 |
| 3. Holloman | 0.0 |
| 4. Elmendorf | 0.0 |
| 5. Edwards | 0.6 |
| 6. Nellis | 0.6 |
| 7. Langley | 1.0 |
| 8. Tyndall | 0.0 |
| 9. MacDill | 0.0 |
| 10. Shaw | 0.2 |
| 11. Eglin | 0.8 |
| 12. Hahn | 0.0 |
| 13. Bitburg | 0.6 |
| 14. Aviano | 1.2 |
| 15. Zaragoza | 0.6 |
| 16. Camp New Amsterdam | 0.6 |
| 17. Torrejon | 0.4 |
| 18. Osan | 0.2 |
| 19. Clark | 0.8 |
| 20. Anderson | 0.6 |
| 21. Kadena | 0.4 |

Mean: 0.5 ± .04



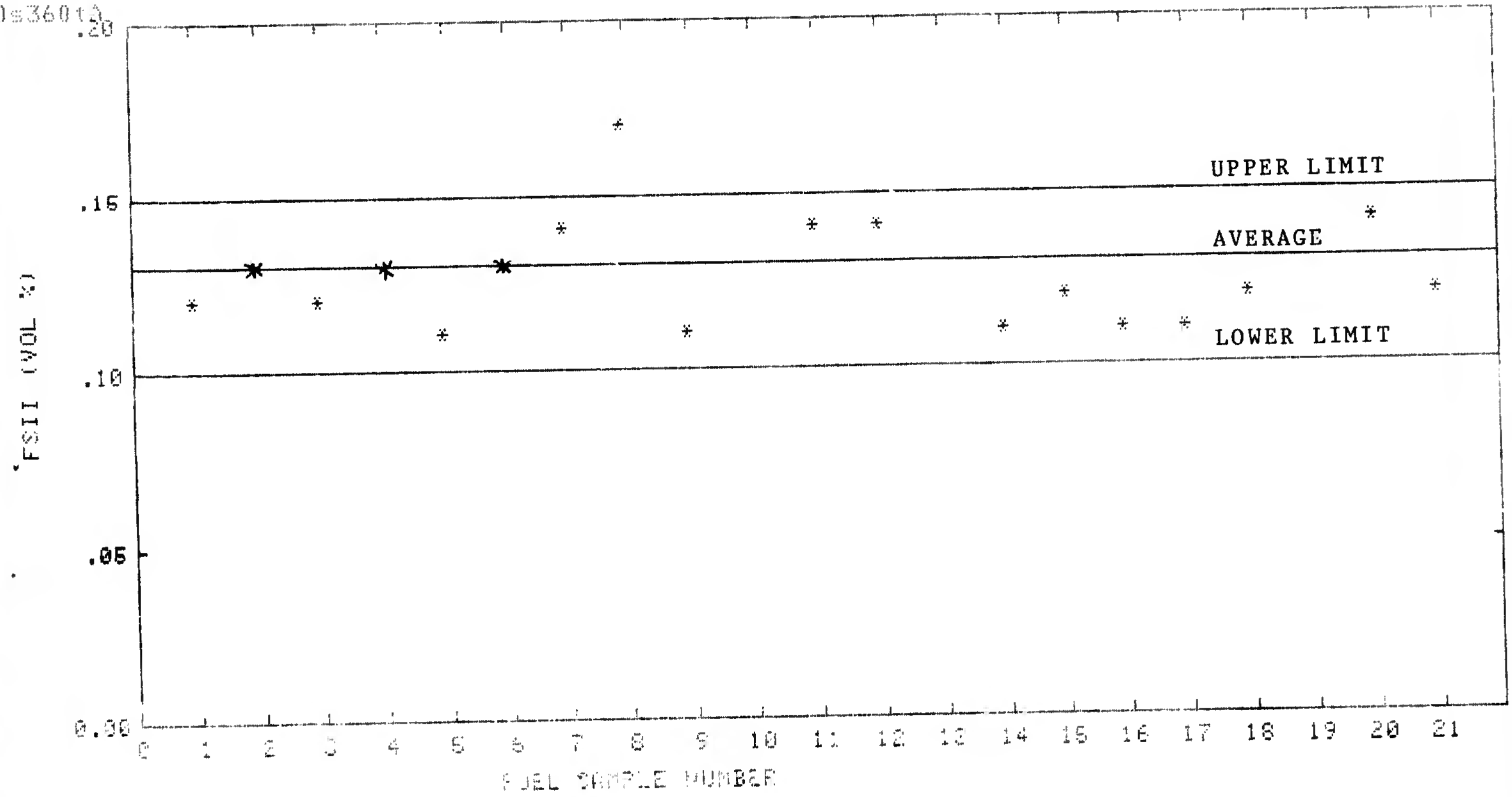
| FUEL SAMPLE | EXISTENT GUM (mg/ml) |
|---|---|
| HILL | 0.4 |
| LUKE | 0.6 |
| HOLLOMAN | 0.0 |
| ELMENDORF | 0.0 |
| EDWARDS | 0.6 |
| NELLIS | 0.6 |
| LANGLEY | 1.0 |
| TYNDALL | 0.0 |
| MACDILL | 0.0 |
| SHAW | 0.2 |
| EGLIN | 0.8 |
| HAHN | 0.0 |
| BITBURG | 0.6 |
| AVIANO | 1.2 |
| ZARAGOZA | 0.6 |
| CAMP NEW AMSTERDAM | 0.6 |
| TORREJON | 0.4 |
| OSAN | 0.2 |
| CLARK | 0.8 |
| ANDERSON | 0.6 |
| KADENA | 0.4 |

Figure A11. Existent Gum

## TABLE A19
## VOL % FUEL SYSTEM ICING INHIBITOR ANALYSES

Spec: 10 minimum; 15 maximum
"Average" from 1980/81 JP-4 Study: 0.13 Vol %

| Fuel | Vol % FSII |
|---|---|
| 1. Hill | 0.12 |
| 2. Luke | 0.13 |
| 3. Holloman | 0.12 |
| 4. Elmendorf | 0.13 |
| 5. Edwards | 0.11 |
| 6. Nellis | 0.13 |
| 7. Langley | 0.14 |
| 8. Tyndall | 0.17 |
| 9. MacDill | 0.11 |
| 10. Shaw | 0.10 |
| 11. Eglin | 0.14 |
| 12. Hahn | 0.14 |
| 13. Bitburg | 0.15 |
| 14. Aviano | 0.11 |
| 15. Zaragoza | 0.12 |
| 16. Camp New Amsterdam | 0.11 |
| 17. Torrejon | 0.14 |
| 18. Osan | 0.12 |
| 19. Clark | 0.13 |
| 20. Anderson | 0.14 |
| 21. Kadena | 0.12 |
|  | Mean 0.13 ± 0.02 |



| FUEL SAMPLE | FSII (vol %) |
|---|---|
| HILL | 0.12 |
| LUKE | 0.13 |
| HOLLOMAN | 0.12 |
| ELMENDORF | 0.13 |
| EDWARDS | 0.11 |
| NELLIS | 0.13 |
| LANGLEY | 0.14 |
| TYNDALL | 0.17 |
| MACDILL | 0.11 |
| SHAW | 0.10 |
| EGLIN | 0.14 |
| HAHN | 0.14 |
| BITBURG | 0.15 |
| AVIANO | 0.11 |
| ZARAGOZA | 0.12 |
| CAMP NEW AMSTERDAM | 0.11 |
| TORREJON | 0.14 |
| OSAN | 0.12 |
| CLARK | 0.13 |
| ANDERSON | 0.14 |
| KADENA | 0.12 |

Figure A12. Fuel System Icing Inhibitor

# APPENDIX B

## CHARACTERIZATION ANALYSES

### TABLE B1

### PHYSICAL PROPERTIES AS A FUNCTION OF TEMPERATURE

| | Vapor pressure (mm Hg) | Kinematic viscosity (centi-stokes) | Density (g/cm$^3$) | Surface tension (dynes/cm) |
|---|---|---|---|---|
| Hill | | | | |
| -30.1°F | - | 2.013 | - | - |
| -20°F | 8[a] | 1.785 | 0.7936 | 28.1[b] |
| -4°F | - | 1.512 | - | - |
| 32°F | 33 | 1.139 | 0.7718 | 25.4 |
| 59°F | - | - | 0.7589 | - |
| 70°F | 74 | 0.863 | 0.7546 | 23.4 |
| 100°F | 133 | 0.720 | 0.7409 | 21.9 |
| 140°F | 270 | 0.583 | 0.7230 | 19.8 |
| Luke | | | | |
| -30.1°F | - | 2.010 | - | - |
| -20°F | 8[a] | 1.798 | 0.7998 | 28.2[b] |
| -4°F | - | 1.514 | - | - |
| 32°F | 32 | 1.135 | 0.7767 | 25.4 |
| 59°F | - | - | 0.7653 | - |
| 70°F | 76 | 0.862 | 0.7608 | 23.4 |
| 100°F | 134 | 0.719 | 0.7471 | 21.8 |
| 140°F | 290 | 0.582 | 0.7296 | 19.7 |
| Holloman | | | | |
| -30.1°F | - | 2.345 | - | - |
| -20°F | 7[a] | 2.072 | 0.8051 | 28.4[b] |
| -4°F | - | 1.755 | - | - |
| 32°F | 32 | 1.283 | 0.7850 | 25.9 |
| 59°F | - | - | 0.7738 | - |
| 70°F | 78 | 0.9660 | 0.7689 | 24.0 |
| 100°F | 145 | 0.7694 | 0.7555 | 22.6 |
| 140°F | 305 | 0.6359 | 0.7369 | 20.6 |

[a] Value determined by extrapolation of Log P versus 1/T vapor pressure relationship.

[b] Obtained by linear regression extrapolation of data.

TABLE B1 (Continued)
PHYSICAL PROPERTIES AS A FUNCTION OF TEMPERATURE

| | Vapor pressure (mm/Hg) | Kinematic viscosity (centistokes) | Density (g/cm$^3$) | Surface tension (dynes/cm) |
|---|---|---|---|---|
| Elmendorf | | | | |
| -30.1°F | - | 1.629 | - | - |
| -20°F | 7[a] | 1.471 | 0.7928 | 27.8[b] |
| -4°F | - | 1.277 | - | - |
| 32°F | 32 | 0.9676 | 0.7710 | 25.1 |
| 59°F | - | - | 0.7583 | - |
| 70°F | 76 | 0.7587 | 0.7539 | 23.2 |
| 100°F | 140 | 0.6375 | 0.7398 | 21.2 |
| 140°F | 288 | 0.5201 | 0.7214 | 19.5 |
| Edwards | | | | |
| -30.1°F | - | 2.188 | - | - |
| -20°F | 6[a] | 1.942 | 0.8023 | 28.3[b] |
| -4°F | - | 1.653 | - | - |
| 32°F | 26 | 1.224 | 0.7815 | 25.6 |
| 59°F | - | - | 0.7695 | - |
| 70°F | 66 | 0.9254 | 0.7644 | 23.6 |
| 100°F | 125 | 0.7620 | 0.7507 | 22.0 |
| 140°F | 270 | 0.6153 | 0.7326 | 19.8 |
| Nellis | | | | |
| -30.1°F | - | 2.603 | - | - |
| -20°F | 7[a] | 2.262 | 0.8143 | 29.2[b] |
| -4°F | - | 1.917 | - | - |
| 32°F | 30 | 1.391 | 0.7936 | 26.6 |
| 59°F | - | - | 0.7811 | - |
| 70°F | 70 | 1.028 | 0.7761 | 24.8 |
| 100°F | 128 | 0.8430 | 0.7628 | 23.3 |
| 140°F | 265 | 0.6703 | 0.7444 | 21.4 |

[a] Value determined by extrapolation of Log P versus 1/T vapor pressure relationship.

[b] Obtained by linear regression extrapolation of data.

## TABLE B1 (Continued)
## PHYSICAL PROPERTIES AS A FUNCTION OF TEMPERATURE

| | Vapor pressure (mm/Hg) | Kinematic viscosity (centistokes) | Density ($g/m^3$) | Surface tension (dynes/cm) |
|---|---|---|---|---|
| Shaw | | | | |
| -30.1°F | - | 2.404 | - | - |
| -20°F | 6[a] | 2.116 | 0.7971 | 27.7[b] |
| -4°F | - | 1.761 | - | - |
| 32°F | 29 | 1.284 | 0.7745 | 25.1 |
| 59°F | - | - | 0.7642 | - |
| 70°F | 71 | 0.969 | 0.7592 | 23.2 |
| 100°F | 137 | 0.797 | 0.7457 | 21.7 |
| 140°F | 282 | 0.639 | 0.7293 | 19.6 |
| Eglin | | | | |
| -30.1°F | - | 2.242 | - | - |
| -20°F | 8.9[a] | 2.061 | 0.7944 | 27.6[b] |
| -4°F | - | 1.703 | - | - |
| 32°F | 35 | 1.256 | 0.7730 | 25.2 |
| 59°F | - | - | 0.7606 | - |
| 70°F | 77 | 0.941 | 0.7588 | 23.2 |
| 100°F | 133 | 0.776 | 0.7424 | 21.9 |
| 140°F | 265 | 0.630 | 0.7256 | 20.0 |
| Hahn | | | | |
| -30.1°F | - | 2.373 | - | - |
| -20°F | 6[a] | 2.088 | 0.7939 | 28.9[b] |
| -4°F | - | 1.796 | - | - |
| 32°F | 28 | 1.295 | 0.7722 | 26.2 |
| 59°F | - | - | 0.7615 | - |
| 70°F | 68 | 0.972 | 0.7565 | 24.3 |
| 100°F | 128 | 0.799 | 0.7433 | 22.6 |
| 140°F | 265 | 0.644 | 0.7259 | 20.4 |

[a] Value determined by extrapolation of Log P versus 1/T vapor pressure relationship.

[b] Obtained by linear regression extrapolation of data.

TABLE B1 (Continued)
PHYSICAL PROPERTIES AS A FUNCTION OF TEMPERATURE

| | Vapor pressure (mm/Hg) | Kinematic viscosity (centistokes) | Density $(g/cm^3)$ | Surface tension (dynes/cm) |
|---|---|---|---|---|
| Langley | | | | |
| -30.1°F | - | 2.120 | - | - |
| -20°F | 7[a] | 1.876 | 0.7899 | 27.4[b] |
| -4°F | - | 1.580 | - | - |
| 32°F | 32 | 1.174 | 0.7678 | 24.7 |
| 59°F | - | - | 0.7557 | - |
| 70°F | 74 | 0.887 | 0.7512 | 22.8 |
| 100°F | 138 | 0.740 | 0.7377 | 21.2 |
| 140°F | 285 | 0.596 | 0.7199 | 19.2 |
| Tyndall | | | | |
| -30.1°F | - | 2.048 | - | - |
| -20°F | 7[a] | 1.818 | 0.7895 | 27.8[b] |
| -4°F | - | 1.521 | - | - |
| 32°F | 30 | 1.149 | 0.7681 | 25.1 |
| 59°F | - | - | 0.7563 | - |
| 70°F | 70 | 0.872 | 0.7513 | 23.2 |
| 100°F | 125 | 0.719 | 0.7378 | 21.6 |
| 140°F | 255 | 0.587 | 0.7206 | 19.6 |
| MacDill | | | | |
| -30.1°F | - | 2.464 | - | - |
| -20°F | 7[a] | 2.185 | 0.8014 | 28.1[b] |
| -4°F | - | 1.810 | - | - |
| 32°F | 30 | 1.334 | 0.7806 | 25.4 |
| 59°F | - | - | 0.7690 | - |
| 70°F | 71 | 0.981 | 0.7643 | 23.5 |
| 100°F | 130 | 0.806 | 0.7508 | 21.8 |
| 140°F | 268 | 0.647 | 0.7327 | 19.8 |

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[a] Value determined by extrapolation of Log P versus 1/T vapor pressure relationship.

[b] Obtained by linear regression extrapolation of data.

## TABLE B1 (Continued)

## PHYSICAL PROPERTIES AS A FUNCTION OF TEMPERATURE

| | Vapor pressure (mm/Hg) | Kinematic viscosity (centistokes) | Density ($g/cm^3$) | Surface tension (dynes/cm) |
|---|---|---|---|---|
| Bitburg | | | | |
| -30.1°F | - | 2.372 | - | - |
| -20°F | 8[a] | 2.084 | 0.7966 | 28.2[b] |
| -4°F | - | 1.775 | - | - |
| 32°F | 37 | 1.304 | 0.7726 | 25.8 |
| 59°F | - | - | 0.7627 | - |
| 70°F | 78 | 0.9729 | 0.7579 | 24.0 |
| 100°F | 140 | 0.7998 | 0.7444 | 22.6 |
| 140°F | 290 | 0.6423 | 0.7276 | 20.8 |
| Aviano | | | | |
| -30.1°F | - | 2.128 | - | - |
| -20°F | 10[a] | 1.818 | 0.7904 | 28.4 |
| -4°F | - | 1.549 | - | - |
| 32°F | 39 | 1.163 | 0.7672 | 25.7 |
| 59°F | - | - | 0.7562 | - |
| 70°F | 85 | 0.879 | 0.7512 | 23.8 |
| 100°F | 148 | 0.733 | 0.7378 | 22.1 |
| 140°F | 284 | 0.594 | 0.7202 | 20.2 |
| Zaragoza | | | | |
| -30.1°F | - | 2.514 | - | - |
| -20°F | 6.4[a] | 2.225 | 0.7950 | 28.3[b] |
| -4°F | - | 1.825 | - | - |
| 32°F | 29 | 1.334 | 0.7732 | 25.5 |
| 59°F | - | - | 0.7619 | - |
| 70°F | 71 | 0.999 | 0.7571 | 23.5 |
| 100°F | 135 | 0.829 | 0.7438 | 21.8 |
| 140°F | 288 | 0.660 | 0.7272 | 19.7 |

[a] Value determined by extrapolation of Log P versus 1/T vapor pressure relationship.

[b] Obtained by linear regression extrapolation of data.

TABLE B1 (Continued)

PHYSICAL PROPERTIES AS A FUNCTION OF TEMPERATURE

| | Vapor pressure (mm/Hg) | Kinematic viscosity (centistokes) | Density (g/cm$^3$) | Surface tension (dynes/cm) |
|---|---|---|---|---|
| Camp New Amsterdam | | | | |
| -30.1°F | - | 2.628 | - | - |
| -20°F | 4.9[a] | 2.326 | 0.8019 | 27.9[b] |
| -4°F | - | 1.901 | - | - |
| 32°F | 23.5 | 1.382 | 0.7812 | 25.5 |
| 59°F | - | - | 0.7688 | - |
| 70°F | 59 | 1.024 | 0.7639 | 23.8 |
| 100°F | 114 | 0.848 | 0.7507 | 22.2 |
| 140°F | 245 | 0.664 | 0.7336 | 20.5 |
| Torrejon | | | | |
| -30.1°F | - | 2.516 | - | - |
| -20°F | 5.2[a] | 2.238 | 0.7946 | 28.4[b] |
| -4°F | - | 1.839 | - | - |
| 32°F | 25 | 1.357 | 0.7742 | 25.7 |
| 59°F | - | - | 0.7617 | - |
| 70°F | 65 | 1.005 | 0.7569 | 23.6 |
| 100°F | 124 | 0.829 | 0.7437 | 22.1 |
| 140°F | 270 | 0.662 | 0.7265 | 20.0 |
| Osan | | | | |
| -30.1°F | - | 2.325 | - | - |
| -20°F | 8.1[a] | 2.054 | 0.7955 | 28.8[b] |
| -4°F | - | 1.731 | - | - |
| 32°F | 33 | 1.282 | 0.7723 | 26.1 |
| 59°F | - | - | 0.7617 | - |
| 70°F | 76 | 0.958 | 0.7568 | 24.0 |
| 100°F | 138 | 0.791 | 0.7434 | 22.4 |
| 140°F | 278 | 0.640 | 0.7264 | 20.4 |

[a] Value determined by extrapolation of Log P versus 1/T vapor pressure relationship.

[b] Obtained by linear regression extrapolation of data.

## TABLE B1 (Concluded)
## PHYSICAL PROPERTIES AS A FUNCTION OF TEMPERATURE

| | Vapor pressure (mm/Hg) | Kinematic viscosity (centistokes) | Density (g/cm$^3$) | Surface tension (dynes/cm) |
|---|---|---|---|---|
| Clark | | | | |
| -30.1°F | - | 1.908 | - | - |
| -20°F | 6.1[a] | 1.687 | 0.7940 | 29.3[b] |
| -4°F | - | 1.440 | - | - |
| 32°F | 28 | 1.091 | 0.7722 | 26.0 |
| 59°F | - | - | 0.7599 | - |
| 70°F | 69 | 0.850 | 0.7550 | 23.6 |
| 100°F | 130 | 0.701 | 0.7412 | 21.7 |
| 140°F | 276 | 0.569 | 0.7238 | 19.2 |
| Anderson | | | | |
| -30.1°F | - | 1.868 | - | - |
| -20°F | 6.8[a] | 1.702 | 0.7956 | 28.4[b] |
| -4°F | - | 1.429 | - | - |
| 32°F | 32 | 1.085 | 0.7746 | 25.5 |
| 59°F | - | - | 0.7616 | - |
| 70°F | 75 | 0.834 | 0.7566 | 23.3 |
| 100°F | 140 | 0.695 | 0.7429 | 21.5 |
| 140°F | 300 | 0.578 | 0.7253 | 19.4 |
| Kadena | | | | |
| -30.1°F | - | 1.809 | - | - |
| -20°F | 6.6 | 1.636 | 0.7886 | 28.2[b] |
| -4°F | - | 1.389 | - | - |
| 32°F | 32 | 1.062 | 0.7675 | 25.4 |
| 59°F | - | - | 0.7552 | - |
| 70°F | 76 | 0.814 | 0.7502 | 23.4 |
| 100°F | 135 | 0.681 | 0.7369 | 21.8 |
| 140°F | 276 | 0.576 | 0.7190 | 19.6 |

[a] Value determined by extrapolation of Log P versus 1/T vapor pressure relationship.

[b] Obtained by linear regression extrapolation of data.

## TABLE B2

## COMPARISON OF TYPICAL JP-4 AND AVERAGED F100 SAMPLES VAPOR PRESSURE AS A FUNCTION OF TEMPERATURE

| Temperature °F (°C) | | Vapor Pressure (mm Hg)<br>Typical JP-4 | F100 Samples |
|---|---|---|---|
| -20 | (-28.9) | no data | 7 |
| 32 | (0) | 23.25[a] | 30.8 |
| 70 | (21.1) | 81.01 | 72.6 |
| 100 | (37.8) | 126 | 133 |
| 140 | (60) | 283.5 | 276.9 |

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[a] Obtained by extrapolation

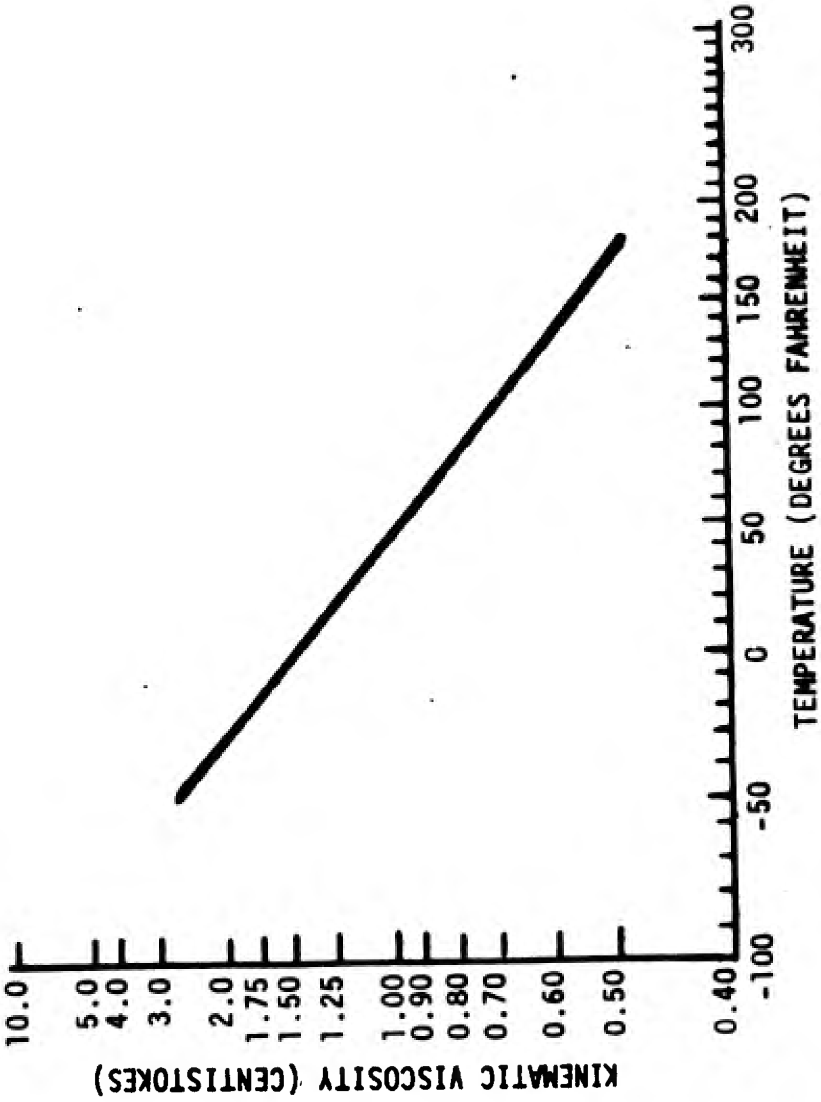

Figure B1. Temperature/Viscosity Plot for Hill Fuel Sample

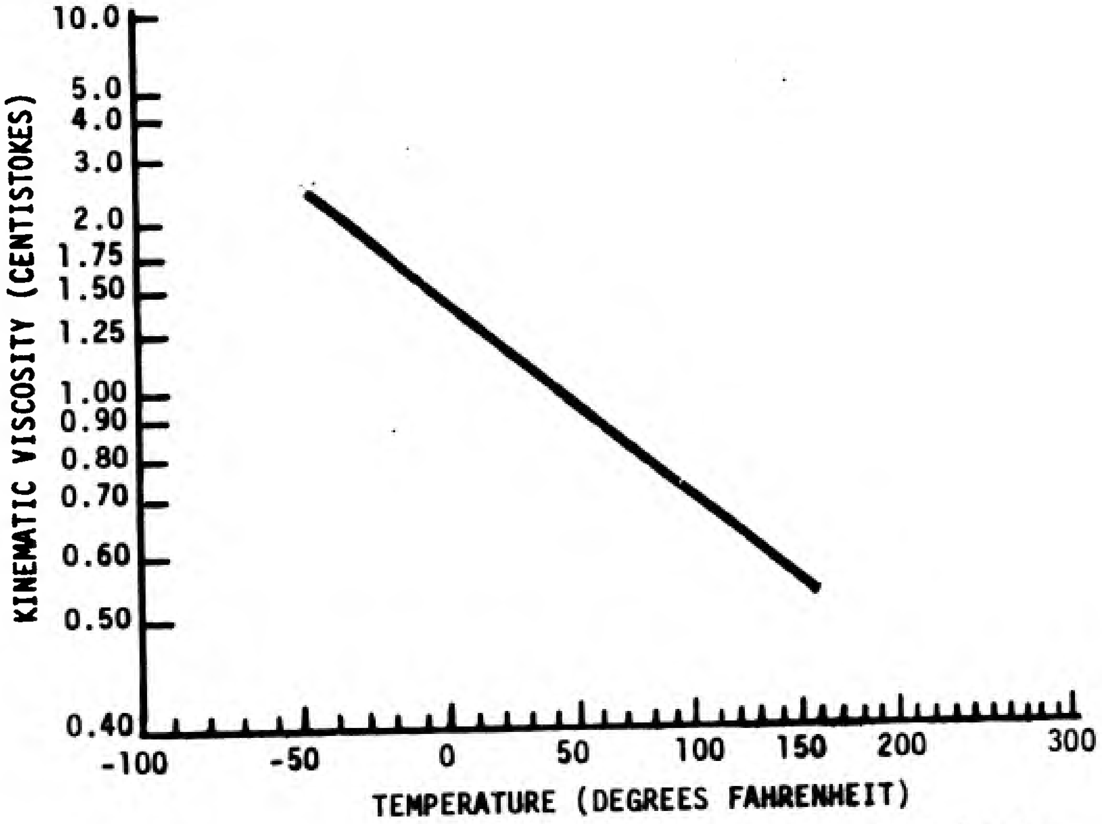

Figure B2. Temperature/Viscosity Plot for Luke Fuel Sample

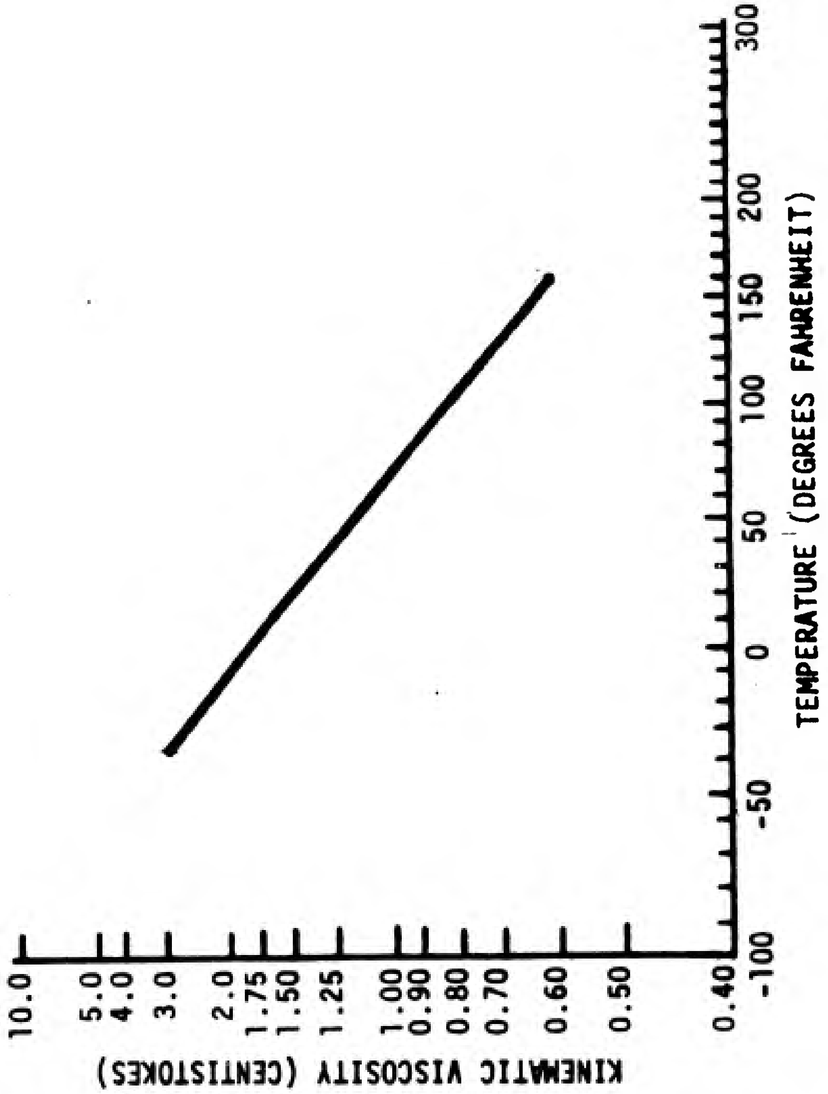

Figure B3. Temperature/Viscosity Plot for Holloman Fuel Sample

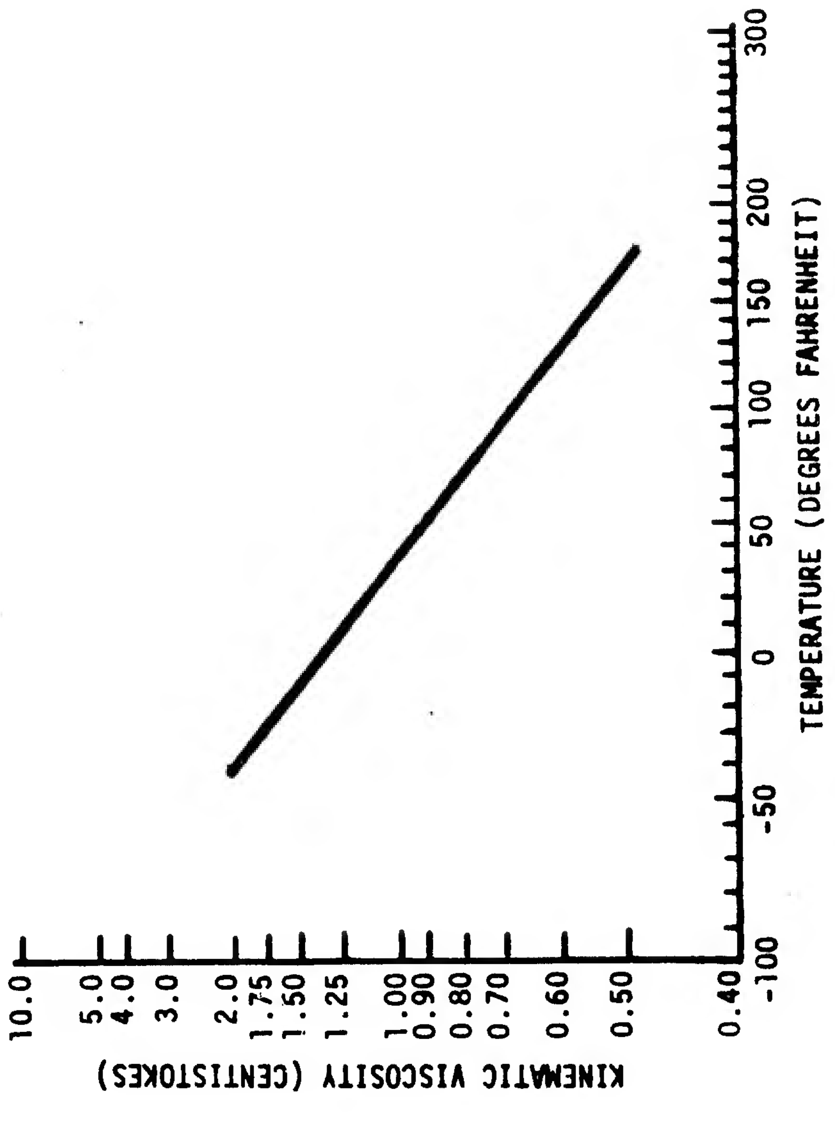

Figure B4. Temperature/Viscosity Plot for Elmendorf Fuel Sample

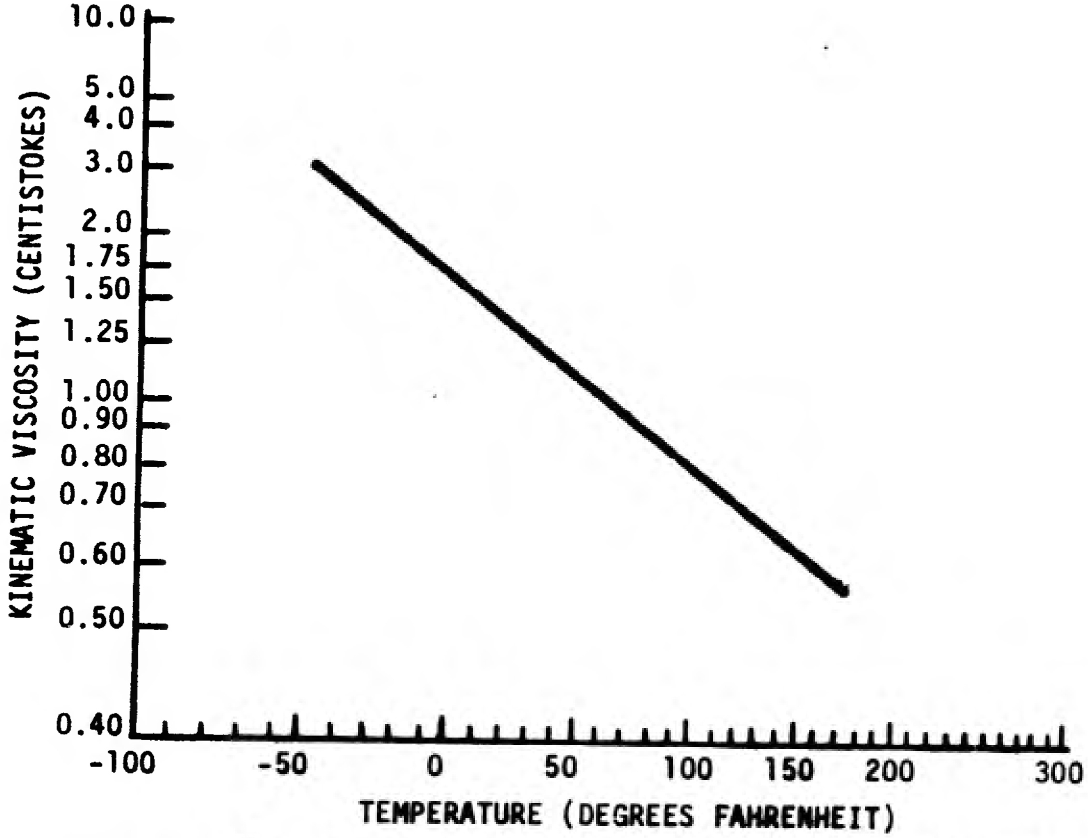

Figure B5. Temperature/Viscosity Plot for Edwards Fuel Sample

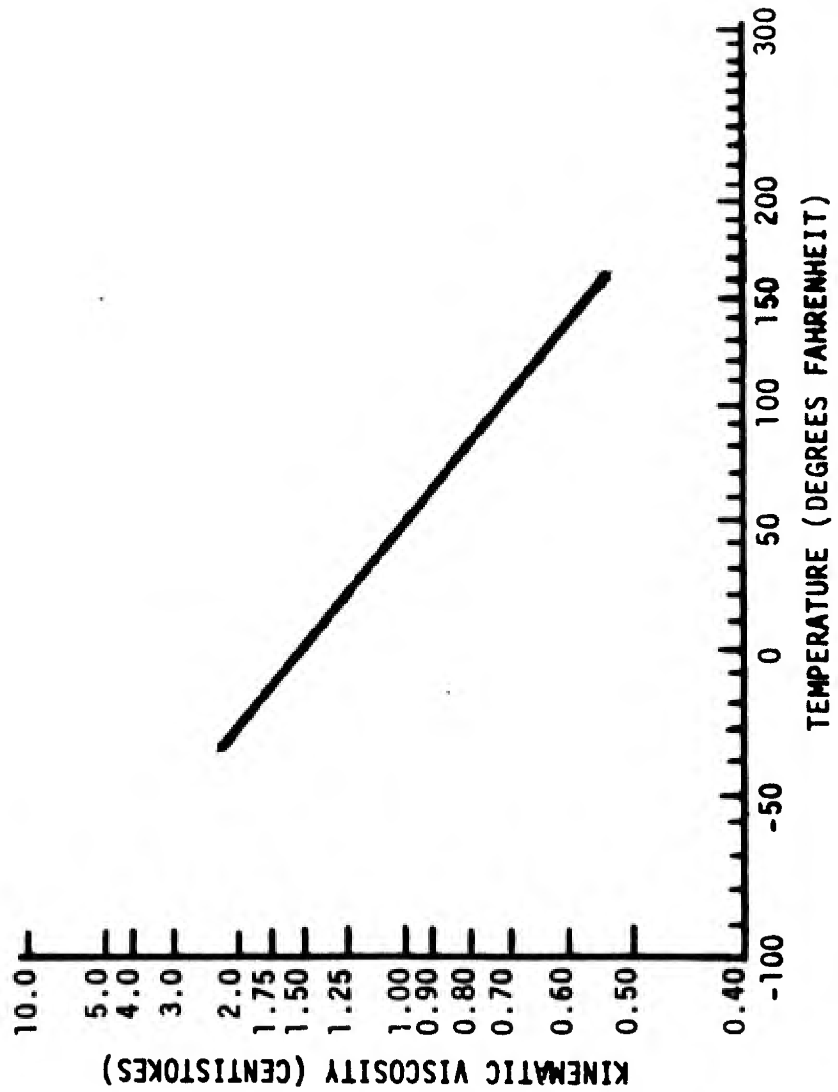

Figure B6. Temperature/Viscosity Plot for Langley Fuel Sample

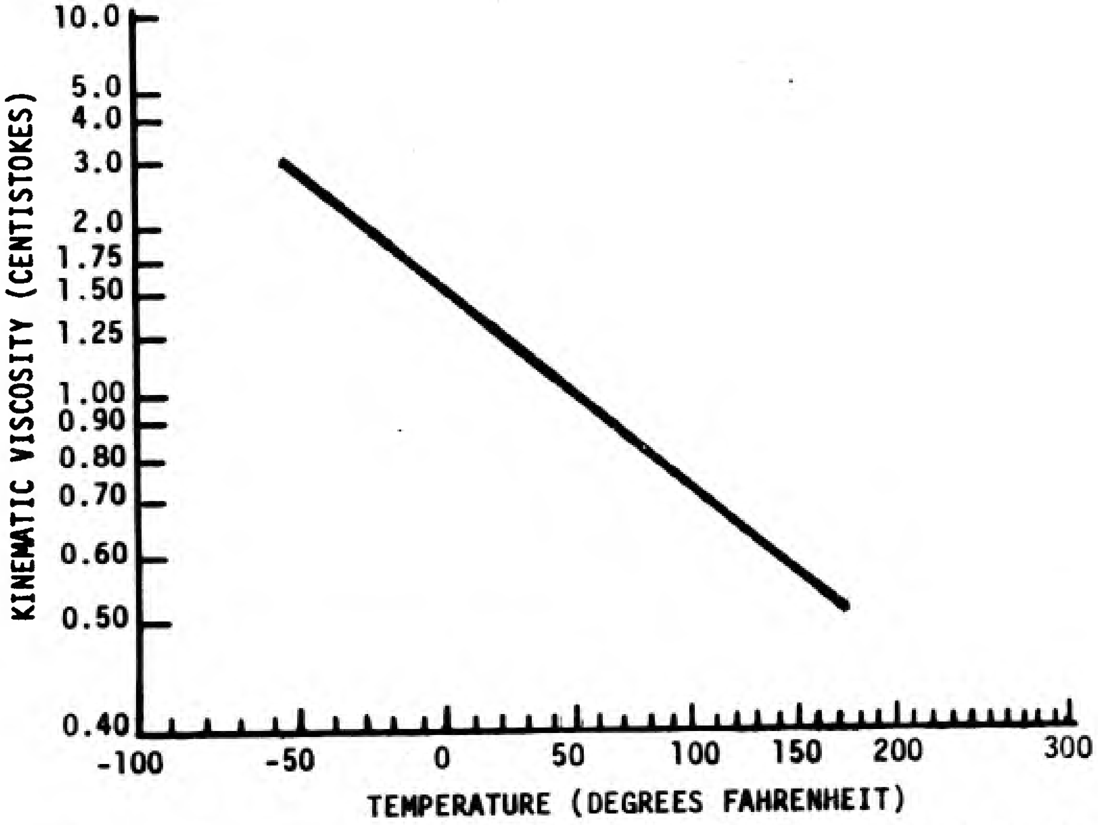

Figure B7. Temperature/Viscosity Plot for Tyndall Fuel Sample

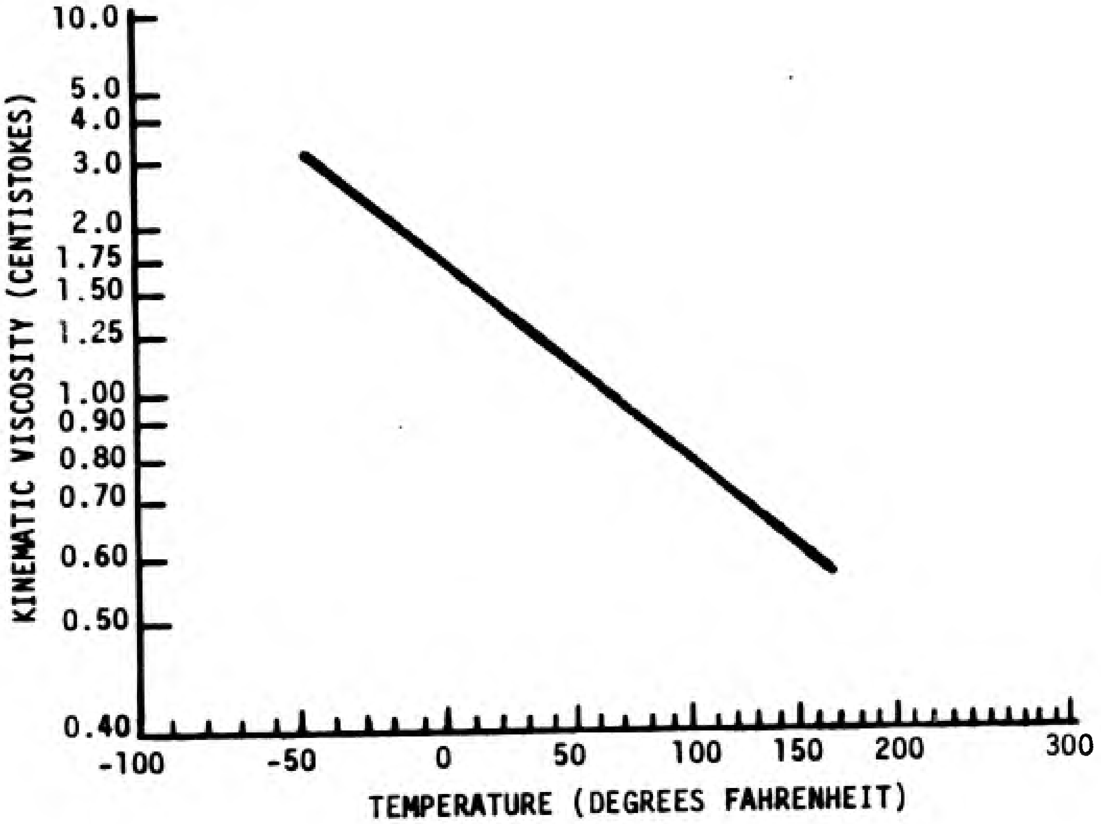

Figure B8. Temperature/Viscosity Plot for MacDill Fuel Sample

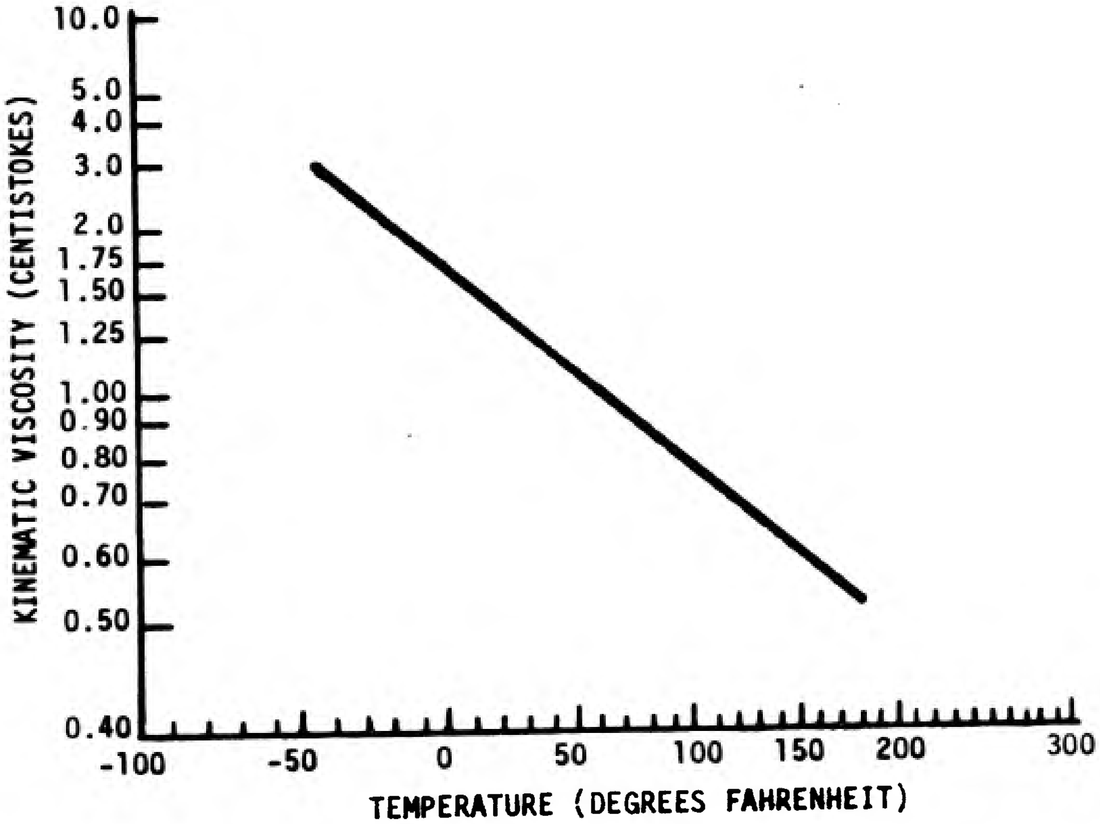

Figure B9. Temperature/Viscosity Plot for Shaw Fuel Sample

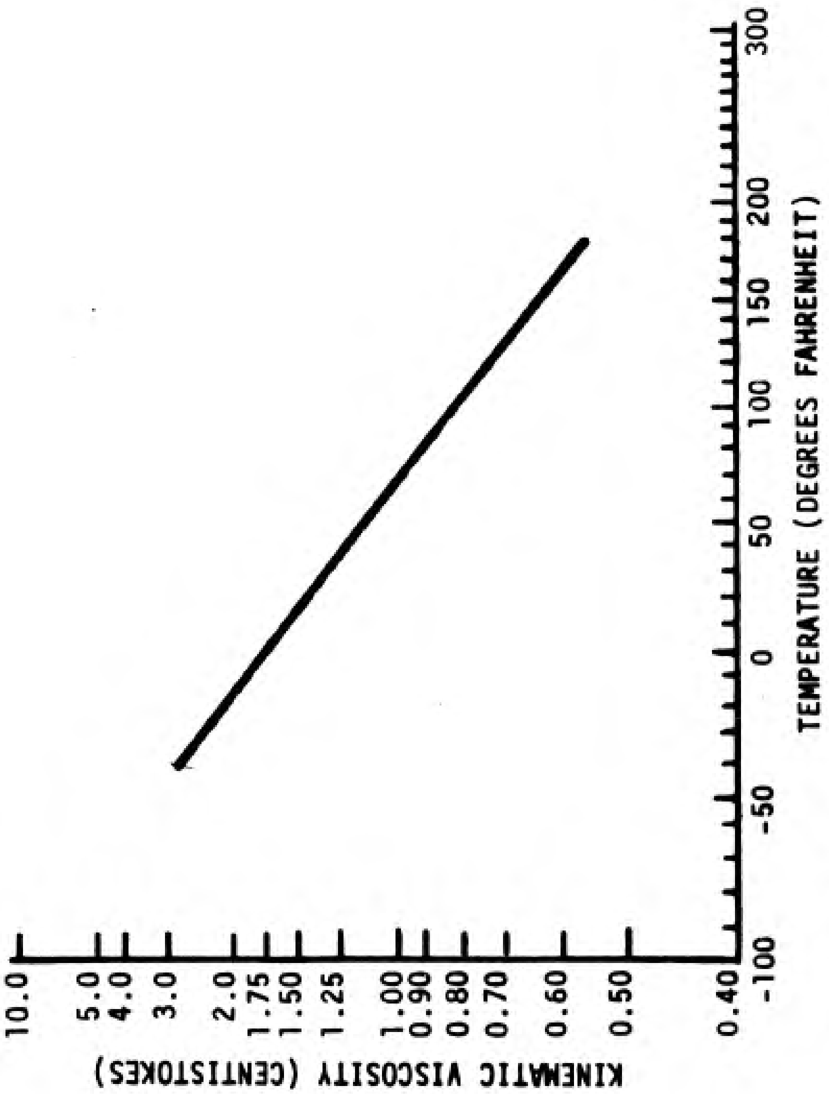

Figure B10. Temperature/Viscosity Plot for Eglin Fuel Sample

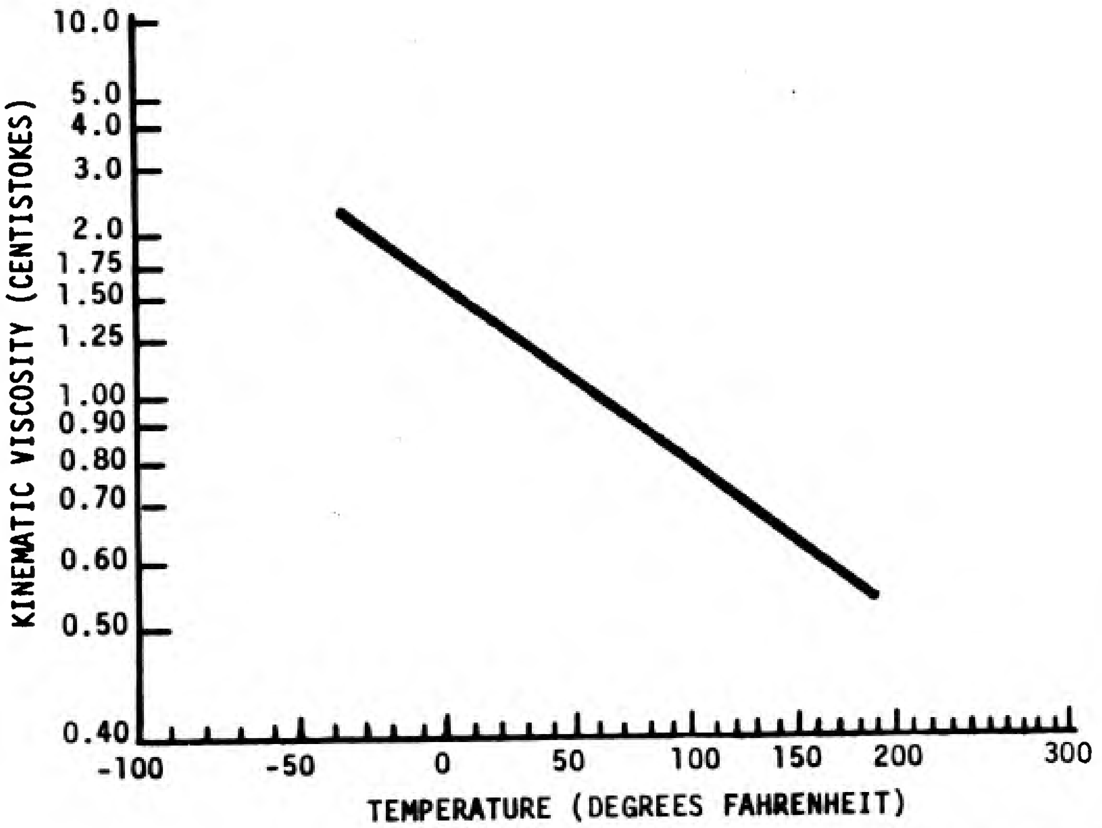

Figure B11. Temperature/Viscosity Plot for Aviano Fuel Sample

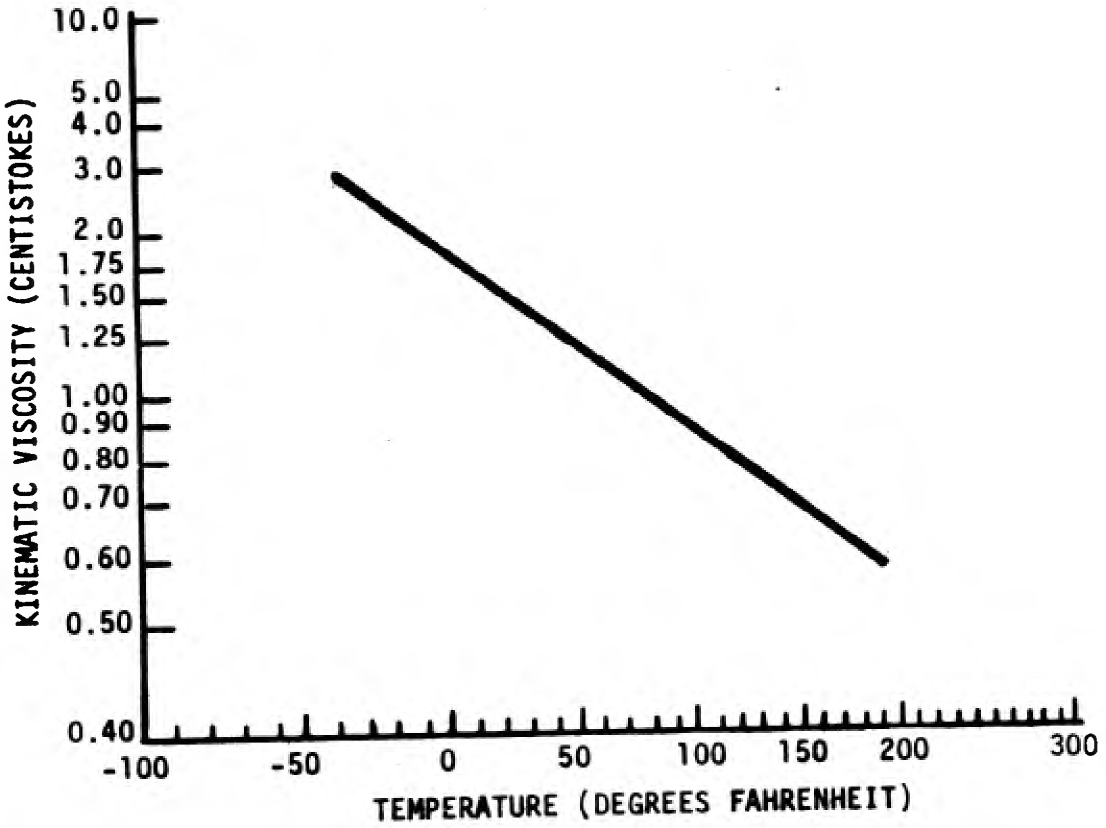

Figure B12. Temperature/Viscosity for Zaragoza Fuel Sample

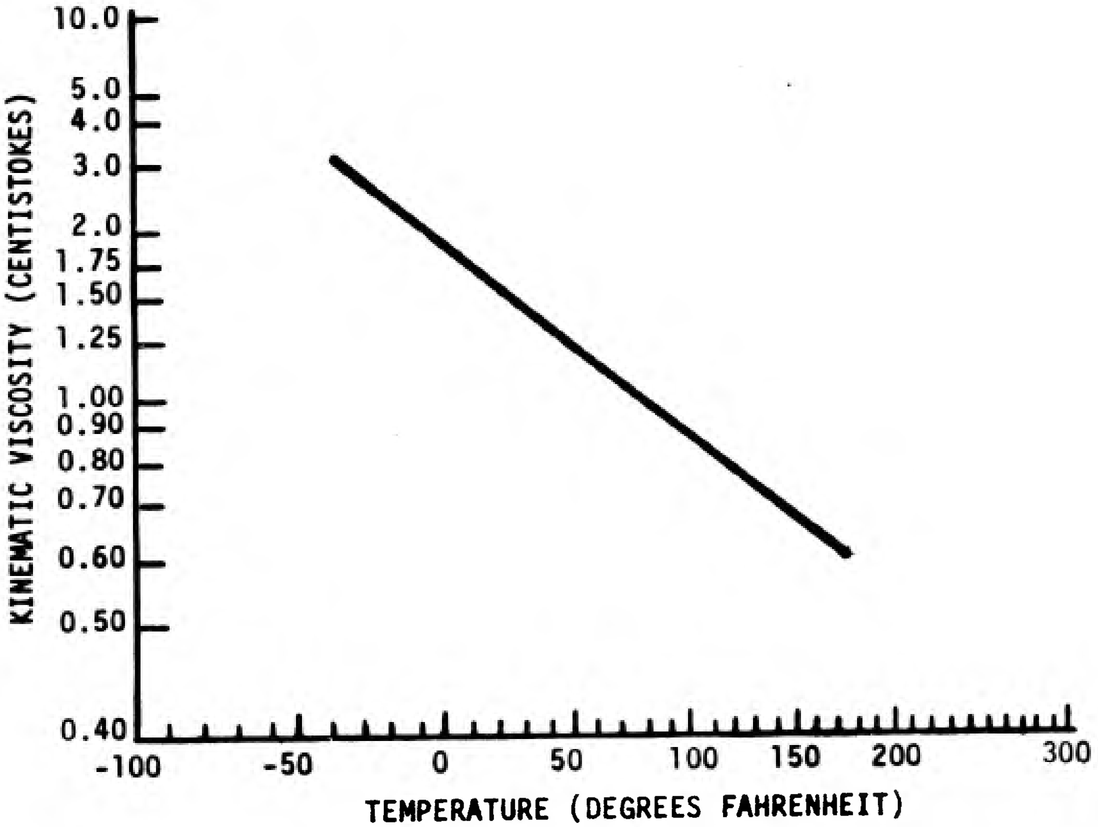

Figure B13. Temperature/Viscosity Plot for Camp New Amsterdam Fuel Sample

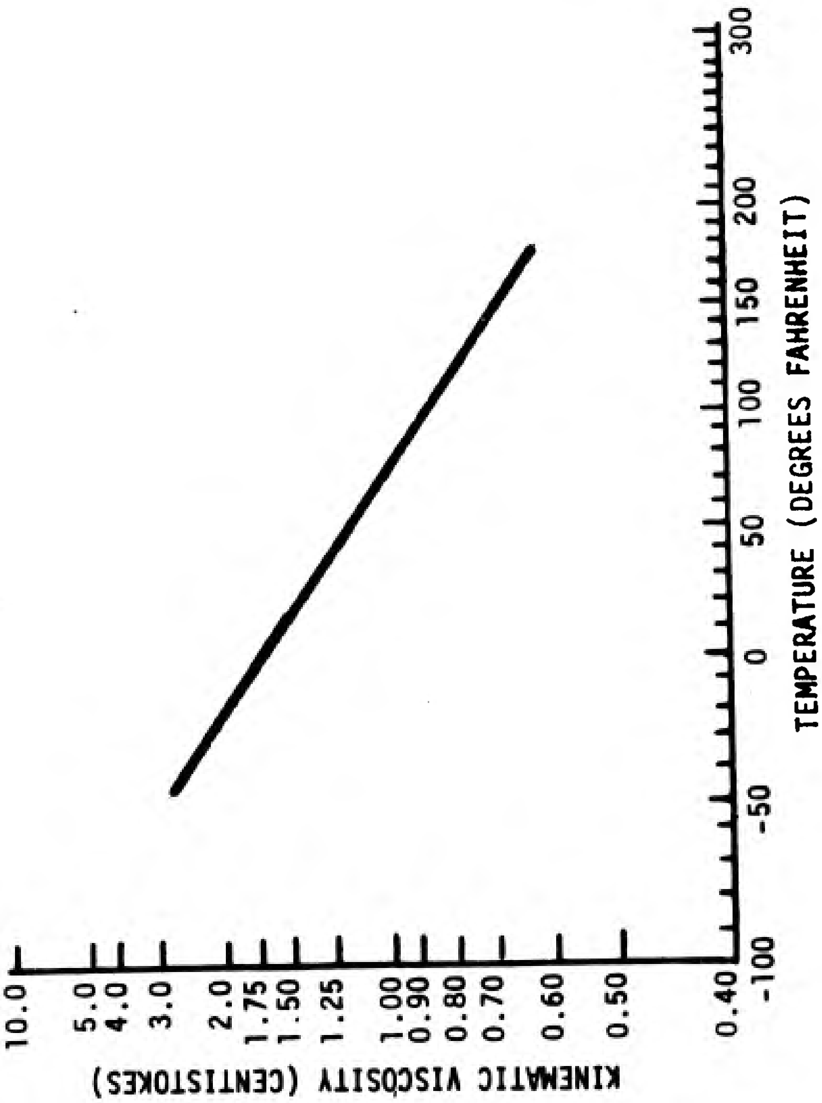

Figure B14. Temperature/Viscosity Plot for Torrejon Fuel Sample

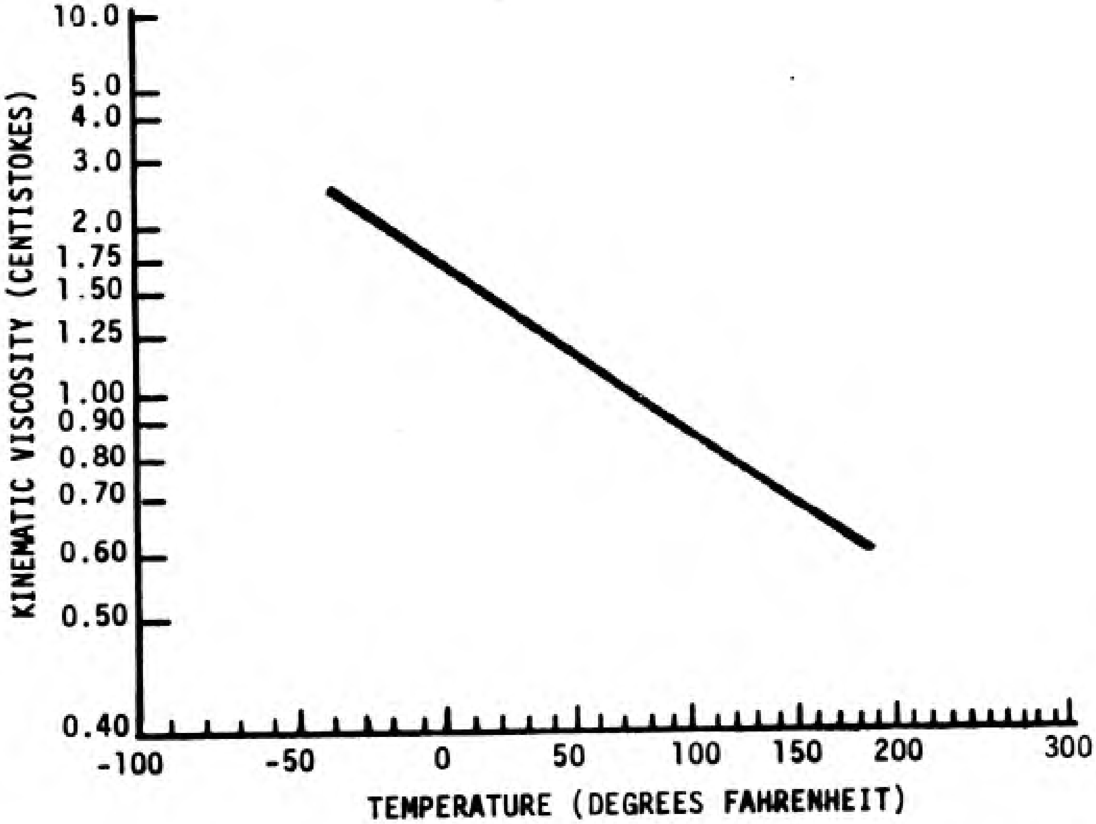

Figure B15. Temperature/Viscosity Plot for Osan Fuel Sample

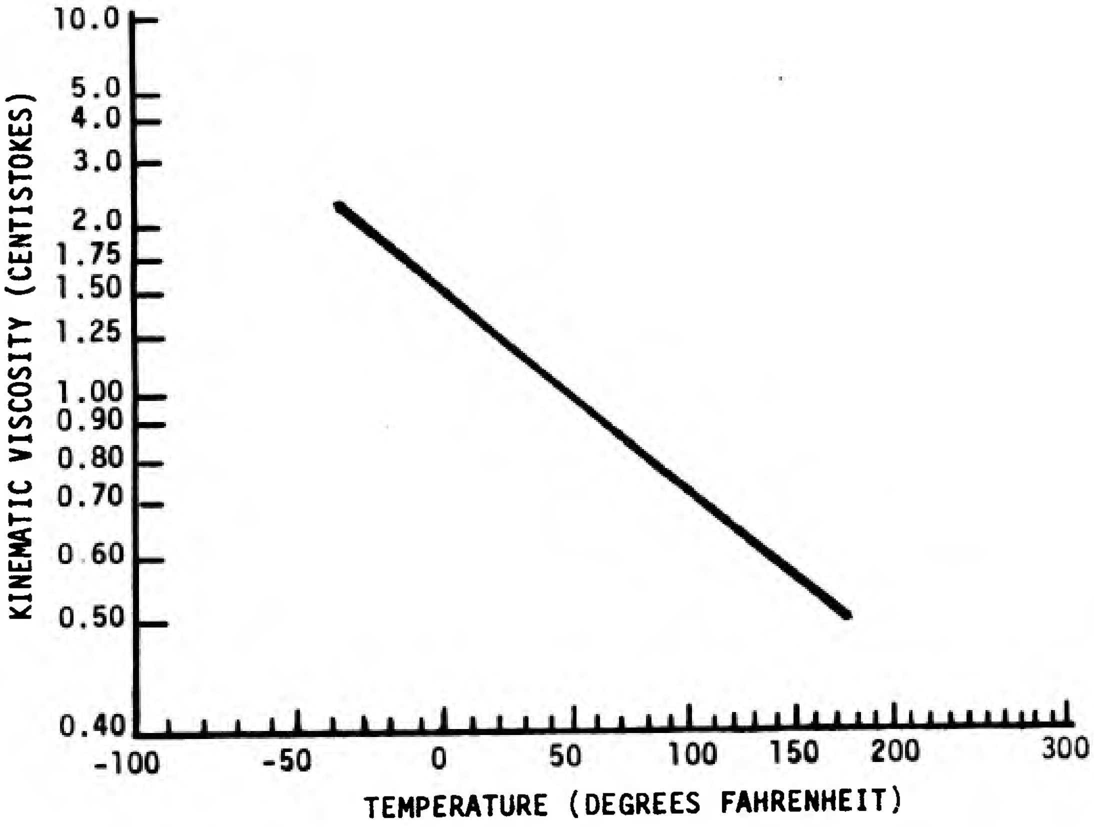

Figure B16. Temperature/Viscosity Plot for Clark Fuel Sample

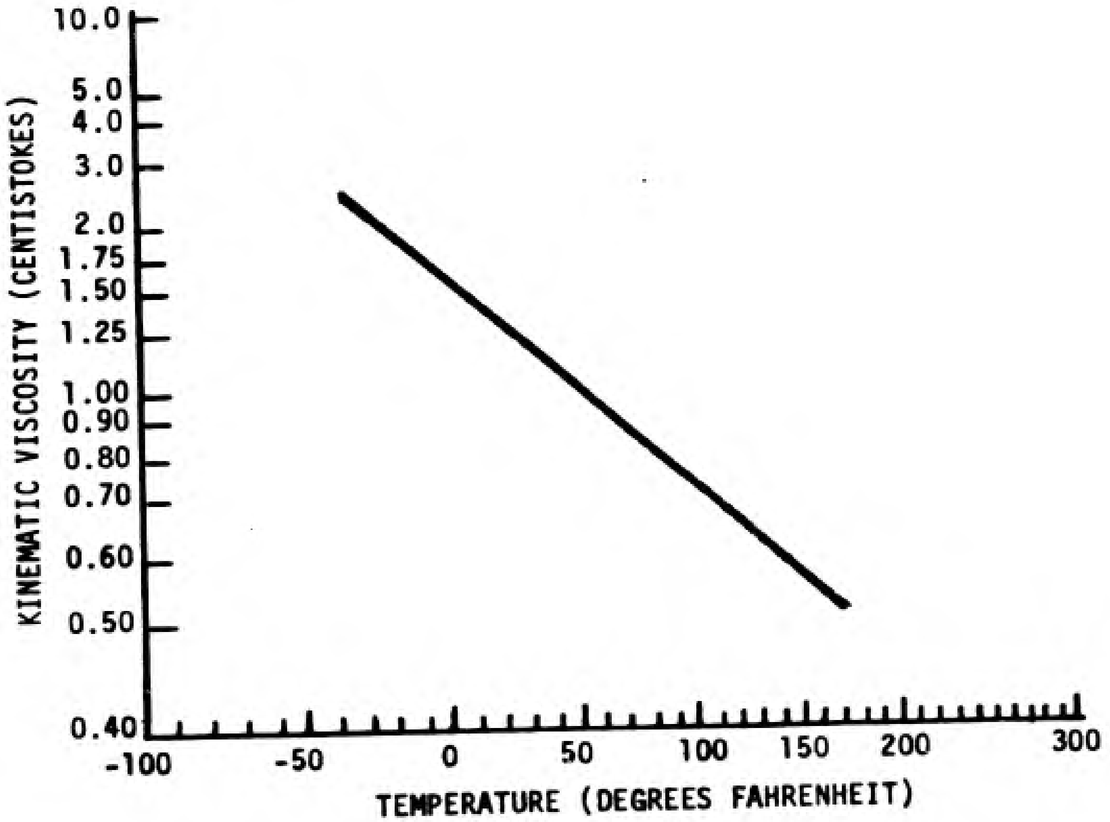

Figure B17. Temperature/Viscosity Plot for Anderson Fuel Sample

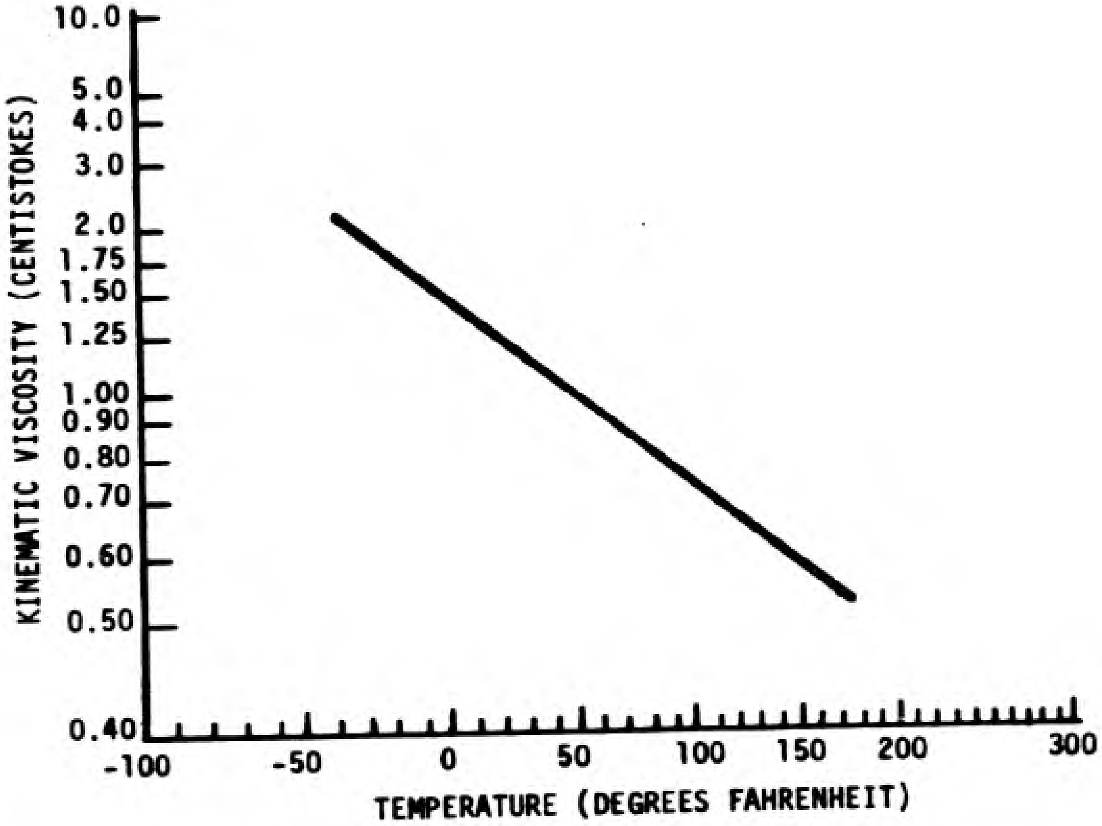

Figure B18. Temperature/Viscosity Plot for Kadena Fuel Sample

## TABLE B3

## COMPARISON OF TYPICAL JP-4 AND AVERAGED F100 SAMPLES KINEMATIC VISCOSITY AS A FUNCTION OF TEMPERATURE

| Temperature °F | (°C) | Kinematic Viscosity Cs<br>Typical JP-4 | F100 Samples |
|---|---|---|---|
| -30.1 | (-34.5) | 2.3 | 2.21 |
| -20 | (-28.8) | 2.1 | 1.96 |
| -4 | (-20) | 1.70 | 1.65 |
| 32 | (0) | 1.23 | 1.22 |
| 70 | (21.1) | .56 | .932 |
| 100 | (37.8) | .44 | .762 |
| 140 | (60) | .40 | .616 |

## TABLE B4

## COMPARISON OF TYPICAL JP-4 AND AVERAGED F100 SAMPLES DENSITY AS A FUNCTION OF TEMPERATURE

| Temperature °F | (°C) | Density (g/cm$^3$)<br>Typical JP-4 | F100 Samples |
|---|---|---|---|
| -20 | -28.8 | .797 | .796 |
| 32 | (0) | .775 | .774 |
| 59 | (15) | .764 | .763 |
| 70 | (21.1) | .758 | .759 |
| 100 | (37.8) | .698[a] | 0.745 |
| 140 | (60) | not avail. | .727 |

[a] Obtained by extrapolation

## TABLE B5

## COMPARISON OF TYPICAL JP-4 AND AVERAGED F100 SAMPLES SURFACE TENSION AS A FUNCTION OF TEMPERATURE

| Temperature °F (°C) | | Surface Tension (dyne/cm)<br>Typical JP-4 | F100 Samples |
|---|---|---|---|
| -20 | _28.8 | 25.9 | 28.3 |
| -4 | (-20) | 25.2 | 25.6 |
| 70 | (21.1) | 21.7 | 23.6 |
| 100 | (37.8) | 20.3 | 22.0 |
| 140 | (60) | 18.4 | 20.0 |

## TABLE B6

## THERMAL CONDUCTIVITY ANALYSES

| Sample | Thermal Conductivity (Watt/meter° Kelvin)<br>0°C | 20°C | 40°C |
|---|---|---|---|
| Hill | 0.123 ± 2.12% | 0.117 ± 2.69% | 0.110 ± 2.92% |
| Luke | 0.123 ± 4.05% | 0.116 ± 2.40% | 0.113 ± 2.49% |
| Langley | 0.123 ± 1.26% | 0.116 ± 1.34% | 0.114 ± 2.55% |
| Tyndall | 0.123 ± 1.50% | 0.118 ± 1.88% | 0.114 ± 1.71% |
| MacDill | 0.122 ± 3.11% | 0.119 ± 3.65% | 0.111 ± 3.05% |
| Shaw | 0.122 ± 1.62% | 0.117 ± 1.62% | 0.113 ± 1.80% |
| Holloman | 0.123 ± 1.75% | 0.119 ± 5.44% | 0.113 ± 1.50% |
| Elmendorf | 0.121 ± 1.89% | 0.115 ± 1.39% | 0.111 ± 1.27% |
| Edwards | 0.120 ± 1.34% | 0.115 ± 1.23% | 0.110 ± 1.06% |
| Toluene (standard) | 0.140 ± 3.71% | 0.1317 ± 2.12% | 0.1253 ± 3.05% |
| Toluene (literature value[a]) | 0.1366 | 0.1308 | 0.1250 |

[a] Literature values from Venart & Mani, Can. J. Chem. 49, 2468 (1971).

[b] Standard deviation of 6-8 measurements made at each temperature.

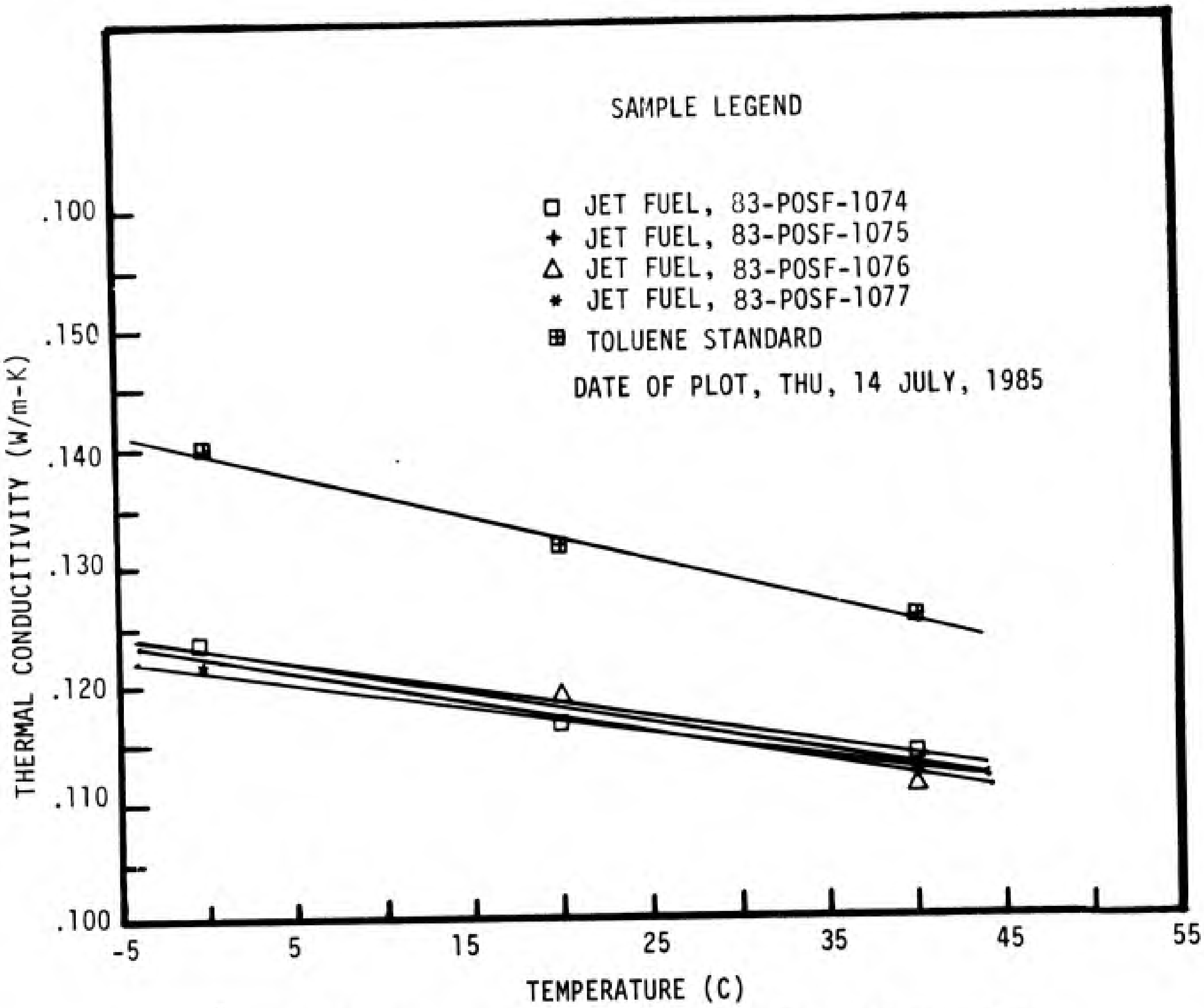

Figure B19. Thermal Conductivity Versus Temperature

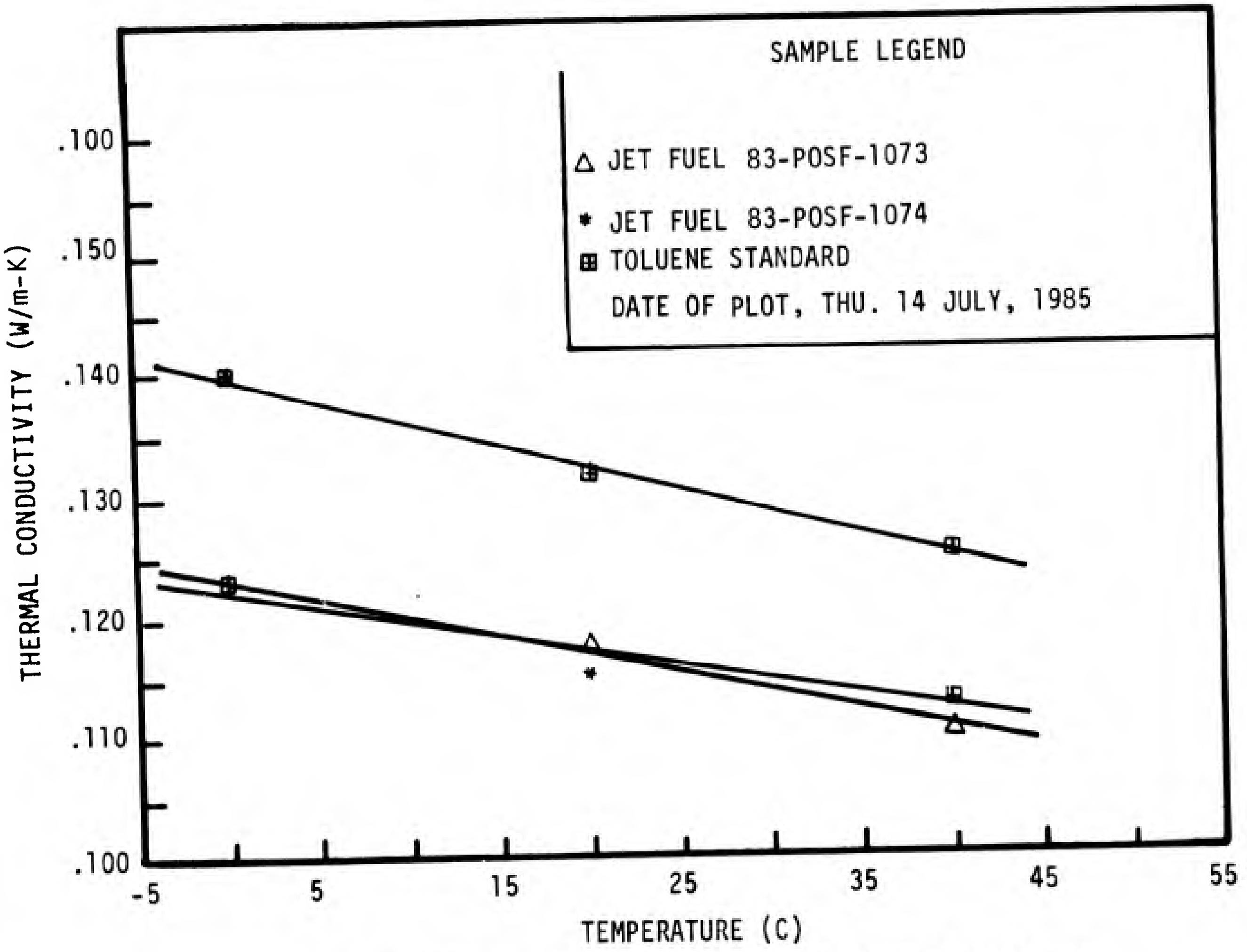

Figure B20. Thermal Conductivity Versus Temperature

### TABLE B7
### COMPARISON OF TYPICAL JP-4 AND AVERAGED F100 SAMPLES
### THERMAL CONDUCTIVITY

| | Thermal Conductivity (watt/meter °K) | |
|---|---|---|
| Temperature (°C) | Typical JP-4 | F100 Samples |
| 0 | .1188 | .122 |
| 20 | .1155 | .117 |
| 40 | .1118 | .112 |

## TABLE B8
## SPECIFIC HEAT ANALYSES

| | Specific Heat (cal/g/°C) | | | | | |
|---|---|---|---|---|---|---|
| Sample | 35°C | 45°C | 55°C | 65°C | 75°C | 85°C |
| Hill | 0.489 ± .002 | 0.500 ± .002 | 0.511 ± .003 | 0.520 ± .003 | 0.529 ± .003 | 0.538 ± .002 |
| Luke | 0.499 ± .005 | 0.512 ± .002 | 0.522 ± .003 | 0.534 ± .007 | 0.542 ± .006 | 0.551 ± .003 |
| Langley | 0.504 ± .002 | 0.512 ± .003 | 0.523 ± .005 | 0.534 ± .003 | 0.543 ± .002 | 0.554 ± .001 |
| Tyndall | 0.516 ± .007 | 0.526 ± .006 | 0.537 ± .006 | 0.549 ± .009 | 0.558 ± .009 | 0.566 ± .007 |
| MacDill | 0.499 ± .007 | 0.509 ± .006 | 0.520 ± .005 | 0.533 ± .009 | 0.540 ± .009 | 0.549 ± .007 |
| Shaw | 0.505 ± .013 | 0.517 ± .008 | 0.526 ± .009 | 0.536 ± .013 | 0.546 ± .013 | 0.555 ± .013 |
| Holloman | 0.501 ± .011 | 0.511 ± .009 | 0.521 ± .011 | 0.533 ± .013 | 0.542 ± .012 | 0.550 ± .014 |
| Elmendorf | 0.487 ± .009 | 0.497 ± .008 | 0.510 ± .007 | 0.522 ± .010 | 0.531 ± .010 | 0.543 ± .009 |
| Edwards | 0.493 ± .006 | 0.503 ± .005 | 0.516 ± .004 | 0.527 ± .007 | 0.536 ± .007 | 0.546 ± .006 |
| Diphenylether (Standard) | 0.382 | 0.388 | 0.395 | 0.398 | 0.405 | 0.412 |
| Diphenylether[a] (Literature Value) | 0.382 | 0.388 | 0.394 | 0.401 | 0.407 | 0.414 |

[a] Diphenylether literature values interpolated from D.C. Ginnings and G.T. Furukawa, J. Amer. Chem. Soc. 75, 522 (1953).

### TABLE B9

### COMPARISON OF TYPICAL JP-4 AND AVERAGED F100 SAMPLES SPECIFIC HEAT AS A FUNCTION OF TEMPERATURE

| | Specific Heat (cal/g °C) | |
|---|---|---|
| Temperature (°C) | Typical JP-4 | F100 Samples |
| 35 | .507 | .499 |
| 45 | .517 | .510 |
| 55 | .528 | .521 |
| 65 | .538 | .532 |
| 75 | .547 | .541 |
| 85 | .559 | .550 |

## TABLE B10
## SIMULATED DISTILLATION DATA FOR HILL SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 29 | 84 |
| 1.0 | 31 | 87 |
| 5.0 | 58 | 137 |
| 10 | 78 | 172 |
| 20 | 99 | 209 |
| 30 | 112 | 233 |
| 40 | 127 | 261 |
| 50 | 141 | 286 |
| 60 | 152 | 305 |
| 70 | 164 | 327 |
| 80 | 175 | 347 |
| 90 | 195 | 383 |
| 95 | 213 | 416 |
| 99 | 251 | 483 |
| 99.5 | 262 | 503 |

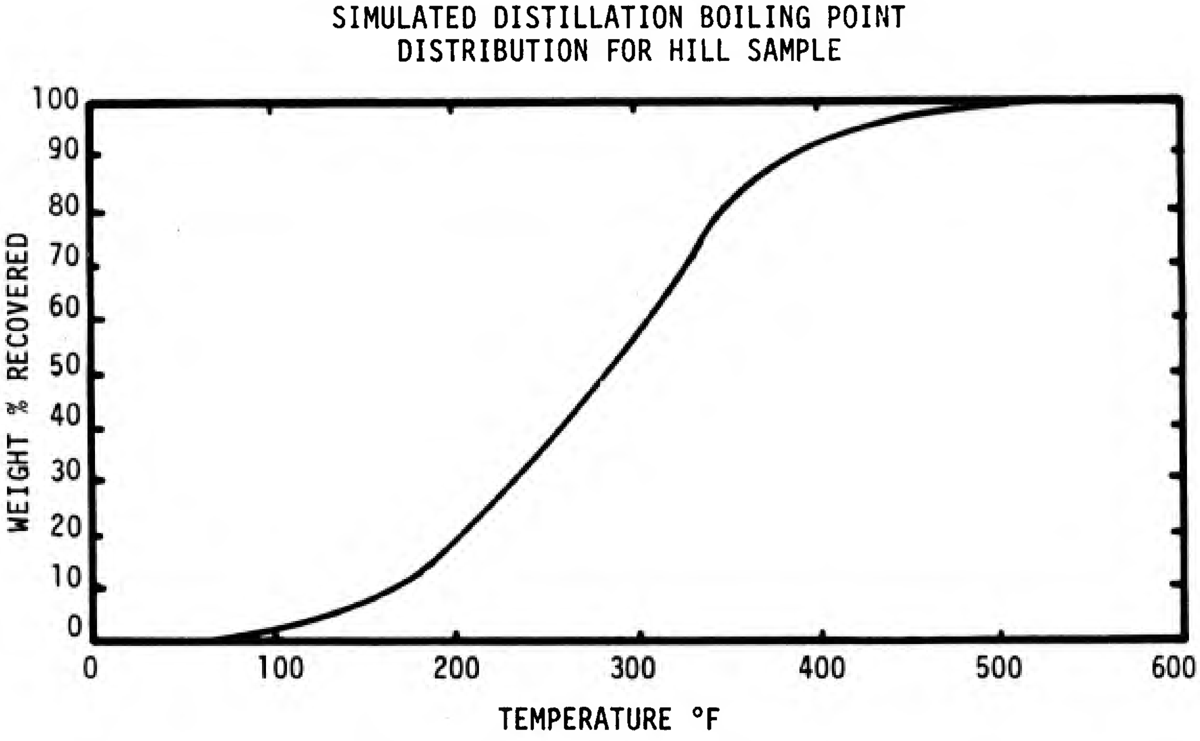

Figure B21. Distillation Curves

## TABLE B11
## SIMULATED DISTILLATION DATA FOR LUKE SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 30 | 86 |
| 1.0 | 32 | 90 |
| 5.0 | 59 | 139 |
| 10 | 73 | 163 |
| 20 | 91 | 196 |
| 30 | 102 | 216 |
| 40 | 118 | 244 |
| 50 | 135 | 275 |
| 60 | 150 | 303 |
| 70 | 168 | 335 |
| 80 | 191 | 376 |
| 90 | 221 | 430 |
| 95 | 239 | 463 |
| 99 | 270 | 518 |
| 99.5 | 281 | 537 |

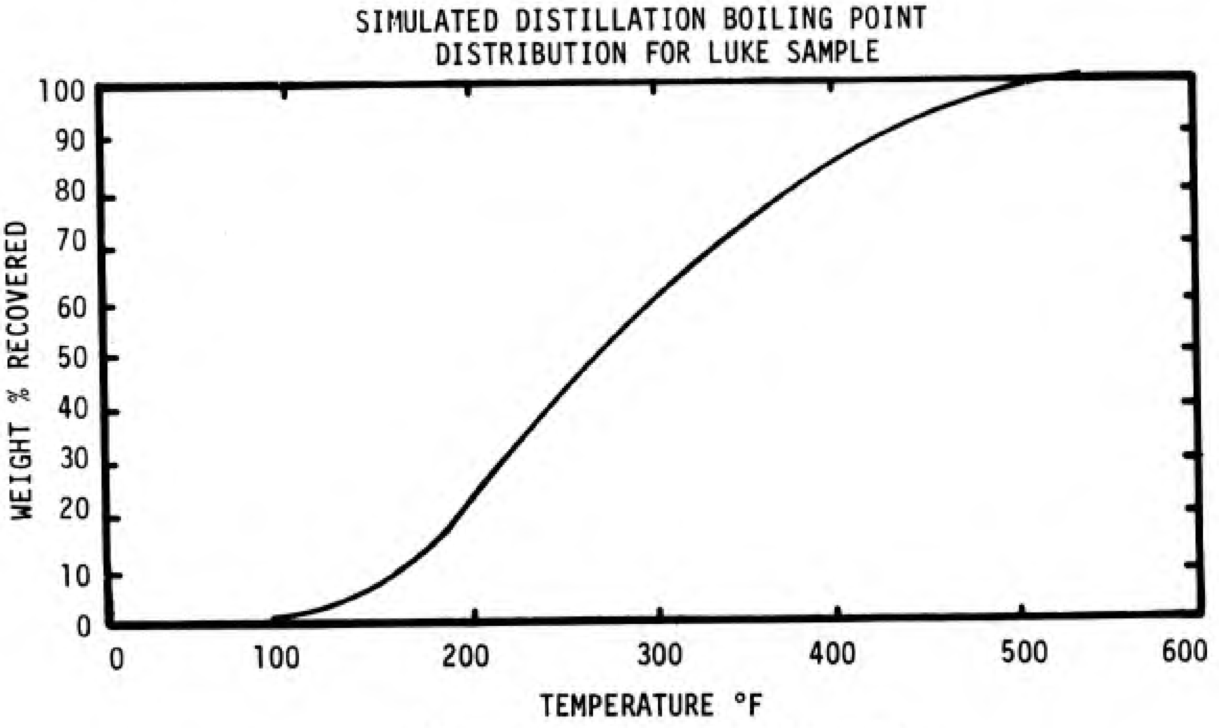

Figure B22. Distillation Curves

## TABLE B12
## SIMULATED DISTILLATION DATA FOR HOLLOMAN SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 27 | 80 |
| 1.0 | 28 | 82 |
| 5.0 | 58 | 137 |
| 10 | 77 | 170 |
| 20 | 98 | 209 |
| 30 | 116 | 241 |
| 40 | 136 | 277 |
| 50 | 159 | 317 |
| 60 | 180 | 356 |
| 70 | 202 | 396 |
| 80 | 222 | 432 |
| 90 | 245 | 472 |
| 95 | 260 | 501 |
| 99 | 305 | 581 |
| 99.5 | 318 | 604 |

SIMULATED DISTILLATION BOILING POINT
DISTRIBUTION FOR HOLLOMAN SAMPLE

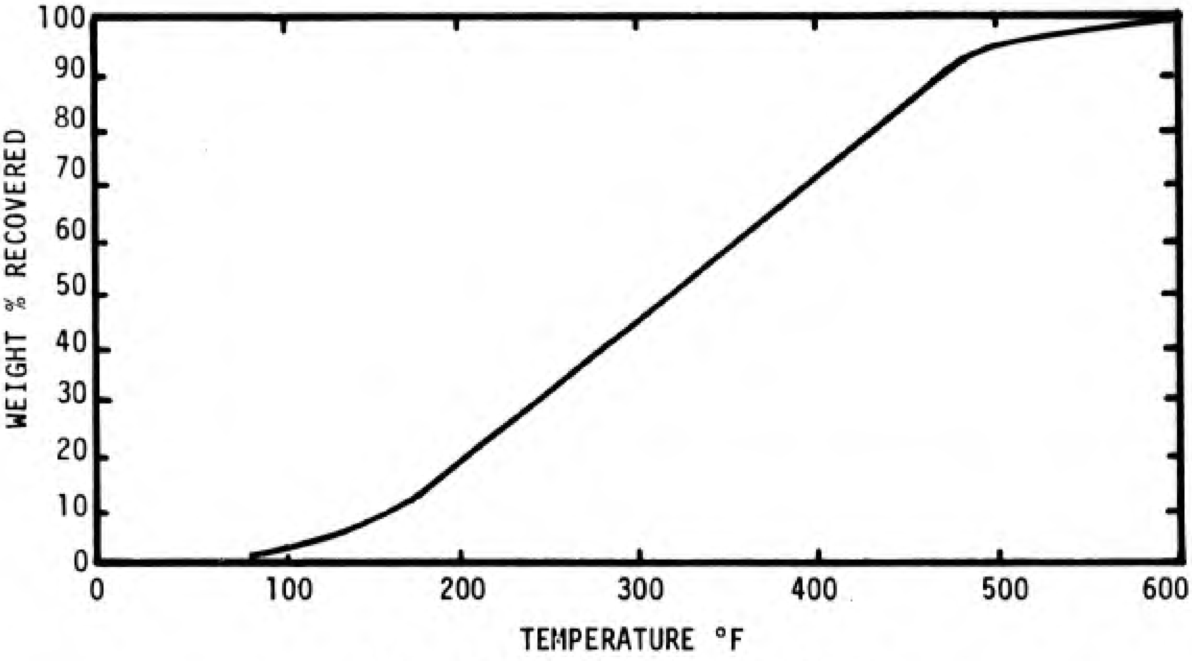

Figure B23. Distillation Curves

## TABLE B-13

## SIMULATED DISTILLATION DATA FOR ELMENDORF SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 34 | 93 |
| 1.0 | 37 | 98 |
| 5.0 | 66 | 150 |
| 10 | 79 | 175 |
| 20 | 91 | 196 |
| 30 | 100 | 212 |
| 40 | 109 | 228 |
| 50 | 116 | 241 |
| 60 | 124 | 255 |
| 70 | 135 | 274 |
| 80 | 152 | 306 |
| 90 | 225 | 419 |
| 95 | 249 | 479 |
| 99 | 289 | 552 |
| 99.5 | 303 | 577 |

SIMULATED DISTILLATION BOILING POINT
DISTRIBUTION FOR ELMENDORF SAMPLE

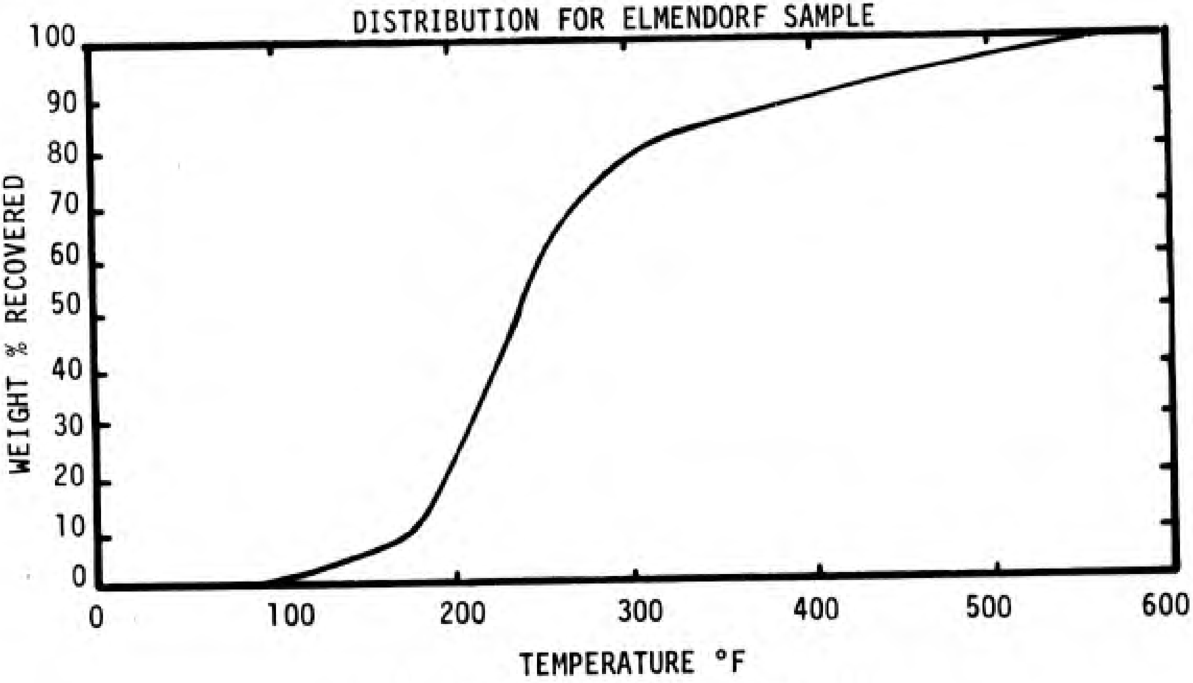

Figure B24. Distillation Curves

## TABLE B14
## SIMULATED DISTILLATION DATA FOR EDWARDS SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 27 | 80 |
| 1.0 | 28 | 82 |
| 5.0 | 59 | 138 |
| 10 | 74 | 166 |
| 20 | 97 | 207 |
| 30 | 114 | 238 |
| 40 | 127 | 261 |
| 50 | 142 | 287 |
| 60 | 160 | 319 |
| 70 | 181 | 358 |
| 80 | 209 | 409 |
| 90 | 238 | 460 |
| 95 | 258 | 496 |
| 99 | 293 | 559 |
| 99.5 | 305 | 580 |

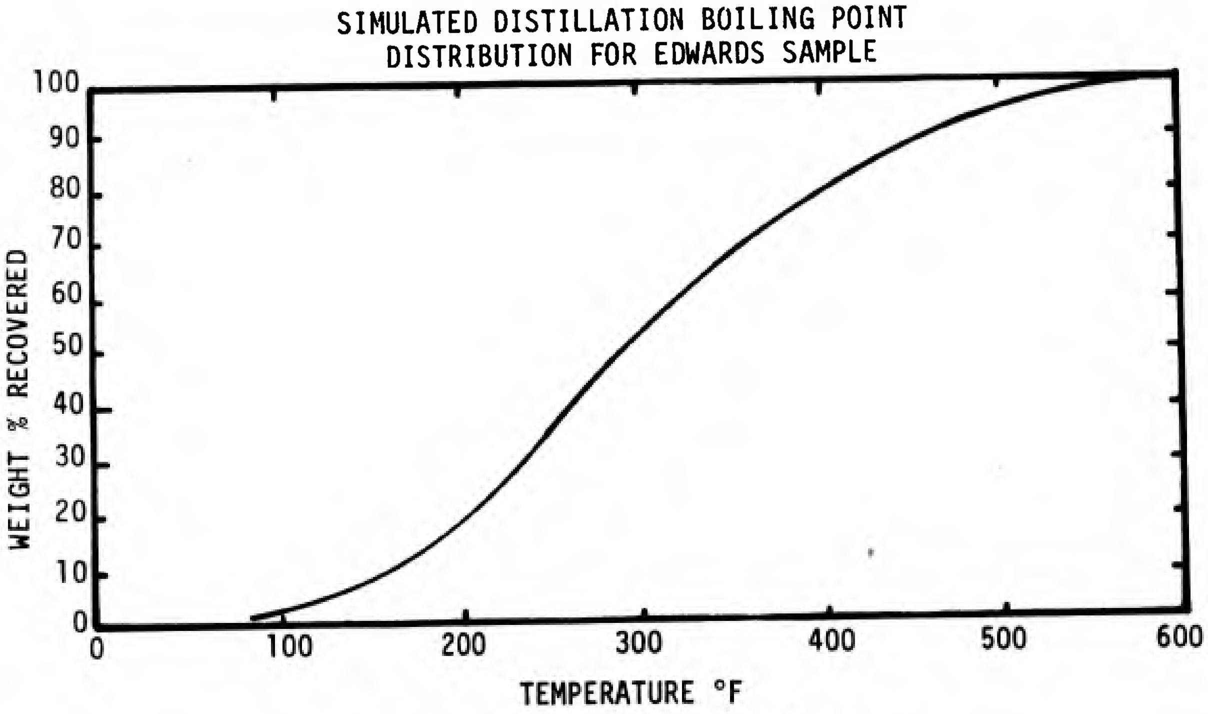

Figure B25. Distillation Curves

## TABLE B-15
## SIMULATED DISTILLATION DATA FOR NELLIS SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 27 | 80 |
| 1.0 | 28 | 83 |
| 5.0 | 65 | 149 |
| 10 | 83 | 181 |
| 20 | 101 | 213 |
| 30 | 121 | 250 |
| 40 | 139 | 282 |
| 50 | 159 | 317 |
| 60 | 177 | 350 |
| 70 | 198 | 388 |
| 80 | 220 | 428 |
| 90 | 244 | 471 |
| 95 | 260 | 500 |
| 99 | 288 | 550 |
| 99.5 | 296 | 565 |

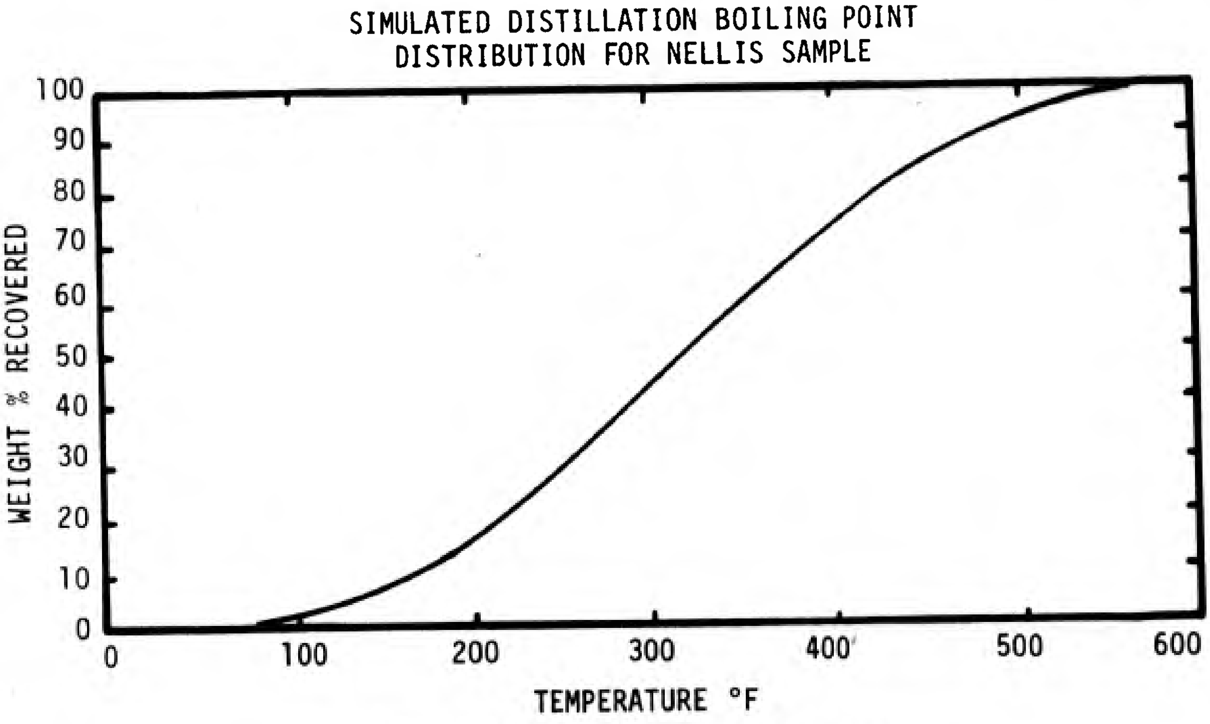

Figure B26. Distillation Curves

## TABLE B16

## SIMULATED DISTILLATION DATA FOR LANGLEY SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 29 | 83 |
| 1.0 | 35 | 95 |
| 5.0 | 56 | 134 |
| 10 | 66 | 150 |
| 20 | 89 | 193 |
| 30 | 112 | 233 |
| 40 | 124 | 256 |
| 50 | 142 | 288 |
| 60 | 163 | 326 |
| 70 | 186 | 367 |
| 80 | 209 | 408 |
| 90 | 233 | 451 |
| 95 | 247 | 477 |
| 99 | 269 | 516 |
| 99.5 | 275 | 527 |

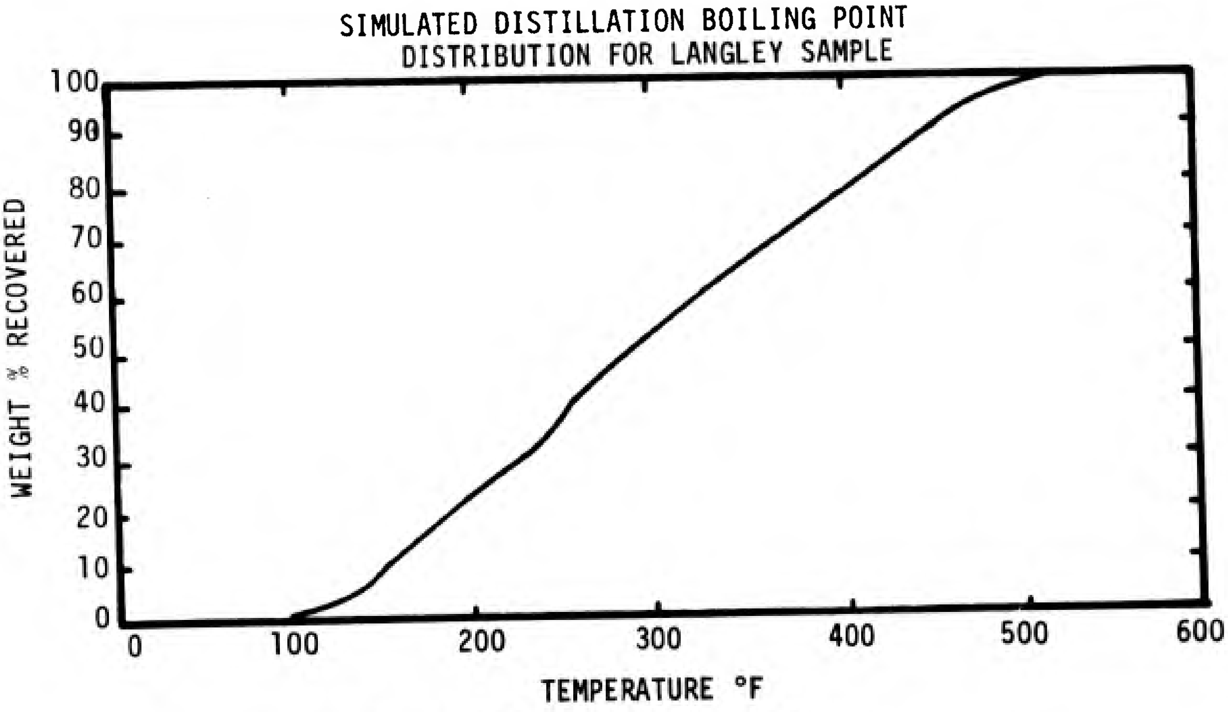

Figure B27. Distillation Curves

## TABLE B17
## SIMULATED DISTILLATION DATA FOR TYNDALL SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 27 | 81 |
| 1.0 | 28 | 83 |
| 5.0 | 59 | 138 |
| 10 | 87 | 189 |
| 20 | 117 | 243 |
| 30 | 126 | 259 |
| 40 | 136 | 277 |
| 50 | 141 | 286 |
| 60 | 145 | 293 |
| 70 | 164 | 328 |
| 80 | 196 | 385 |
| 90 | 229 | 444 |
| 95 | 249 | 479 |
| 99 | 273 | 524 |
| 99.5 | 283 | 542 |

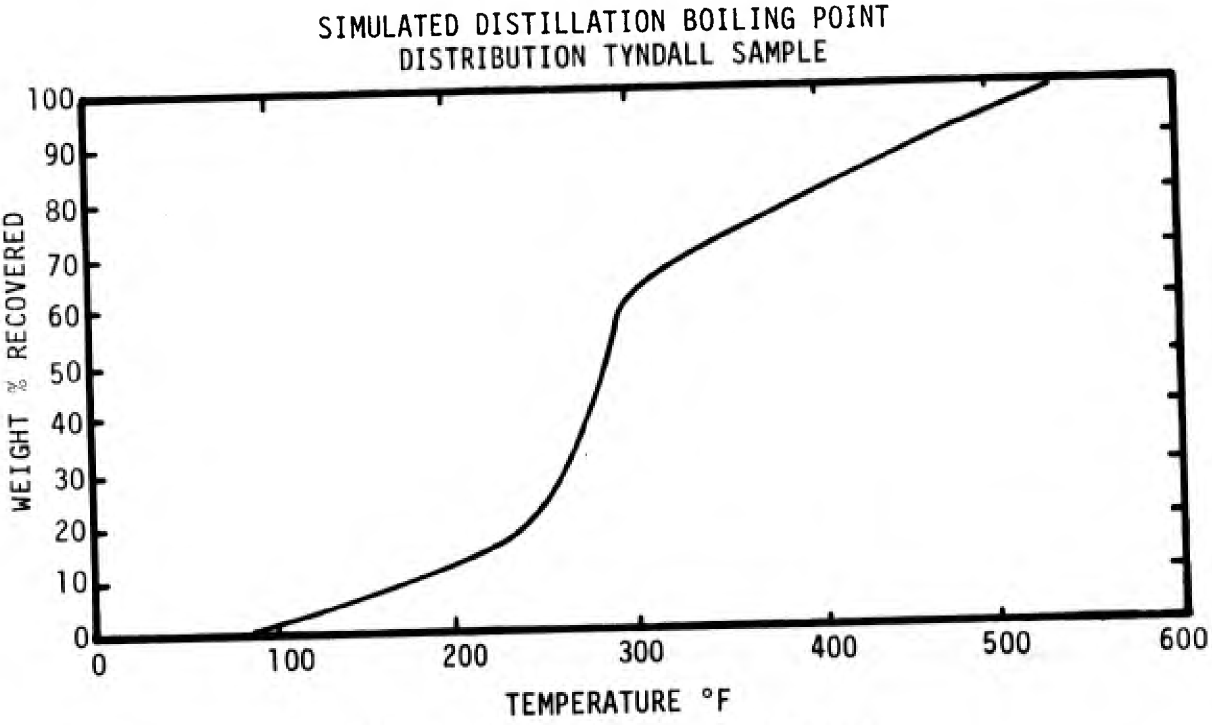

Figure B28. Distillation Curves

## TABLE B18

## SIMULATED DISTILLATION DATA FOR MACDILL SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 29 | 84 |
| 1.0 | 35 | 95 |
| 5.0 | 57 | 135 |
| 10 | 67 | 152 |
| 20 | 95 | 203 |
| 30 | 117 | 243 |
| 40 | 139 | 282 |
| 50 | 163 | 326 |
| 60 | 187 | 369 |
| 70 | 206 | 402 |
| 80 | 224 | 435 |
| 90 | 244 | 470 |
| 95 | 255 | 491 |
| 99 | 279 | 534 |
| 99.5 | 288 | 550 |

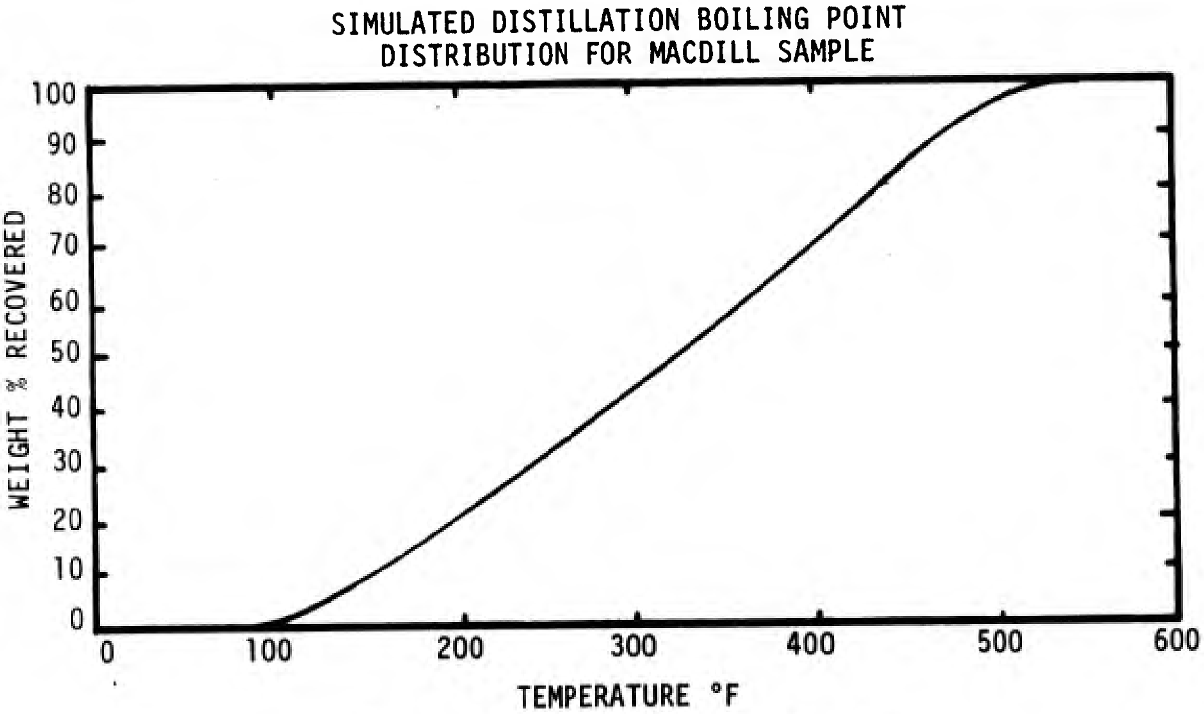

Figure B29. Distillation Curves

## TABLE B19

## SIMULATED DISTILLATION DATA FOR SHAW SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 29 | 84 |
| 1.0 | 34 | 94 |
| 5.0 | 56 | 133 |
| 10 | 62 | 144 |
| 20 | 87 | 189 |
| 30 | 111 | 232 |
| 40 | 142 | 288 |
| 50 | 172 | 341 |
| 60 | 189 | 373 |
| 70 | 206 | 402 |
| 80 | 223 | 433 |
| 90 | 244 | 470 |
| 95 | 257 | 495 |
| 99 | 291 | 556 |
| 99.5 | 304 | 579 |

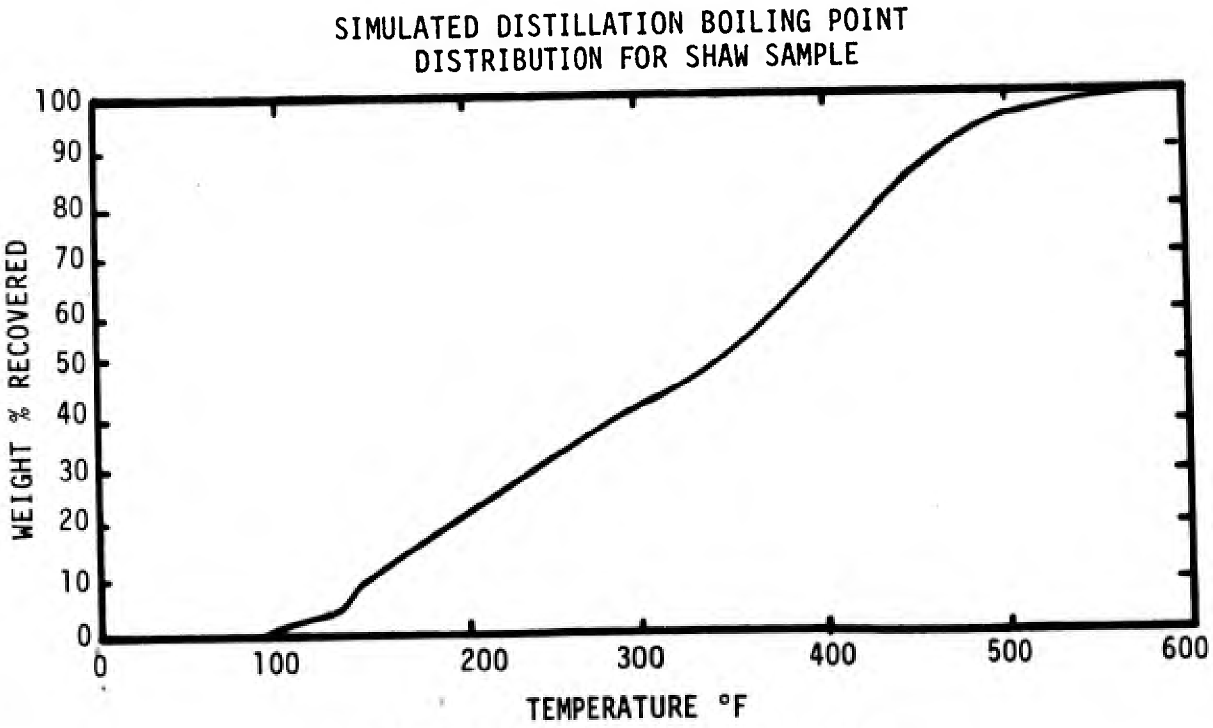

Figure B30. Distillation Curves

## TABLE B20

## SIMULATED DISTILLATION DATA FOR EGLIN SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 28 | 82 |
| 1.0 | 29 | 84 |
| 5.0 | 62 | 143 |
| 10 | 92 | 198 |
| 20 | 119 | 246 |
| 30 | 132 | 269 |
| 40 | 141 | 285 |
| 50 | 145 | 293 |
| 60 | 168 | 334 |
| 70 | 198 | 388 |
| 80 | 225 | 437 |
| 90 | 252 | 486 |
| 95 | 271 | 520 |
| 99 | 321 | 610 |
| 99.5 | 333 | 632 |

SIMULATED DISTILLATION BOILING POINT
DISTRIBUTION FOR EGLIN SAMPLE

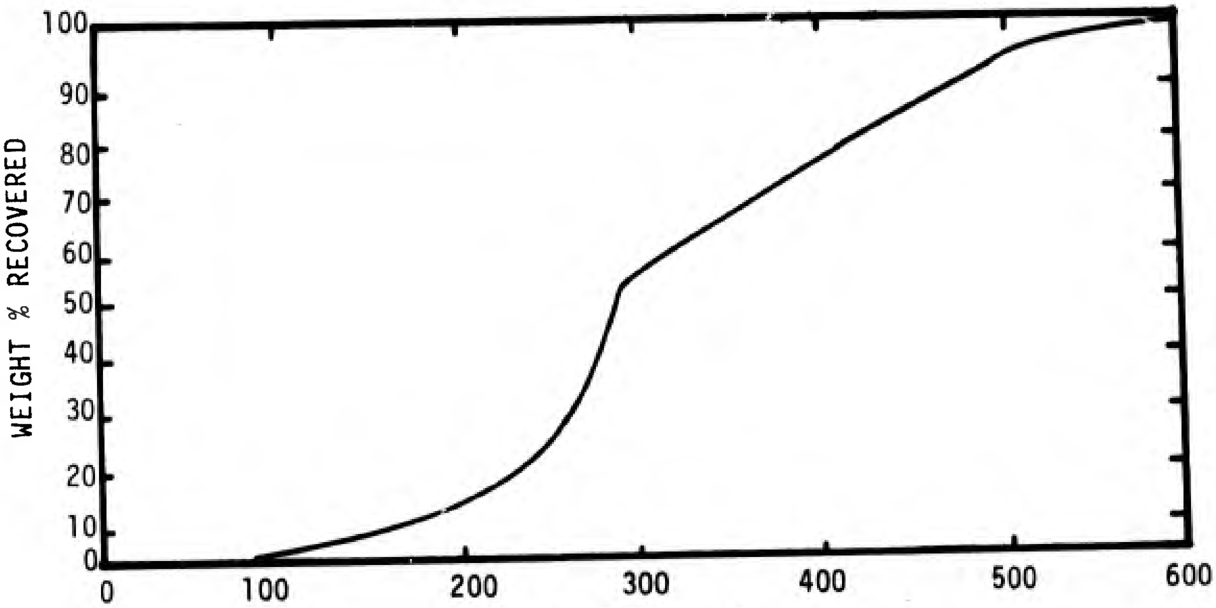

Figure B31. Distillation Curves

## TABLE B21

## SIMULATED DISTILLATION DATA FOR HAHN SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 27 | 81 |
| 1.0 | 32 | 90 |
| 5.0 | 35 | 95 |
| 10 | 60 | 141 |
| 20 | 96 | 205 |
| 30 | 118 | 244 |
| 40 | 141 | 286 |
| 50 | 160 | 320 |
| 60 | 175 | 346 |
| 70 | 192 | 378 |
| 80 | 208 | 406 |
| 90 | 228 | 443 |
| 95 | 244 | 471 |
| 99 | 276 | 529 |
| 99.5 | 288 | 550 |

SIMULATED DISTILLATION BOILING POINT
DISTRIBUTION FOR HAHN SAMPLE

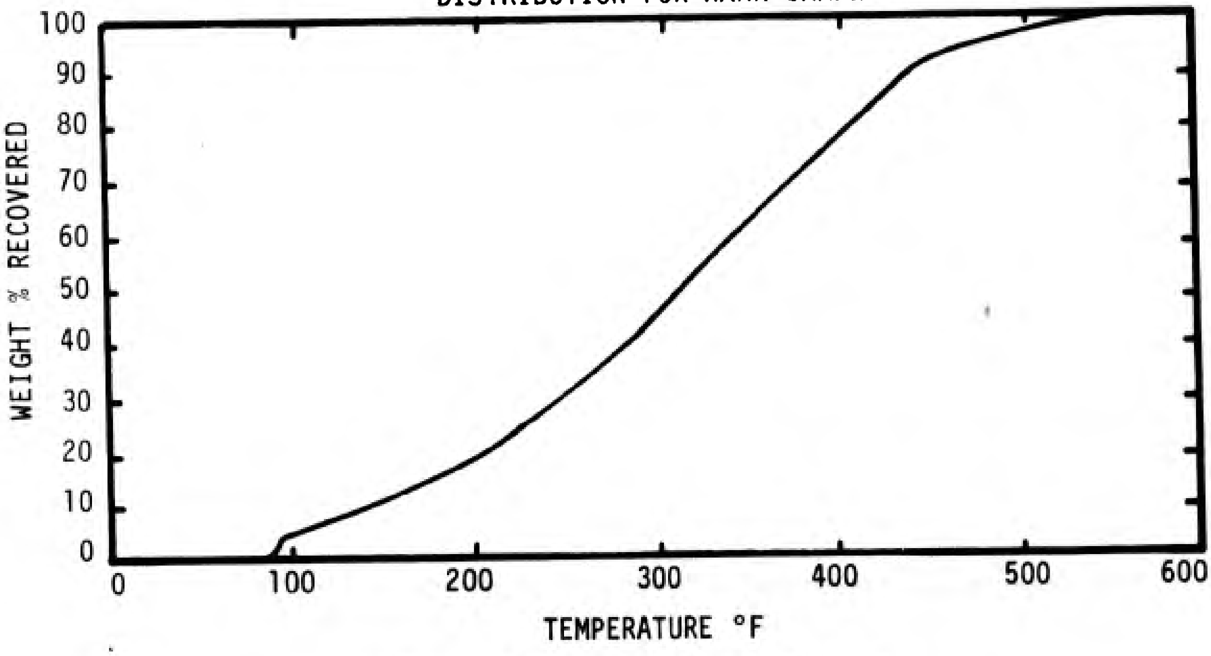

Figure B32. Distillation Curves

## TABLE B22

## SIMULATED DISTILLATION DATA FOR BITBURG SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 27 | 81 |
| 1.0 | 30 | 85 |
| 5.0 | 57 | 135 |
| 10 | 71 | 160 |
| 20 | 98 | 208 |
| 30 | 124 | 255 |
| 40 | 149 | 301 |
| 50 | 170 | 338 |
| 60 | 185 | 366 |
| 70 | 200 | 392 |
| 80 | 216 | 421 |
| 90 | 235 | 456 |
| 95 | 252 | 485 |
| 99 | 285 | 545 |
| 99.5 | 295 | 563 |

SIMULATED DISTILLATION BOILING POINT
DISTRIBUTION FOR BITBURG SAMPLE

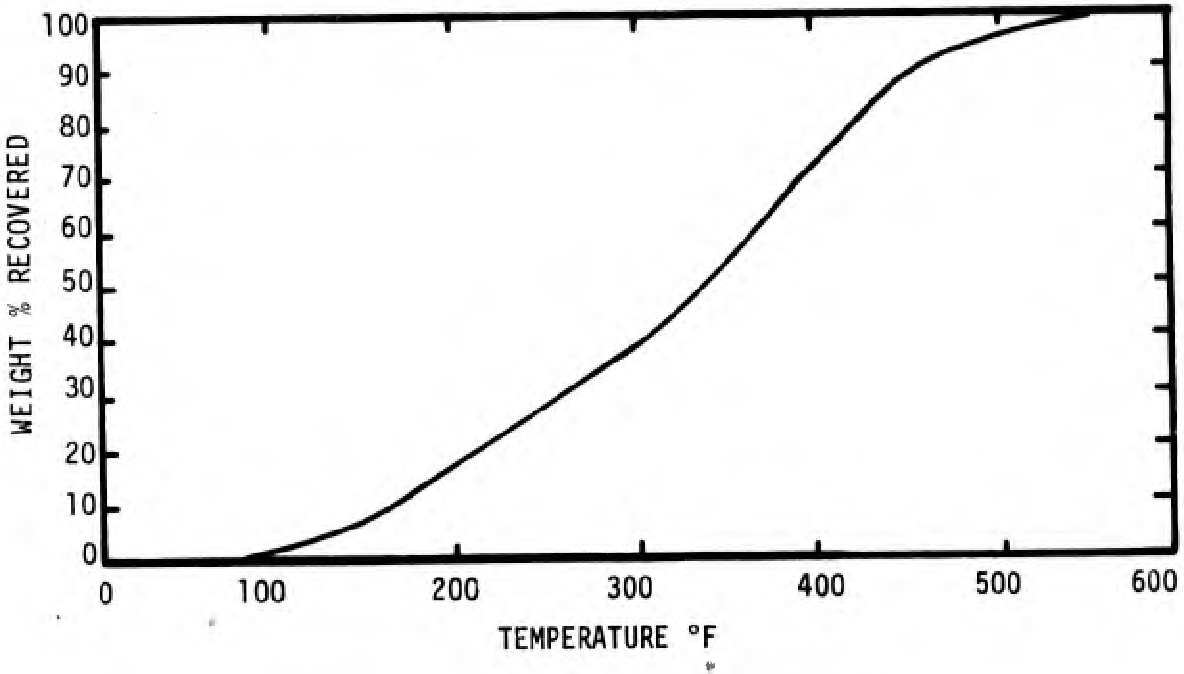

Figure B33. Distillation Curves

## TABLE B23

## SIMULATED DISTILLATION DATA FOR AVIANO SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 26 | 79 |
| 1.0 | 27 | 81 |
| 5.0 | 56 | 133 |
| 10 | 87 | 189 |
| 20 | 107 | 225 |
| 30 | 118 | 244 |
| 40 | 130 | 266 |
| 50 | 141 | 286 |
| 60 | 150 | 302 |
| 70 | 165 | 329 |
| 80 | 186 | 367 |
| 90 | 216 | 421 |
| 95 | 232 | 450 |
| 99 | 253 | 487 |
| 99.5 | 257 | 495 |

SIMULATED DISTILLATION BOILING POINT
DISTRIBUTION FOR AVIANO SAMPLE

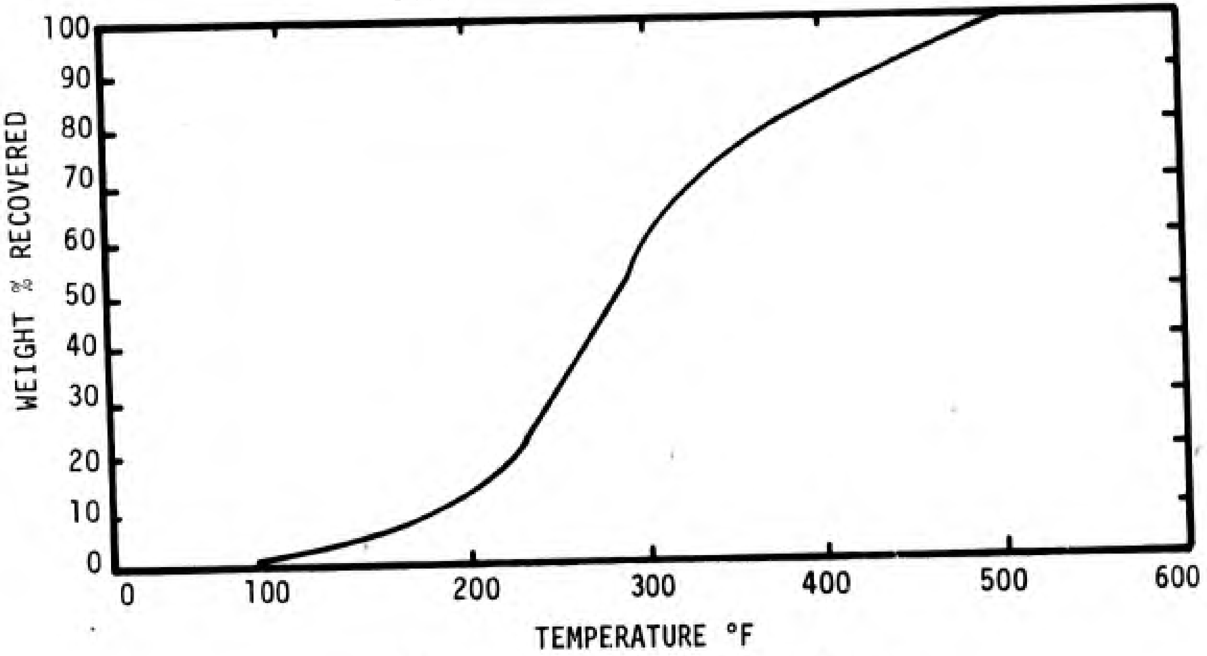

Figure B34. Distillation Curves

## TABLE B24
## SIMULATED DISTILLATION DATA FOR ZARAGOZA SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 29 | 84 |
| 1.0 | 35 | 95 |
| 5.0 | 37 | 98 |
| 10 | 55 | 131 |
| 20 | 93 | 199 |
| 30 | 121 | 250 |
| 40 | 145 | 293 |
| 50 | 165 | 330 |
| 60 | 181 | 357 |
| 70 | 197 | 387 |
| 80 | 217 | 422 |
| 90 | 240 | 463 |
| 95 | 270 | 517 |
| 99 | 351 | 664 |
| 99.5 | 370 | 698 |

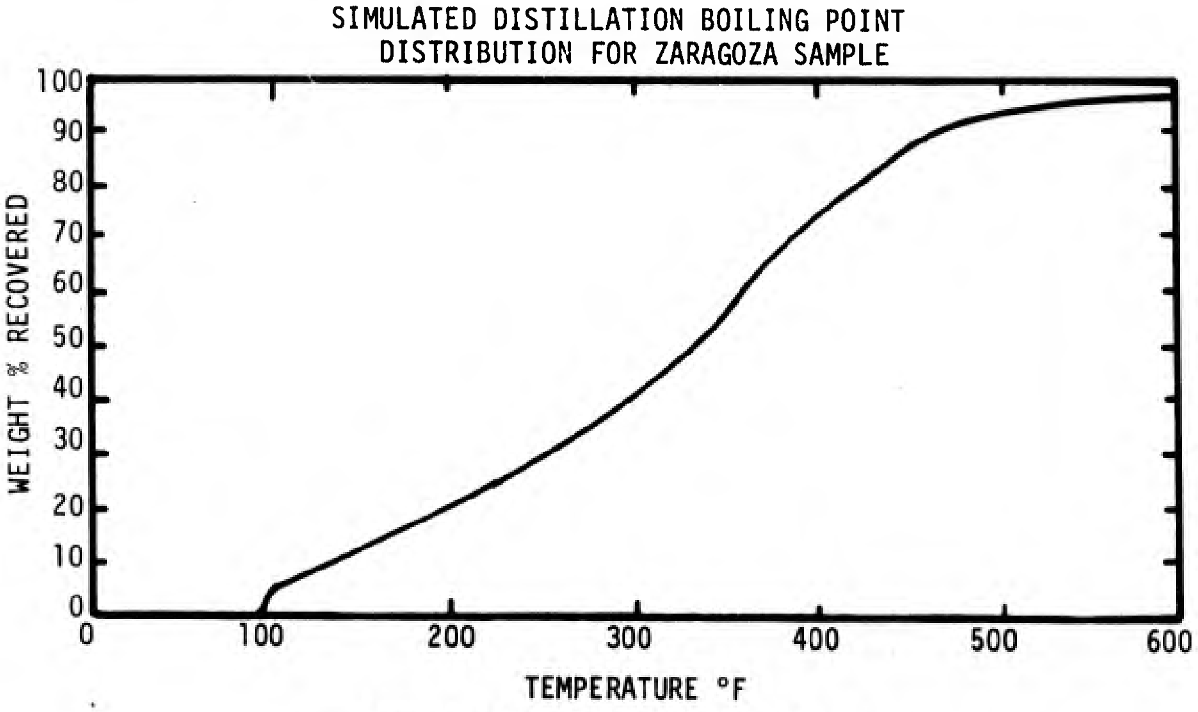

Figure B35. Distillation Curves

## TABLE B25

## SIMULATED DISTILLATION DATA FOR CAMP NEW AMSTERDAM SAMPLE

| % Recovered | 83-POSF-1283 | |
|---|---|---|
| | °C | °F |
| 0.5 | 29 | 84 |
| 1.0 | 34 | 94 |
| 5.0 | 66 | 151 |
| 10 | 82 | 179 |
| 20 | 100 | 212 |
| 30 | 127 | 260 |
| 40 | 152 | 305 |
| 50 | 173 | 344 |
| 60 | 189 | 371 |
| 70 | 205 | 401 |
| 80 | 226 | 439 |
| 90 | 252 | 486 |
| 95 | 282 | 539 |
| 99 | 351 | 663 |
| 99.5 | 373 | 703 |

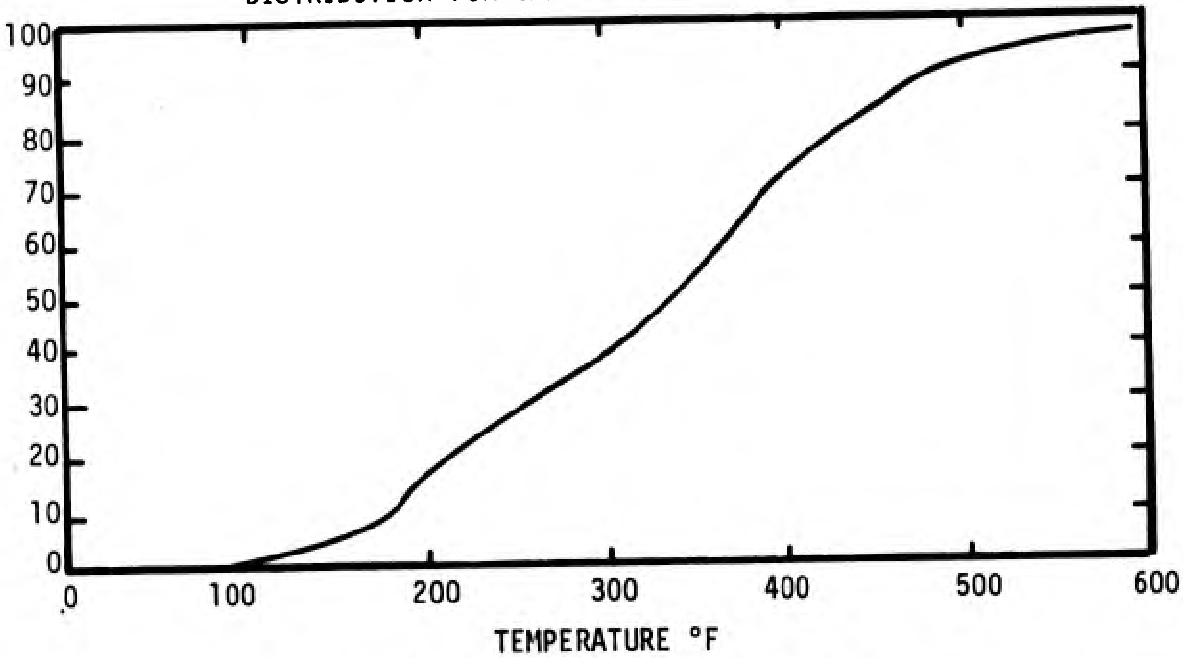
SIMULATED DISTILLATION BOILING POINT DISTRIBUTION FOR CAMP NEW AMSTERDAM SAMPLE

Figure B36. Distillation Curves

## TABLE B26

## SIMULATED DISTILLATION DATA FOR TORREJON SAMPLE

| %<br>Recovered | Temperature<br>°C | <br>°F |
|---|---|---|
| 0.5 | 28 | 82 |
| 1.0 | 34 | 93 |
| 5.0 | 58 | 137 |
| 10 | 73 | 163 |
| 20 | 100 | 213 |
| 30 | 126 | 258 |
| 40 | 149 | 300 |
| 50 | 167 | 332 |
| 60 | 183 | 361 |
| 70 | 199 | 391 |
| 80 | 217 | 423 |
| 90 | 238 | 460 |
| 95 | 259 | 498 |
| 99 | 313 | 595 |
| 99.5 | 330 | 626 |

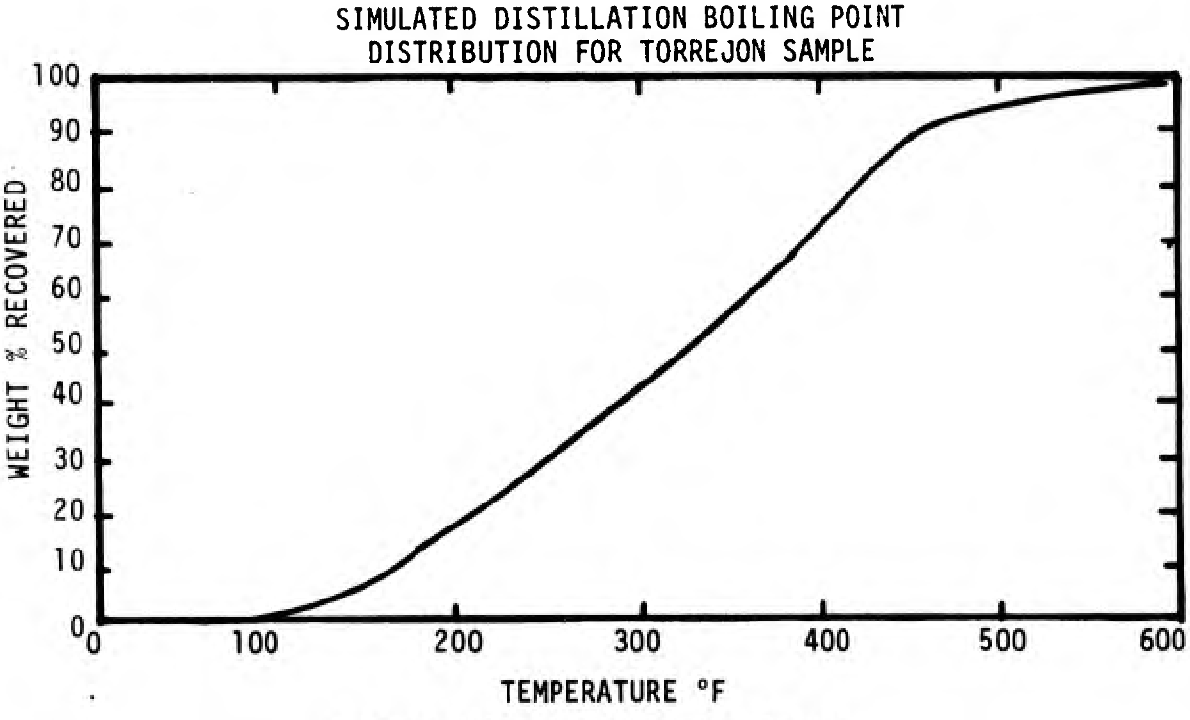

Figure B37. Distillation Curves

## TABLE B27
## SIMULATED DISTILLATION DATA FOR OSAN SAMPLE

| % | Temperature | |
|---|---|---|
| Recovered | °C | °F |
| 0.5 | 10 | 50 |
| 1.0 | 28 | 83 |
| 5.0 | 50 | 122 |
| 10 | 64 | 147 |
| 20 | 96 | 205 |
| 30 | 123 | 253 |
| 40 | 148 | 298 |
| 50 | 166 | 331 |
| 60 | 180 | 356 |
| 70 | 195 | 383 |
| 80 | 214 | 417 |
| 90 | 234 | 453 |
| 95 | 253 | 487 |
| 99 | 317 | 603 |
| 99.5 | 330 | 626 |

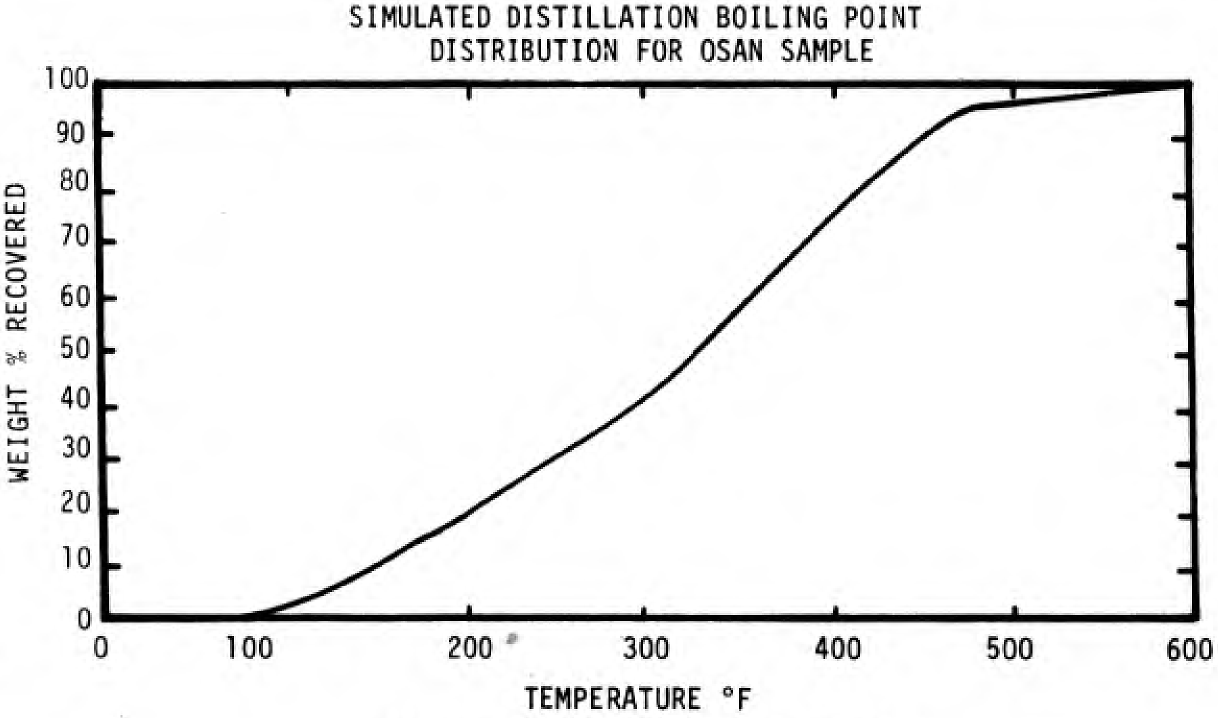

Figure B38. Distillation Curves

## TABLE B28
## SIMULATED DISTILLATION DATA FOR CLARK SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 28 | 82 |
| 1.0 | 29 | 84 |
| 5.0 | 54 | 129 |
| 10 | 72 | 162 |
| 20 | 98 | 209 |
| 30 | 110 | 229 |
| 40 | 119 | 247 |
| 50 | 134 | 274 |
| 60 | 146 | 296 |
| 70 | 165 | 330 |
| 80 | 188 | 370 |
| 90 | 222 | 432 |
| 95 | 252 | 486 |
| 99 | 325 | 617 |
| 99.5 | 342 | 647 |

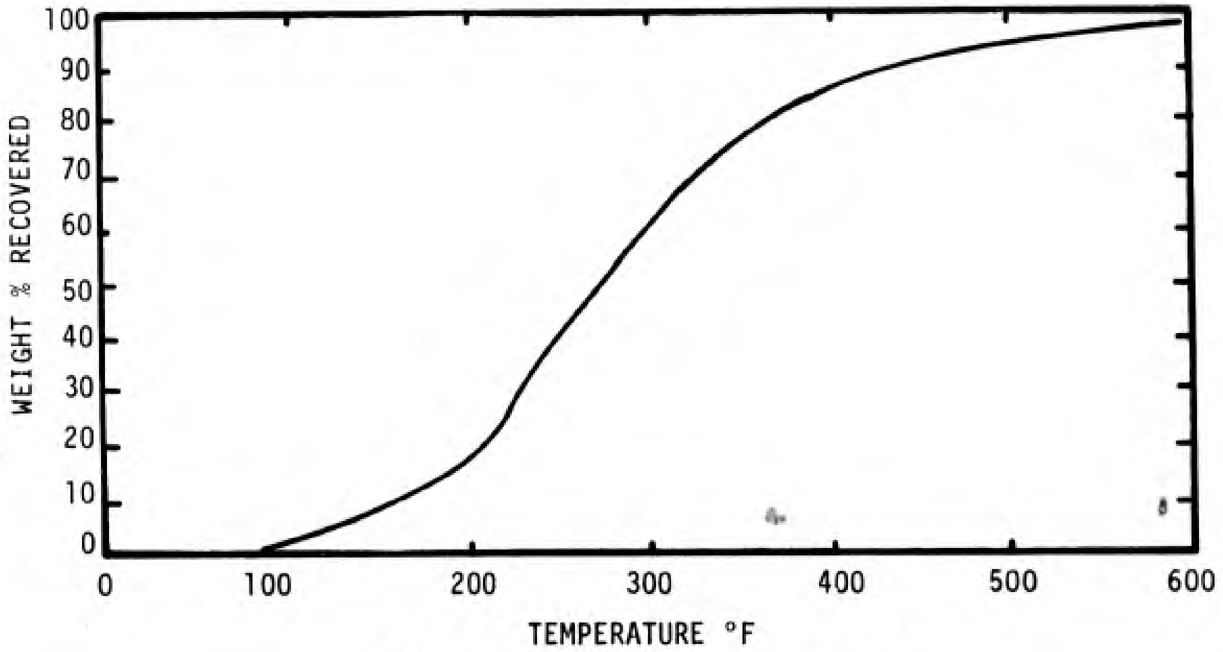
SIMULATED DISTILLATION BOILING POINT DISTRIBUTION FOR CLARK SAMPLE

Figure B39. Distillation Curves

## TABLE B29

## SIMULATED DISTILLATION DATA FOR ANDERSON SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 31 | 88 |
| 1.0 | 33 | 92 |
| 5.0 | 60 | 140 |
| 10 | 73 | 163 |
| 20 | 97 | 207 |
| 30 | 110 | 230 |
| 40 | 124 | 255 |
| 50 | 139 | 282 |
| 60 | 154 | 310 |
| 70 | 173 | 343 |
| 80 | 200 | 391 |
| 90 | 246 | 475 |
| 95 | 283 | 541 |
| 99 | 322 | 611 |
| 99.5 | 334 | 634 |

SIMULATED DISTILLATION BOILING POINT DISTRIBUTION FOR ANDERSON SAMPLE

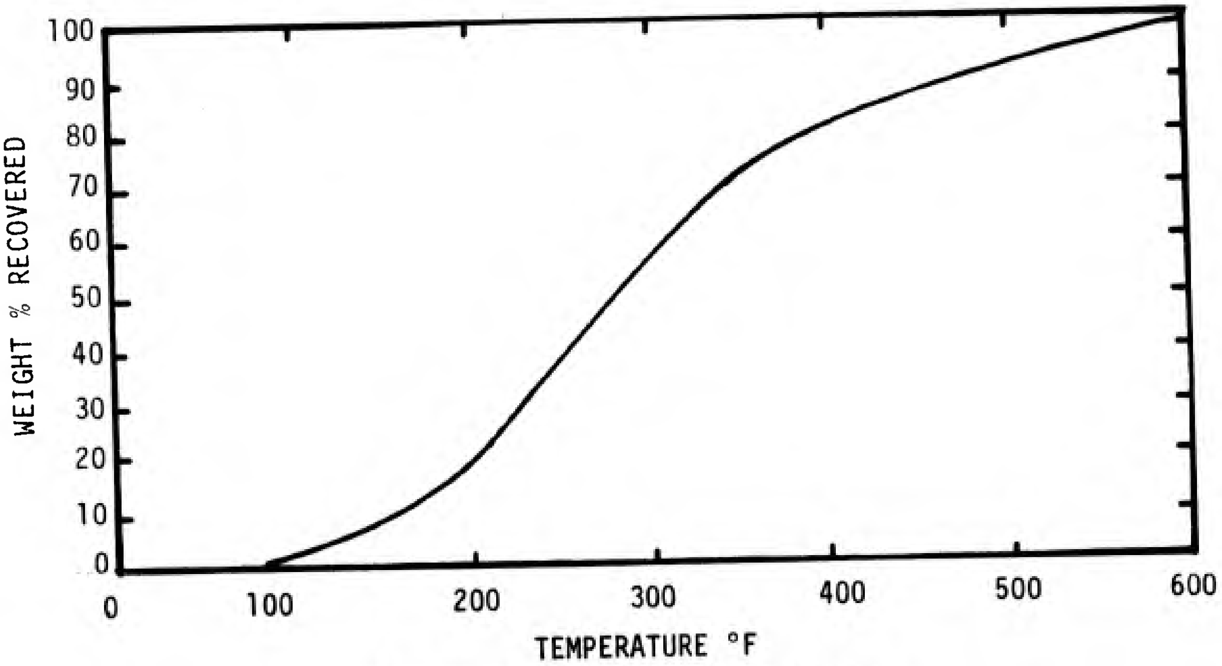

Figure B40. Distillation Curves

## TABLE B30
## SIMULATED DISTILLATION DATA FOR KADENA SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 29 | 85 |
| 1.0 | 31 | 87 |
| 5.0 | 67 | 152 |
| 10 | 84 | 183 |
| 20 | 99 | 211 |
| 30 | 108 | 226 |
| 40 | 118 | 245 |
| 50 | 126 | 259 |
| 60 | 139 | 282 |
| 70 | 151 | 305 |
| 80 | 180 | 355 |
| 90 | 220 | 427 |
| 95 | 248 | 478 |
| 99 | 293 | 559 |
| 99.5 | 311 | 591 |

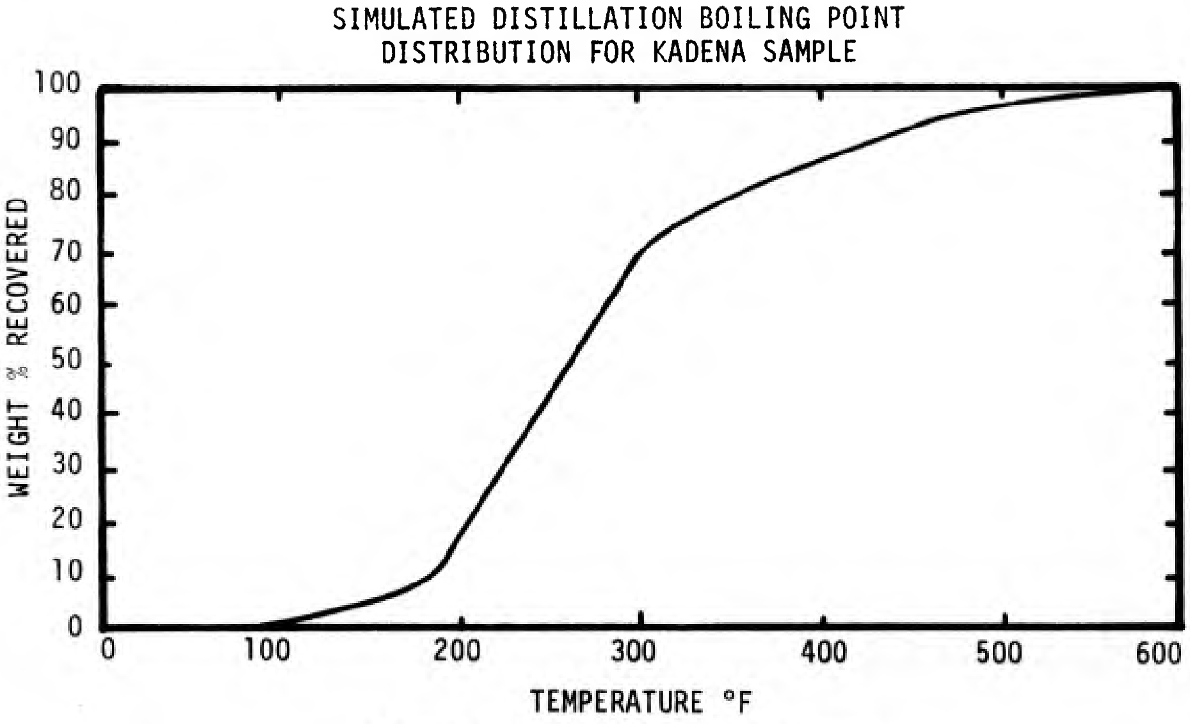

Figure B41. Distillation Curves

## TABLE B31
## HYDROCARBON TYPE ANALYSES

| | Hill | | Luke | | Holloman | | Elmendorf | | Edwards | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ASTM[a] | Monsanto | ASTM | Monsanto | ASTM[a] | Monsanto[b] | ASTM[a] | Monsanto[b] | ASTM[a] | Monsanto[b] |
| Paraffins | 51.4 | 43.1 | 42.8 | 37.1 | 44.7 | 37.7 | 42.5 | 36.0 | 43.7 | 36.5 |
| Cycloparaffins | 30.5 | -[c] | 37.9 | -[c] | 32.6 | -[c] | 39.5 | -[c] | 37.4 | -[c] |
| Dicycloparaffins | 2.9 | -[c] | 2.9 | -[c] | 4.4 | -[c] | 1.3 | -[c] | 5.4 | -[c] |
| Total cycloparaffins | 33.4[d] | 36.1 | 40.8[d] | 39.9 | 37.0[d] | 37.2 | 40.8[d] | 40.9 | 42.8[d] | 45.4 |
| Alkylbenzenes | 14.3 | 20.8 | 14.6 | 22.1 | 15.9 | 22.8 | 15.9 | 23.1 | 10.4 | 15.2 |
| Indans and tetralins | 0.2 | 0 | 1.0 | 0.6 | 1.5 | 1.4 | 0.3 | 0 | 2.2 | 2.5 |
| Indenes and dihydronaphthalenes | -[c] | 0 | -[c] | 0 | -[c] | 0 | -[c] | 0 | -[c] | 0 |
| Naphthalenes | 0.7 | 0 | 0.8 | 0.3 | 0.9 | 0.9 | 0.5 | 0 | 0.9 | 0.4 |
| Average carbon no. | 8.2 | | 8.3 | | 8.8 | | 7.8 | | 8.5 | |

[a] Modification of ASTM Method D 2789, values converted from volume percent using relative densities.

[b] Monsanto Method 21-PQ-38-63.

[c] Dash indicates method does not provide information on this specific compound category.

[d] Sum of two preceding values.

TABLE B31 (Continued)
HYDROCARBON TYPE ANALYSES

| | Nellis | | Langley | | Tyndall | | MacDill | | Shaw | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ASTM[a] | Monsanto[b] | ASTM | Monsanto | ASTM | Monsanto | ASTM | Monsanto | ASTM | Monsanto |
| Paraffins | 39.6 | 33.2 | 60.2 | 54.1 | 66.0 | 59.2 | 56.0 | 48.0 | 57.6 | 50.9 |
| Cycloparaffins | 37.4 | - | 22.3 | -[c] | 13.7 | -[c] | 21.5 | -[c] | 21.4 | -[c] |
| Dicycloparaffins | 8.1 | - | 4.2 | -[c] | 3.0 | -[c] | 5.7 | -[c] | 5.8 | -[c] |
| Total cycloparaffins | 45.5[d] | 46.3 | 26.5[d] | 28.1 | 16.7[d] | 16.1 | 27.2[d] | 27.6 | 27.2[d] | 27.0 |
| Alkylbenzenes | 11.0 | 16.0 | 10.5 | 15.9 | 15.8 | 23.9 | 12.9 | 19.8 | 11.6 | 17.4 |
| Indans and tetralins | 2.9 | 3.5 | 1.8 | 1.9 | 1.0 | 0.8 | 2.8 | 3.3 | 2.4 | 2.7 |
| Indenes and dihydronaphthalenes | -[c] | 0 | -[c] | 0 | -[c] | 0 | -[c] | 0 | -[c] | 0 |
| Naphthalenes | 1.0 | 1.0 | 1.0 | 0 | 0.5 | 0 | 1.1 | 1.3 | 1.2 | 1.1 |
| Average carbon no. | 9.0 | | 8.5 | | 8.9 | | 9.1 | | 8.9 | |

[a] Modification of ASTM Method D 2789, values converted from volume percent using relative densities.

[b] Monsanto Method 21-PQ-38-63.

[c] Dash indicates method does not provide information on these specific compound categories.

[d] Sum of two preceding values.

## TABLE B31 (Continued)
## HYDROCARBON TYPE ANALYSES

| | Eglin | | Hahn | | Bitburg | | Aviano | | Zaragoza | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ASTM[a] | Monsanto[b] | ASTM[a] | Monsanto[b] | ASTM[a] | Monsanto[b] | ASTM[a] | Monsanto[b] | ASTM[a] | Monsanto[b] |
| Paraffins | 64.6 | 57.7 | 57.9 | 51.6 | 57.0 | 50.7 | 56.1 | 49.4 | 58.3 | 52.2 |
| Monocycloparaffins | 16.3 | -[c] | 24.4 | -[c] | 24.6 | -[c] | 28.3 | -[c] | 24.7 | -[c] |
| Dicycloparaffins | 4.1 | -[c] | 3.9 | -[c] | 4.4 | -[c] | 3.2 | -[c] | 4.1 | -[c] |
| Total cycloparaffins | 20.4[d] | 20.6 | 28.3 | 29.4 | 29.0[d] | 30.1 | 31.5[d] | 33.1 | 28.8[d] | 30.1 |
| Alkylbenzenes | 12.7 | 19.6 | 11.6 | 17.5 | 11.2 | 16.9 | 11.2 | 16.7 | 10.7 | 16.2 |
| Indans and tetralins | 1.5 | 1.6 | 1.5 | 1.4 | 1.9 | 2.0 | 0.9 | 0.8 | 1.5 | 1.5 |
| Indenes and dihydronaphthalenes | -[c] | 0 | -[c] | 0 | -[c] | 0 | -[c] | 0 | -[c] | 0 |
| Naphthalenes | 0.8 | 0.5 | 0.7 | 0.1 | 0.9 | 0.3 | 0.3 | 0 | 0.7 | 0 |
| Average carbon no. | 9.1 | | 8.7 | | 8.7 | | 8.7 | | 8.7 | |

[a] Modification of ASTM Method D2789, values converted from volume percent using relative densities.

[b] Monsanto Method 21-PQ-38-63.

[c] Dash indicates method does not provide information on these specific compound categories.

[d] Sum of two preceding values.

TABLE B31 (Continued)
HYDROCARBON TYPE ANALYSES

| | Camp New Amsterdam | | Torrejon | | Osan | | Clark | |
|---|---|---|---|---|---|---|---|---|
| | ASTM$^{a}$ | Monsanto$^{b}$ | ASTM$^{a}$ | Monsanto$^{b}$ | ASTM$^{a}$ | Monsanto$^{b}$ | ASTM$^{a}$ | Monsanto$^{b}$ |
| Paraffins | 54.3 | 49.1 | 57.5 | 51.9 | 58.5 | 52.5 | 50.7 | 43.1 |
| Monocycloparaffins | 25.4 | -$^{c}$ | 26.2 | -$^{c}$ | 22.8 | -$^{c}$ | 30.6 | -$^{c}$ |
| Dicycloparaffins | 5.4 | -$^{c}$ | 4.3 | -$^{c}$ | 4.1 | -$^{c}$ | 2.6 | -$^{c}$ |
| Total cycloparaffins | 30.8$^{d}$ | 30.2 | 30.5 | 31.4 | 26.9$^{d}$ | 27.4 | 33.2$^{d}$ | 35.0 |
| Alkylbenzenes | 12.1 | 17.9 | 9.8 | 14.8 | 12.3 | 18.6 | 14.5 | 21.8 |
| Indans and tetralins | 2.0 | 2.1 | 1.6 | 1.7 | 1.6 | 1.5 | 0.8 | 0.1 |
| Indenes and dihydronaphthalenes | -$^{c}$ | 0 | -$^{c}$ | 0 | -$^{c}$ | 0 | -$^{c}$ | 0 |
| Naphthalenes | 0.8 | 0.7 | 0.6 | 0.2 | 0.7 | 0 | 0.8 | 0 |
| Average carbon no. | 9.1 | | 8.9 | | 8.7 | | 8.1 | |

[a] Modification of ASTM Method D-2789, values converted from volume percent using relative densities.

[b] Monsanto Method 21-PQ-38-63.

[c] Dash indicates method does not provide information on these specific compound categories.

[d] Sum of two preceding values.

## TABLE B31 (Concluded)
## HYDROCARBON TYPE ANALYSES

| | Anderson | | Kadena | |
|---|---|---|---|---|
| | ASTM[a] | Monsanto[b] | ASTM | Monsanto |
| Paraffins | 49.5 | 41.5 | 55.2 | 49.4 |
| Monocycloparaffins | 31.0 | -[c] | 27.4 | -[c] |
| Dicycloparaffins | 2.3 | -[c] | 2.2 | -[c] |
| Total cycloparaffins | 33.3 | 34.5 | 29.6 | 29.6 |
| Alkylbenzenes | 15.7 | 24.0 | 13.7 | 20.9 |
| Indans & Tetralins | 0.7 | 0 | 0.6 | 0.1 |
| Indenes & dihydronaphthalenes | -[c] | 0 | -[c] | 0 |
| Naphthalenes | 0.8 | 0 | 0.9 | 0 |
| Average carbon number | 8.2 | | 8.3 | |

[a] Modification of ASTM Method D 2789, values converted from volume percent using relative densities.

[b] Monsanto Method 21-PQ-38-63.

[c] Dash indicates method does not provide information on these specific compound categories.

[d] Sum of two preceding values.

## TABLE B32

## CORRELATIONS BETWEEN DISTILLATION DATA AND HYDROCARBON TYPE ANALYSES

| Correlation | Correlation Coefficient |
|---|---|
| FBP vs Paraffins | .07 |
| FBP vs Cycloparaffins | -.09 |
| FBP vs Dicycloparaffins | .28 |
| FBP vs Total Cycloparaffins | -.04 |
| FBP vs Indans & Tetralins | .10 |
| FBP vs Naphthalenes | .08 |
| FBP vs Average Carbon Number | .20 |

## TABLE B33

## GC NORMAL PARAFFIN ANALYSES

| | Hill | | Luke | | Holloman | |
|---|---|---|---|---|---|---|
| | % of Total | % of n-paraffin | % of Total | % of n-paraffin | % of Total | % of n-paraffin |
| C-5 | 1.391 | 6.33 | 2.143 | 11.54 | 2.363 | 11.71 |
| C-6 | 2.945 | 13.41 | 3.724 | 20.05 | 3.015 | 14.94 |
| C-7 | 3.637 | 16.56 | 3.099 | 16.69 | 2.547 | 12.62 |
| C-8 | 5.925 | 26.98 | 2.739 | 14.75 | 2.414 | 11.96 |
| C-9 | 4.325 | 19.69 | 2.297 | 12.37 | 2.153 | 10.67 |
| C-10 | 2.196 | 10.00 | 1.646 | 8.86 | 2.221 | 11.00 |
| C-11 | .867 | 3.95 | 1.190 | 6.41 | 2.198 | 10.89 |
| C-12 | .344 | 1.57 | .935 | 5.03 | 1.759 | 8.71 |
| C-13 | .186 | 0.85 | .541 | 2.91 | 1.113 | 5.51 |
| C-14 | .096 | 0.44 | .186 | 1.00 | .323 | 1.60 |
| C-15 | .037 | 0.17 | .052 | 0.28 | .051 | 0.25 |
| C-16 | .011 | 0.05 | .020 | 0.11 | .022 | 0.11 |
| C-17 | - | - | - | - | .007 | 0.03 |
| TOTAL | 21.960 | 100 | 18.572 | 100 | 20.186 | 100 |

TABLE B33 (Continued)

GC NORMAL PARAFFIN ANALYSES

| | Langley | | Tyndall | | MacDill | | Shaw | |
|---|---|---|---|---|---|---|---|---|
| | % of Total | % of n-paraffin | % of Total | % of n-paraffin | % of Total | % of n-paraffin | % of Total | % of n-paraffin |
| C-5 | 1.074 | 4.73 | 1.319 | 6.74 | 1.327 | 6.07 | 1.226 | 5.19 |
| C-6 | 5.383 | 23.70 | 1.614 | 8.25 | 4.763 | 21.77 | 6.272 | 26.57 |
| C-7 | 4.779 | 21.04 | 7.480 | 38.22 | 3.246 | 14.84 | 1.829 | 7.75 |
| C-8 | 2.724 | 11.99 | 3.411 | 17.43 | 1.746 | 7.98 | 1.585 | 6.71 |
| C-9 | 2.180 | 9.60 | 1.201 | 6.14 | 1.731 | 7.91 | 2.694 | 11.41 |
| C-10 | 2.114 | 9.31 | 1.266 | 6.47 | 2.419 | 11.06 | 3.385 | 14.34 |
| C-11 | 1.821 | 8.02 | 1.211 | 6.19 | 2.388 | 10.92 | 2.731 | 11.57 |
| C-12 | 1.433 | 6.31 | .980 | 5.01 | 2.080 | 9.51 | 2.024 | 8.57 |
| C-13 | .876 | 3.86 | .699 | 3.57 | 1.497 | 6.84 | 1.343 | 5.69 |
| C-14 | .266 | 1.17 | .257 | 1.31 | .548 | 2.50 | .408 | 1.73 |
| C-15 | .060 | 0.26 | .061 | 0.31 | .112 | 0.51 | .089 | 0.38 |
| C-16 | - | - | .070 | 0.36 | .020 | 0.09 | .023 | 0.09 |
| C-17 | - | - | - | - | - | - | - | |
| TOTAL | 22.71 | 100 | 19.569 | 100 | 21.877 | 100 | 23.609 | 100 |

TABLE B33 (Continued)

GC NORMAL PARAFFIN ANALYSES

| | Eglin | | Hahn | | Bitburg | | Aviano | |
|---|---|---|---|---|---|---|---|---|
| | % of Total | % of n-paraffin | % of Total | % of n-paraffin | % of Total | % of n-paraffin | % of Total | % of n-paraffin |
| C-5 | 1.654 | 8.24 | 2.594 | 9.17 | 2.840 | 10.61 | 2.874 | 11.47 |
| C-6 | 1.595 | 7.95 | 3.972 | 14.05 | 4.312 | 16.11 | 1.407 | 5.61 |
| C-7 | 6.966 | 34.70 | 3.794 | 13.42 | 2.983 | 11.14 | 6.988 | 27.88 |
| C-8 | 3.225 | 16.07 | 3.897 | 13.78 | 2.768 | 10.34 | 6.349 | 25.33 |
| C-9 | .943 | 4.70 | 4.340 | 15.35 | 3.885 | 14.51 | 3.071 | 12.25 |
| C-10 | 1.410 | 7.02 | 4.054 | 14.34 | 3.757 | 14.03 | 1.582 | 6.31 |
| C-11 | 1.417 | 7.06 | 2.943 | 10.41 | 3.088 | 11.53 | 1.455 | 5.81 |
| C-12 | 1.204 | 6.00 | 1.700 | 6.01 | 1.980 | 7.40 | .897 | 3.58 |
| C-13 | 1.011 | 5.04 | .786 | 2.78 | .945 | 3.53 | .365 | 1.46 |
| C-14 | .475 | 2.37 | .156 | 0.55 | .186 | 0.69 | .065 | 0.26 |
| C-15 | .137 | 0.68 | .031 | 0.11 | .030 | 0.11 | .011 | 0.04 |
| C-16 | .037 | 0.18 | .009 | 0.03 | - | - | - | - |
| C-17 | - | - | - | - | - | - | - | - |
| TOTAL | 20.074 | 100 | 28.276 | 100 | 26.774 | 100 | 25.064 | 100 |

## TABLE B33 (Continued)
## GC NORMAL PARAFFIN ANALYSES

| | | | | | data not available | | data not available | |
|---|---|---|---|---|---|---|---|---|
| | Zaragoza | | Camp New Amsterdam | | Torrejon | | Osan | |
| | % of Total | % of n-paraffin | % of Total | % of n-paraffin | % of Total | % of n-paraffin | % of Total | % of n-paraffin |
| C-5 | 2.919 | 9.84 | .938 | 3.87 | | | | |
| C-6 | 3.568 | 12.02 | 3.233 | 13.35 | | | | |
| C-7 | 3.490 | 11.76 | 2.882 | 11.90 | | | | |
| C-8 | 4.113 | 13.86 | 2.801 | 11.56 | | | | |
| C-9 | 4.828 | 16.27 | 4.243 | 17.52 | | | | |
| C-10 | 4.404 | 14.84 | 3.836 | 15.84 | | | | |
| C-11 | 3.330 | 11.22 | 2.632 | 10.87 | | | | |
| C-12 | 1.996 | 6.73 | 1.994 | 8.23 | | | | |
| C-13 | .811 | 2.73 | 1.310 | 5.41 | | | | |
| C-14 | .174 | 0.59 | .299 | 1.23 | | | | |
| C-15 | .037 | 0.12 | .046 | .19 | | | | |
| C-16 | .007 | 0.02 | .010 | 0.04 | | | | |
| C-17 | - | - | - | - | | | | |
| TOTAL | 29.677 | 100 | 24.224 | 100 | | | | |

TABLE B33 (Concluded)

GC NORMAL PARAFFIN ANALYSES

| | Clark | | Anderson | | Kadena | |
|---|---|---|---|---|---|---|
| | % of Total | % of n-paraffin | % of Total | % of n-paraffin | % of Total | % of n-paraffin |
| C-5 | 1.845 | 9.32 | 2.210 | 10.74 | 1.839 | 8.93 |
| C-6 | 2.807 | 14.18 | 3.910 | 19.01 | 3.111 | 15.10 |
| C-7 | 5.366 | 27.11 | 3.914 | 19.03 | 7.834 | 38.03 |
| C-8 | 3.764 | 19.01 | 3.691 | 17.94 | 3.502 | 17.00 |
| C-9 | 2.513 | 12.69 | 2.551 | 12.40 | 1.701 | 8.26 |
| C-10 | 1.661 | 8.39 | 1.716 | 8.34 | 1.306 | 6.34 |
| C-11 | 1.080 | 5.46 | 1.191 | 5.79 | .678 | 3.29 |
| C-12 | .481 | 2.43 | .776 | 3.77 | .392 | 1.90 |
| C-13 | .195 | .99 | .430 | 2.09 | .164 | 0.80 |
| C-14 | .063 | .32 | .141 | .69 | .059 | 0.29 |
| C-15 | .021 | .11 | .039 | .19 | .014 | 0.07 |
| C-16 | - | - | - | - | - | - |
| C-17 | - | - | - | - | - | - |
| TOTAL | 19.796 | 100 | 20.569 | 100 | 20.600 | 100 |

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