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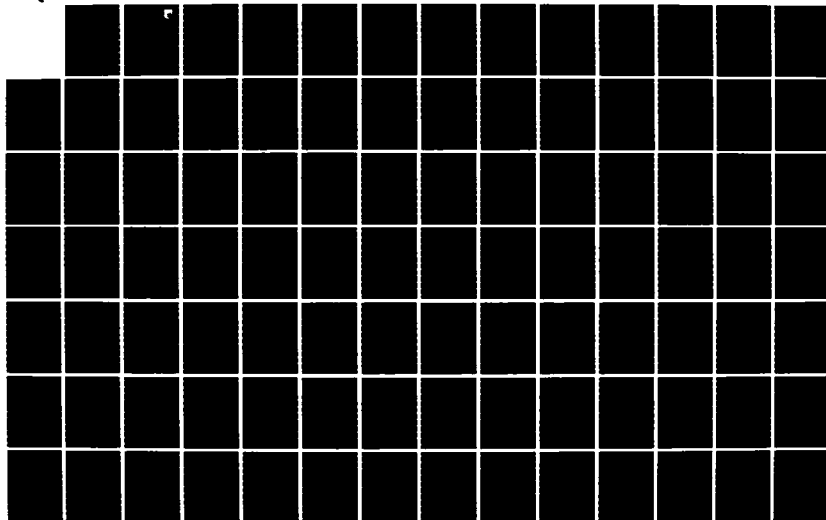
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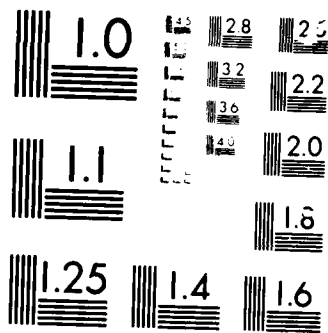
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F100 FUEL SAMPLING ANALYSIS:
FOREIGN SAMPLES

L.O. Maurice

Fuels Branch
Fuels and Lubrication Division

March 1986

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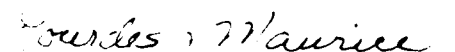
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This technical report has been reviewed and is approved for publication.


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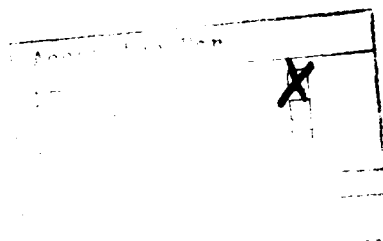
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FOREWORD

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 O. Maurice was the Project Engineer.

This report presents physical and chemical analyses of aviation turbine fuel used in F100 engines at Foreign National 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 for her 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.



A-1



TABLE OF CONTENTS

SECTION		PAGE
I	INTRODUCTION	1
II	BACKGROUND	2
III	EXPERIMENTAL/DISCUSSION	4
	1. Specification Tests	4
	2. Lubricity Test	9
	3. Characterization Tests	12
IV	CONCLUSIONS	21
V	RECOMMENDATIONS	23
	APPENDIX A - Specification Analyses	25
	APPENDIX B - Characterization Analyses	57
	REFERENCES	104

LIST OF ILLUSTRATIONS

FIGURE		PAGE
1	Lubricity Results	11
A-1	Total Acid Number	28
A-2	Volume Percent Aromatics	30
A-3	Volume Percent Olefins	32
A-4	Mercaptan Sulfur	34
A-5	Total Sulfur	36
A-6	API Gravity	42
A-7	Heat of Combustion	46
A-8	Smoke Point	48
A-9	Hydrogen Content ⁺	50
A-10	Existent Gum	54
A-11	Fuel System Icing Inhibitor	56
B-1 - B-14	Viscosity vs Temperature Plots	64-77
B-15 - B-29	Distillation Curves	84-98

LIST OF TABLES

TABLE		PAGE
1	Foreign National Bases Participating in Fuel Sampling Program	3
2	Results of Questionnaire	3
3	Summary of Specification Test Failures	6
4	Comparison of Average JP-4 Fuels	7
5	Lubricity Analyses	10
A-1	Saybolt Color Analyses	26
A-2	Total Acid Number Analyses	27
A-3	Volume Percent Aromatics Analyses	29
A-4	Volume Percent Olefins Analyses	31
A-5	Mercaptan Sulfur Analyses	33
A-6	Total Weight Percent Sulfur Analyses	35
A-7	Boiling Range Distribution Specifications	37
A-8	Simulated Distillation Analyses	38
A-9	Vapor Pressure Analyses,	40
A-10	API Gravity Analyses	41
A-11	Freezing Point Analyses	43
A-12	Viscosity Analyses	44
A-13	Heat of Combustion Analyses	45
A-14	Smoke Point Analyses	47
A-15	Hydrogen Content Analyses	49
A-16	Copper Strip Corrosion Analyses	51
A-17	Thermal Stability Analyses	52
A-18	Existent Gum Analyses	53
A-19	Fuel System Icing Inhibitor Analyses	55
B-1	Physical Properties as a Function of Temperature	58
B-2	Comparison of Typical JP-4 and Averaged F100 Samples Vapor Pressure as a Function of Temperature	78
B-3	Comparison of Typical JP-4 and Averaged F100 Samples Kinematic Viscosity as a Function of Temperature	79
B-4	Comparison of Typical JP-4 and Averaged F100 Samples Density as a Function of Temperature	79
B-5	Comparison of Typical JP-4 and Averaged F100 Samples Surface Tension as a Function of Temperature	80
B-6	Thermal Conductivity Analyses	80

LIST OF TABLES (Concluded)

TABLE		PAGE
B-7	Comparison of Typical JP-4 and Averaged F100 Samples Thermal Conductivity	80
B-8	Specific Heat Analyses	81
B-9	Comparison of Typical JP-4 and Averaged F100 Samples Specific Heat as a Function of Temperature	83
B-10	Typical JP-8 Properties as a Function of Temperature	83
B-11 - B-25	Distillation Analyses	84-98
B-26	Hydrocarbon Type Analyses	99
B-27	Average Hydrocarbon Types in JP-4	103

LIST OF ABBREVIATIONS

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
BOCLE	Ball-on-Cylinder Lubricity Evaluator
$^{\circ}\text{C}$	degrees Celsius
cm	centimeter
Δ	Delta, mathematical change
$^{\circ}\text{F}$	degrees Fahrenheit
FIA	Fluorescent Indicator Adsorption
FSII	Fuel System Icing Inhibitor
ft^3	cubic feet
q	cubic feet
g	grams
H_2SO_4	sulfuric acid
Hg	mercury
JFTOT	Jet Fuel Thermal Oxidation Tester
kPa	kilo pascal
m	minute
max	maximum
min	minimum
mm	millimeter
mm Hg	millimeter of mercury
NO	nitric oxide
P	pressure
P&WA	Pratt & Whitney Aircraft
PDC	Preheater Deposit Code
%	percent
ppm	part per million
psi	pounds per square inch
pS/M	pico Siemens per meter
rpm	revolution per minute
SA-ALC/SFTLA	Quality Control Laboratory
sec	second

LIST OF ABBREVIATIONS (Concluded)

SO ₂	sulfur dioxide
SO ₃	sulfur trioxide
US	United States
vol%	volume percent
WSD	wear scar diameter
wt%	weight percent

SUMMARY

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

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

Only a few fuels failed to meet specifications prescribed by Military Specifications MIL-T-5624L (JP-4) and MIL-T-83133A (JP-8). Fuels from Egypt (JP-8), Pakistan (JP-4), King Fahad, Saudi Arabia (JP-4), and King Aziz, Saudi Arabia (JP-4) failed the FSII specification. The fuels from Saudi Arabia and Pakistan failed the static conductivity specification. All three JP-4 fuel samples from Egypt, and the JP-4 sample from Rygge, Norway did not meet the simulated distillation specification requirements.

Static conductivity and FSII failures are not indicative of fuels likely to contribute to fuel pump failure. Rather, they are indicative of insufficient amounts of additives. The Air Bases concerned have been advised, and required additive concentrations are now being used. Simulated distillation failures (which are directly proportional to low vapor pressure) are indicative of poor fuel volatility. 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, it is likely that the failures noted were more the result of fuel handling techniques, rather than caused by poor volatility fuel. Since all samples received were handled by several parties, it is reasonable to presume that poor fuel handling techniques resulted in the loss of fuel light boiling constituents. This in turn would 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. Three of the fuels analyzed had suspect lubricity test results: those from King Fahad and King Aziz, and

Skrydstru, Denmark. These failures could be indicative of lack of corrosion inhibitor, and the parties involved have been advised of a potential problem. However, the failures observed were marginal, and since the Ball-on-Cylinder Lubricity Evaluator (BOCLE) used for lubricity analyses was the older, less repeatable model, the failures do not necessarily reflect a widespread problem. The remaining fuels all had acceptable lubricating qualities.

Chemical and physical characterization test results showed no indication of properties likely to cause fuel pump failure. The three Egyptian JP-4 samples and the Pakistani JP-4 sample had some properties that resembled JP-8 more than JP-4, but this should not present a problem because the F100 engine is qualified to operate on JP-8.

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

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 16 fuel samples (12 JP-4 fuels and four JP-8 fuels) from F-15 and F-16 Foreign National bases to identify any fuel characteristics that might be contributing to increased fuel pump cavitation and fuel pump failure. The data was collected between April 1984 and April 1985. This report contains the following five sections:

Section I is the introduction; Section II is discussion of the fuel pump cavitation problem and a summary of the samples involved in the analyses; Section III describes tests performed and the results; Section IV summarizes conclusions; and 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. The results of Phase I, which analyzed samples for US Air Force Bases, have already been published (AFWAL-TR-85-2045). During Phase II, 16 samples from 9 foreign countries were submitted for analysis, and the results are the subject of this report. A list of samples is shown in Table 1.

In order to obtain reliable data from which sound conclusions could be derived, the same measures taken to ensure sample purity for the US Air Base samples were taken with the foreign national fuel samples. AFWAL/POSF provided each Air 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. Questionnaire response was poor, with only a few bases responding. The results of those questionnaires received are tabulated in Table 2 and were used to try to account for any unusual sample characteristics.

Each of the participating bases sent fuel samples to the F100 engine manufacturer, Pratt & Whitney Aircraft (P&WA). P&WA in turn shipped the samples to AFWAL/POSF at WPAFB. Two gallons and one pint of each fuel were requested. However, in several cases, insufficient fuel was received and complete analyses of the fuel sample could not be obtained. Samples received were distributed to several organizations for analyses. The Quality Control Laboratory, SA-ALC/SFTLA, performed a series of specification tests, Monsanto Research Company (under contract to the Fuels Branch) was responsible for several characterization tests, and AFWAL/POSF performed lubricity as well as characterization tests.

TABLE 1
FOREIGN NATIONAL BASES PARTICIPATING IN FUEL SAMPLING PROGRAM

BASE	FUEL TYPE	SAMPLE CODE
INSHAS, EGYPT	JP-4	83-POSF-1004*
INSHAS, EGYPT	JP-4	83-POSF-1005*
EGYPT	JP-4	83-POSF-1268*
KING FAHAD, SAUDI ARABIA	JP-4	84-POSF-1952
KING AZIZ, SAUDI ARABIA	JP-4	84-POSF-1951
JAPAN	JP-4	83-POSF-1488
PAKISTAN	JP-4	84-POSF-1744
BEAUVECHAIN, BELGIUM	JP-4	84-POSF-2034
KLEINE BROGEN, BELGIUM	JP-4	84-POSF-2036
SKRYDSTRU, DENMARK	JP-4	84-POSF-2037
RODO, NORWAY	JP-4	84-POSF-2113
RYGGE, NORWAY	JP-4	84-POSF-2114
EGYPT	JP-8	83-POSF-0758
VENEZUELA	JP-8	84-POSF-1723*
LEEWARDEN, THE NETHERLANDS	JP-8	83-POSF-2035
VOLKEL, THE NETHERLANDS	JP-8	84-POSF-2038

*Insufficient sample provided for complete analysis.

TABLE 2
RESULTS OF QUESTIONNAIRE

BASE	SAMPLING PROCEDURE	SUPPLIERS	ADDITIVES USED
KLEINE BROGEN	Samples drawn from a Bowser after refueling of an aircraft on the flight line.	NATO Pipeline/ 4th Belgian Pipeline	No information
BEAUVECHAIN	No information provided.	NATO Pipeline/ 4th Belgian Pipeline	No information
VOLKEL	From a refueling truck on the Air Base.	Defense Pipeline Organization	No information
LEEWARDEN	Samples drawn from the top of a refueling truck. Hatch was opened and fuel was taken from the top level.	Defense Pipeline Organization	No information

SECTION III

EXPERIMENTAL/DISCUSSION

1. 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 12 of the 16 fuel samples. The results of these tests can be found in Appendix A.

All specification tests were performed using American Society for Testing and materials (ASTM) test methods and applicable Federal Test Methods prescribed by Military Specification MIL-T-5624L for JP-4 and MIL-T-83133A for JP-8. 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 (JP-4) and MIL-T-83133A (JP-8). With a few minor exceptions, all fuel samples analyzed were well within the specification limits.

The two Saudi Arabian samples, the Pakistani sample and the Egyptian JP-8 sample all failed the fuel system icing inhibitor (FSII) content test. The fuels appeared to have virtually no icing inhibitor additive, and although this is not a critical problem, potential harmful effects should not be overlooked. Icing inhibitor acts like "anti-freeze" in the fuel system and it also inhibits the growth of microorganisms that cause corrosion and plug filters. Thus, its absence could cause operational problems.

Since it was suspected that none of the additives recommended by the specifications were being added to the fuel samples, other additive detection tests (static conductivity and peroxides) were performed on the two Saudi Arabian and the Pakistani samples. Additional Egyptian JP-8 fuel was not available for testing.

Both the Saudi samples and the Pakistani sample failed the static conductivity test, denoting insufficient antistatic additive. Antistatic additive enables the fuel to dissipate static charge, therefore, its absence could also result in operational problems.

The peroxide test did not indicate a lack of antioxidant. However, the peroxide test is not a specification test. A positive result does indicate the absence of antioxidant, but a negative result does not assure its presence. Since neither FSII nor antistatic additive were being added, it was likely that antioxidant was also not being used. It was also possible that corrosion inhibitor was not being used. This problem is discussed in subsection 2 of this section.

Overall, both the Saudi Arabian samples and the Pakistani samples are good quality fuels with the exception of the lack of additives. The additive deficiency can easily be remedied by blending the "additive package" recommended by MIL-T-5624L and MIL-T-8133A to the fuel, and all three countries involved have been advised of the necessity to use additives.

Three JP-4 fuel samples from Egypt failed the 20% recovered simulated distillation test at Monsanto Research Corporation. The Egyptian samples and the Rygge, Norway sample failed the 50% recovered simulated distillation test. However, all the fuels met end point specification. Considering the distance traveled, and the amount of handling encountered by these fuels, it is reasonable to assume that the failures were caused by the loss of the fuel's low boiling components en route from the sampling point to the laboratory. The samples were shipped from the field to Pratt and Whitney and then to the Fuels Branch of the Aero Propulsion Laboratory. The Fuels Branch then provided samples to the Monsanto Research Corporation. Thus, there were several chances for the fuel's light ends to be lost.

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

Results of specification tests for the JP-4 samples were also compared to the average specification properties of JP-4 determined in 1980/81 (Reference 2). They were also compared to the average US F100 JP-4 samples (Reference 4). These comparisons are shown in Table 4.

The average aromatic content of the foreign JP-4 samples was lower than that for the average US F100 JP-4, but higher than 1980/81 average JP-4. An increased aromatic content is a negative trend because aromatics tend to increase visible smoke and contribute to shorter combustor life spans.

The average weight percent total sulfur of the JP-4 samples remained unchanged from the average 1980/81 JP-4 average sulfur, but was higher than the weight percent total sulfur of the average US F100 JP-4. This higher average sulfur was caused by the high total sulfur content of the two Saudi Arabian samples. Overall, the foreign average JP-4 had total sulfur content comparable with the US F100 average JP-4 total sulfur content. This is a favorable trend 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 can potentially contribute to thermal stability problems.

TABLE 3

SUMMARY OF SPECIFICATION TEST FAILURES

TEST	SPEC LIMIT	SAMPLE LOCATION	VALUE OF PROPERTY
Fuel System Icing	0.10 vol% min	King Fahad	0.00
Inhibitor		King Aziz	0.00
(FSID 791 5327)	0.15 vol% max	Pakistan	0.01
		Egypt (JP-8)	0.00
Electrical conductivity	200 pS/m min	King Fahad	160 pS/m
		King Aziz	140 pS/m
	600 pS/m max	Pakistan	10 pS/m
Simulated Distillation	130 °C maximum	Inshas #1	161 °C
ASTM D 2887 20% Recovered		Inshas #2	160 °C
		Egypt (JP-4)	159 °C
Simulated Distillation	185 °C maximum	Inshas #1	189 °C
ASTM D 2887 50% Recovered		Inshas #2	188 °C
		Egypt (JP-4)	189 °C
		Rygge, Norway (1)	186 °C
		Rygge, Norway (2)	187 °C

(1) Value determined by Air Force Quality Control Laboratory

(2) Value determined by Monsanto Research Corporation

TABLE 4

COMPARISON OF AVERAGE JP-4s

Property	1980/81 Study Average JP-4	US F100 Average JP-4	Foreign National Average JP-4
Total Acid Number	0.005 mg KOH/g	0.005 mg KOH/g	0.003 mg KOH/g
Vol % Aromatics	12.6	14.0	13.6
Vol % Olefins	0.8	0.7	0.7
Wt % Mercaptan Sulfur	0.0004	0.0002	0.001
Wt % Total Sulfur	0.04	0.02	0.04
Vapor Pressure, psi	2.6	2.29	2.5
API Gravity	54.2	53.9	54.5
Net Heat of Combustion MJ/kg	43.5	43.5	43.6
Smoke Point, mm	27.0	25	27
Wt% Hydrogen Content	14.3	14.2	14.4
Thermal Stability, PDC	< 3	< 2	< 1
Thermal Stability, AP	1 mm Hg	2 mm Hg	0 mm Hg
Existent Gum	0.8 mg/100 ml	0.4 mg/100 ml	0.5 mg/100 ml
Vol % FSII	0.13	0.13	0.11

The existent gum content of the foreign JP-4 was reduced from the 1980/81 average JP-4, but was greater than the US F100 average JP-4. Large quantities of gum in a fuel are indicative of contamination of higher molecular weight components or particulate matter. Turbine engines that use prevaporizer fuel tubes are known to be sensitive to existent gum. Thus, lower existent gum is a favorable trend.

The vol % FSII content of the foreign JP-4 was lower than both the 1980/81 and US F100 average JP-4. This problem was already discussed.

The Total Acid Number decreased over both the 1980/81 and US F100 average JP-4. This test is a measure of the level of organic acids in the fuel. These acids tend to cause corrosion problems, thus a lower total acid number is an improvement.

The olefin content decreased over the 1980/81 average olefin content and was identical to the US F100 average JP-4 olefin content. Lower olefins can reduce stability problems caused by the gum-forming tendencies of olefins.

Weight percent mercaptan sulfur content decreased overall. This is a favorable trend because some sulfur compounds, such as mercaptans, attack elastomers, and solubilize trace metals such as copper, which can cause thermal stability problems.

Vapor pressure of the foreign JP-4 was slightly lower than the 1980/81 average JP-4 vapor pressure, but was much improved from the US F100 average JP-4. Fuels with low vapor pressure do not vaporize readily, which could lead to difficult starting at low temperatures. Also, fuel vapor pressure is theoretically inversely proportional to fuel pump cavitation. Thus, lower fuel vapor pressures could tend to increase fuel pump cavitation.

API gravity was higher than both the 1980/81 JP-4 and US F100 average JP-4. A higher API gravity would indicate lower density, which would be favorable for some systems. However, a lower API gravity indicates overall a tendency towards denser fuels. This increases volumetric heat of combustion, and in turn increases volume-limited aircraft range, thus lower API gravity could also be beneficial.

Hydrogen content increased overall, and smoke point increased over the F100 and average JP-4. Smoke point and hydrogen content are closely related, and they show a favorable trend. High hydrogen content/smoke point fuels have good combustion properties, lead to longer combustor life and result in less smoke emissions.

Net Heat of Combustion was higher on a gravimetric basis as a result of the lower average density. The thermal stability remained nearly the same.

2. 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 required by design 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 in cases of low lubricity fuel can even result in fuel pump failure.

The lubricity of the fuel samples was evaluated using the modified Furey Ball-on-Cylinder Lubricity Evaluator (BOCLE) test rig (Reference 5). The test consists of contacting a stationary, loaded test ball perpendicular to a rotating cylinder. The cylinder and ball are located in a rectangular test cell, and the cylinder is approximately one-third immersed 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 applied load, 240 rpm cylinder speed, dry air environment with 0.5 L/m indirect purging, and 25°C fuel temperature. The lubricity of the fuel is evaluated by measuring the average wear scar diameter (WSD) 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 marginally acceptable if the average diameter of the wear scar is less than 0.45 mm.

The results of lubricity tests for 13 of the 16 fuel samples analyzed are presented in Table 5 and Figure 1. A fuel lubricity problem would be one of the most likely ways in which a fuel could cause fuel pump failure, thus these data were thoroughly studied.

The wear scar diameters of the 13 samples ranged between 0.259 mm and 0.455 mm, with an average wear scar diameter of 0.38 mm. This average is the same as that for the US F100 samples. However, three of the fuel samples had suspect wear scars. The samples from the two Saudi Arabian bases and the sample from Denmark had wear scars of 0.455, 0.443, and 0.44 respectively. These are higher than normally seen

TABLE 5

LUBRICITY ANALYSES

Fuel Sample	Average WSD (mm)
<u>JP-4 fuels</u>	
1. Inshas, Egypt	N/A
2. Inshas, Egypt	N/A
3. Egypt	N/A
4. King Fahad, Saudi Arabia	0.455
5. King Aziz, Saudi Arabia	0.443
6. Japan	0.335
7. Pakistan	0.383
8. Beauvechain, Belgium	0.39
9. Kleine Brogen, Belgium	0.35
10. Skrydstru, Denmark	0.44
11. Bodo, Norway	0.333
12. Rygge, Norway	0.338
<u>JP-8 fuels</u>	
13. Egypt	0.414
14. Venezuela	0.259
15. Leeuwarden, The Netherlands	0.43
16. Volkel, The Netherlands	0.34

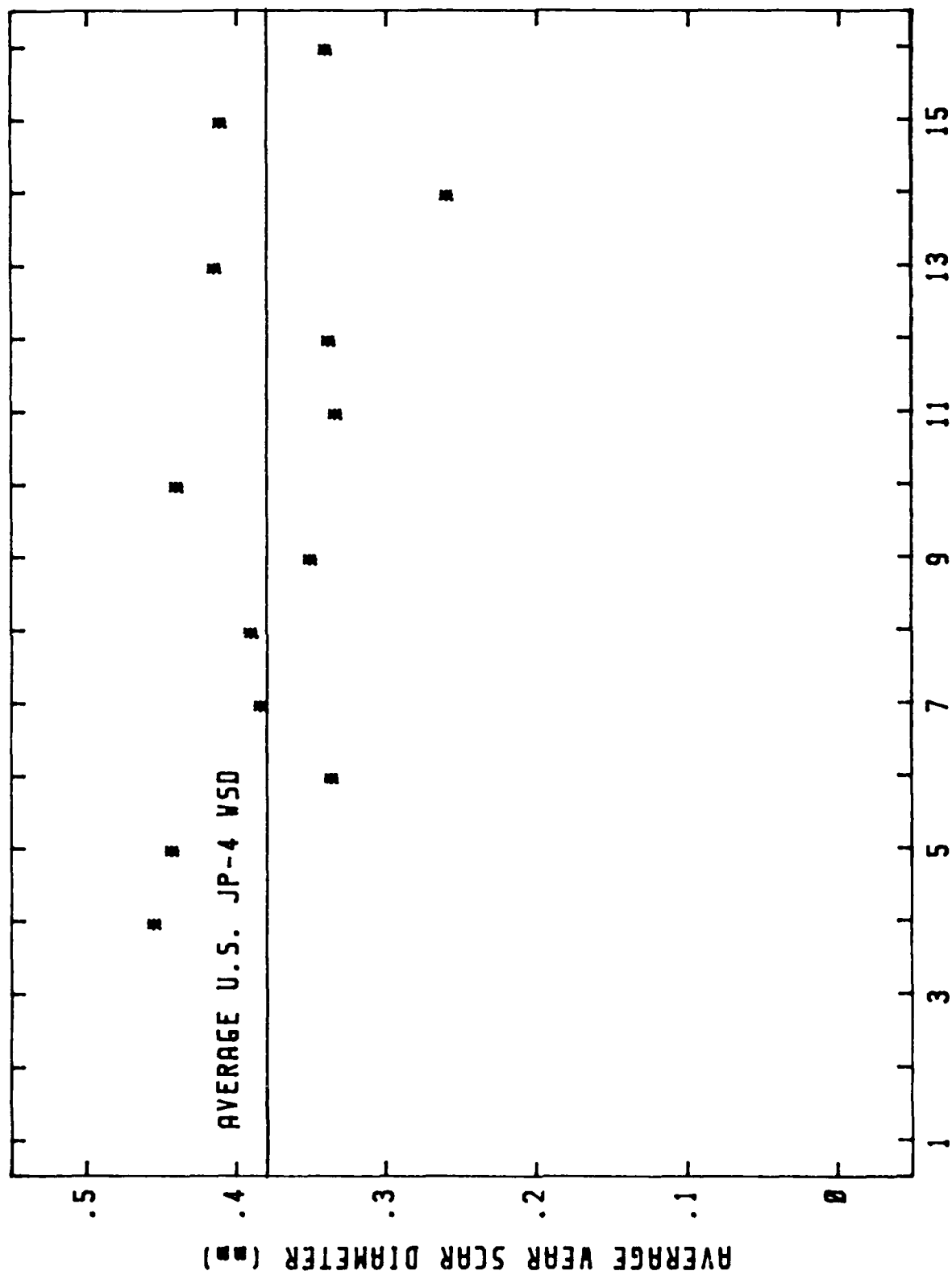


Figure 1. Lubricity Results

for JP-4 (0.35 - 0.40 mm). These high wear scar diameters suggest a possibly low corrosion inhibitor content. Corrosion inhibitor enhances the lubricating qualities of jet fuel, in addition to preventing corrosion of fuel system components. Insufficient amount of corrosion inhibitor can result in decreased life of engine components, such as the fuel pump. However, it must be kept in mind that the BOCLE test is not a specification requirement, thus its results cannot be used to rate a fuel unacceptable.

As in the previous discussion on additives, low level of corrosion inhibitor can be easily remedied by utilizing the "additive package" recommended by MIL-T-5624L.

The Pakistani sample, which had no anti-icing additive or antistatic additive had adequate lubricity. None of the other fuel samples appeared to have any adverse lubricity characteristics that might cause fuel pump problems.

3. CHARACTERIZATION TESTS

a. Description

Monsanto Research Corporation, Dayton Laboratory, performed a series of characterization tests (Reference 6). These tests were not necessarily specification tests, and were initiated to provide additional information about the fuel samples aside from 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

(1) Physical Properties as a Function of Temperature

The physical properties specification tests performed by the Quality Control Laboratory are generally performed at one specific temperature and the

results are evaluated according to the pass/fail criteria provided by either MIL-T-5624L or MIL-T-83133A. 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 thus 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°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, 100, and 140°F using ASTM D 445. This 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°F using a pyrex dilatometer. The method consisted 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 6). The density was then plotted as a function of temperature.

The surface tension was measured at 32, 70, 100, and 140°F using the capillary rise method (Reference 6). The surface tension was calculated using the following expression:

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

- d = density of liquid, g/cm³
- h = height of column of liquid, cm
- g = acceleration of gravity, cm/sec
- r = radius of the capillary, cm
- θ = contact angle, degrees

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

(2) Simulated Distillation

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

(3) Hydrocarbon Type Analysis

This test identifies hydrocarbon types in fuel samples. Information provided includes weight percent paraffins, cycloparaffins, dicycloparaffins, alkylbenzenes, indans and tetralins, indenenes 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 D 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.

(4) Thermal Conductivity Analysis

Monsanto Research Corporation measured the thermal conductivity of two of the fuel samples. The thermal conductivity of a fuel is that thermal property which controls the rate at which heat can flow by conduction through the fuel. A fuel with low thermal conductivity may not be able to perform as a "heat sink" in aircraft, thus possibly causing thermal stability problems.

The thermal conductivity was determined using a transient hot wire apparatus built by Monsanto Research Corporation, St. Louis. 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 6). The remaining 14 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 might cause fuel pump cavitation.

(5) Specific Heat

The specific heat of nine 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 $\pm 7\%$, 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 7).

b. Results

Characterization test results can be found in Appendix B.

(1) Physical Properties

(a) Vapor Pressure

Monsanto evaluated the vapor pressure as a function of temperature of 14 of the 16 samples. Some difficulties were encountered when measuring the vapor pressure of the samples from Bodo and Rygge, thus no vapor pressure data are presented for these samples.

The vapor pressure of the fuel samples as a function of temperature was compared to the typical vapor pressure of JP-4 or JP-8 as a function of temperature (Reference 8).

The average foreign JP-4 samples had lower vapor pressures than the average US F100 JP-4 sample, with one exception: the foreign JP-4 had higher than typical JP-4 vapor pressure at 0°C. Samples with particularly poor vapor pressure included the two JP-4 fuels from Inshas, the Egyptian JP-4, and Pakistani fuels. Theoretically, the lower than average vapor pressure could lead to increased fuel pump cavitation. However, this correlation is generally valid at sea level condition, and may not be applicable to the aircraft's entire range.

The JP-8 samples had very low vapor pressure, as expected. Since, as stated previously, lower vapor pressure fuels may lead to increased pump cavitation, the use of JP-8 in the F100 engine could lead to increased pump cavitation. However, it must be stressed again that this correlation may not apply throughout the aircraft's entire operating range.

(b) Kinematic Viscosity

Monsanto also measured the kinematic viscosity as a function of temperature of the 16 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 8). All the JP-8 samples met the viscosity specifications (8 cS maximum at -20°C). The kinematic viscosity as a function of temperature of the F100 JP-8 samples was also compared to typical JP-8 viscosity measurements (Reference 8).

The average foreign F100 sample has higher kinematic viscosity than the average JP-4 US F100 sample and typical JP-4. However, this high average was mainly caused by a few samples; most of the fuels had typical kinematic viscosity. All the Egyptian JP-4 samples and the Pakistani sample had exceptionally high kinematic viscosity. The Pakistani sample had a kinematic viscosity profile which more closely resembled JP-8 than JP-4. The higher than typical viscosity, especially at low temperatures, is likely to decrease fuel pumpability, and thus could lead to increased pump failures. However, since the F100 fuel pump is designed to operate on JP-8, these fuels should not result in unusual operational problems.

All F100 JP-8 fuel samples had lower average viscosity at low temperatures than typical JP-8 fuel. On the other hand, the samples had higher average viscosity at high temperatures. High kinematic viscosity affects fuel pumpability more at the lower temperatures than at the higher temperatures. Thus, since the F100 JP-8 samples have better than typical pumpability at low temperatures, they are less likely to cause fuel pump failures.

(c) Density

The average density of the foreign JP-4 F100 samples is slightly higher than the average density of typical JP-4 and US F100 JP-4. Again, the Egyptian and Pakistani samples were the cause of the high average. However, the density of all the samples is below typical JP-8 density. Since the F100 pump is designed to operate on JP-8, none of the JP-4 fuel samples should lead to unusual operational problems.

The density of the JP-8 samples was lower than that of typical JP-8 fuel. No unusual problems were noted.

(d) Surface Tension

Low surface tension favors the atomization and ignition of fuel droplets (Reference 7). Monsanto measured the surface tension of the 16 foreign F100 samples versus temperature, and results were compared with typical JP-4 and JP-8 surface tensions at varying temperatures.

The average surface tension of the JP-4 samples is higher than the typical surface tension of JP-4 and the average US F100 JP-4 sample. Again, the Egyptian samples and the Pakistani sample are responsible for the high

average. The high surface tension 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.

(2) Thermal Properties

(a) Thermal Conductivity Analyses

Thermal conductivity analyses were only performed on two JP-4 fuel samples. The results were compared to the typical thermal conductivity values of JP-4 and the average US F100 JP-4. No unusual characteristics were noted.

(b) Specific Heat

The specific heat as a function of temperature of seven of the foreign JP-4 and two of the foreign JP-8 F100 samples was calculated and compared to typical JP-4 and average US F100 JP-4 specific heat and typical JP-8 specific heat at various temperatures. All foreign F100 samples had lower than typical specific heat. The lower specific heat would indicate a tendency towards poorer thermal stability, but not towards increased fuel pump cavitation problems.

(3) Chemical Composition

(a) Boiling Point Distribution

The simulated distillation data was obtained by Monsanto for 15 of the 16 foreign F100 samples. No simulated distillation data are reported for the Bodo sample, since some difficulty was encountered during this test.

No abnormalities are noted in the distillation curves, with the exception of the curves for the two Inshas samples, the Egyptian JP-4, and the Rygge samples. These four samples failed the boiling point distribution specifications, and their distillation curves have higher slopes than normal JP-4 distillation curves.

(b) Hydrocarbon Type Analyses

Hydrocarbon type analyses were performed by both modified ASTM D 2789-71 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 indenes and dihydronaphthalenes.

The average paraffin content for the JP-4 samples was 56.1 wt%, with values ranging from 64.8 wt% for the King Aziz sample to 49.2 wt% for the Inshas #1 sample. The average cycloparaffin content was 27.4 wt%, with values ranging from 34.7 wt% for the Egyptian JP-4 sample to 16.9 wt% for the king Aziz sample. The dicycloparaffin content was low, ranging from 0 wt% for several samples (all the Egyptian and the Rygge samples) to 5.3 wt% for the Skrydstru sample. As compared to the average US F100 JP-4, the foreign samples generally have higher normal paraffins and lower cycloparaffins. However, total paraffin content is nearly identical.

The JP-8 samples' average paraffin content was 44.5 wt%, with the Venezuelan sample having a rather low paraffin content of 38.3 wt%. The average cycloparaffin content was 36.3 wt% and the average dicycloparaffin content was 0.2 wt%. Total average paraffins was 81.0 wt%. The higher than JP-4 cycloparaffin content accounts for some of the higher density of JP-8.

The average alkylbenzene content for the JP-4 samples was 12.6 wt%. Values range from 16.0 wt% for the Bodo sample to 9.5 wt% for the Skrydstru sample. The indans and tetralins content was low, averaging 1.7 wt%. Values ranged from 3.0 wt% for the Rygge sample to 0.4 wt% for the Bodo sample. The naphthalene content was also low. The average naphthalene content was 1.0 wt%, with values ranging 2.2 wt% for the Inshas #1 sample to 0.1 wt% for the Skrydstru sample. The total aromatic content of the foreign F100 JP-4 samples is nearly identical to that of the average US F100 JP-4 sample. The European samples normally had lower total aromatic content.

The JP-8 samples' average alkylbenzene content was 12.6 wt%. The average indans and tetralins content was 4.0 wt% and the average naphthalene content was 2.8 wt%. The average total aromatic content was 19.4 wt%. The higher than average JP-4 aromatic content would again account for the higher density of JP-8.

No unusual trends were noted in the hydrocarbon type analyses. However, the three Egyptian JP-4 samples were not "typical". They had lower than typical normal-paraffin content, and higher than typical aromatic content. In fact, these samples resembled JP-8 in several other ways (viscosity, density, surface

tension). However, in all cases, properties fell between those typical of JP-4 and those typical of JP-8. Therefore, it is impossible to accurately state that the Egyptian samples were JP-8, rather than JP-4. In the case of the Pakistani sample, physical properties resembled JP-8, but hydrocarbon types resembled JP-4. In any case, even though the Egyptian and Pakistani samples are unusual, their properties should not be contributing to increased pump failure, as the F100 engine is qualified to operate on JP-8.

SECTION IV

CONCLUSIONS

Due to fuel pump cavitation problems experienced in the F-15/F-16 aircraft, 16 fuel samples from 9 F-15 and F-16 Foreign National Air Bases were thoroughly analyzed to possibly identify fuel properties that might contribute to increased fuel pump cavitation and/or fuel pump failure. The analyses performed did not yield any conclusive results that would indicate that the fuels being presently used at Foreign National Air Bases have any inherent characteristics that contribute to fuel pump cavitation or failure.

Only three areas resulted in fuels not meeting specification requirements: Boiling Point Distribution (four failures), Electrical Conductivity (three failures), and FSII (four failures).

FSII and Electrical Conductivity failures are not indicative of characteristics likely to cause fuel pump failure. These failures are indicative of lack of additives, a problem which is easily remedied by blending the "additive package" recommended by MIL-T-5624L and MIL-T-83133A into the fuel. The fuels that failed Boiling Range distribution specifications could theoretically have a tendency to increase fuel pump cavitation. However, the inversely proportional relationship between pump cavitation and vapor pressure (which is closely related to Boiling Range distribution) is generally valid at sea level conditions. At other operating altitudes, this relation may not be valid, thus the Boiling Range distribution failures may not cause a pump cavitation problem.

The characterization tests showed no unusual fuel properties that might lead to fuel pump failures. Most of the JP-4 samples had vapor pressure, kinematic viscosity, surface tension, and density as a function of temperature comparable to typical JP-4. A few samples had lower than typical vapor pressure, and higher than typical kinematic viscosity, surface tension and density. However, all the properties were similar to those of JP-8, and since the F100 engine is qualified to operate on JP-8, the unusual fuels should cause no operational problems. All the JP-8 samples had properties similar to typical JP-8, thus should cause no operational problems. Hydrocarbon type analyses also revealed no exceptional trends for any of the samples, with the exception that some of the JP-4 samples resembled JP-8.

Lubricity tests indicated that most of the samples had adequate lubricating qualities. However, three samples had results which indicated a possible lack of sufficient corrosion inhibitor additive, thus low lubricity. Since poor lubricity fuel is often blamed for fuel pump failures, these samples may present a problem. However, the lubricity test results were "borderline" and it is possible that the fuels did have corrosion inhibitor. In any case, lack of corrosion inhibitor is easily remedied by blending the previously mentioned additive package into the fuel.

Overall, most of the foreign JP-4 and JP-8 samples analyzed for the F100 fuel sampling program were well within specifications. The fuels were generally better than "typical" JP-4 and comparable to US operational JP-4. The JP-8 samples were also comparable to typical JP-8. With the exception of the fuels that lacked additives, none of the fuels used at the Foreign National Air Bases surveyed should be contributing to operational problems in the F100 fuel pump.

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 US Air Force (which are also generally followed by foreign countries using US aircraft) are as viable as they were when the chemical and physical properties of JP-4 for 1980-1981 were published (Reference 3).

SECTION V

RECOMMENDATIONS

The recommendations derived from this report are identical to those derived from the first F100 analyses report.

Since analyzing fuel samples has not offered any clues to the fuel pump cavitation problem, it is recommended that the cavitation problem be studied at a more fundamental level. Fuel pump tests should be conducted to determine if any fuel characteristics not limited by the specification can be causing fuel pump failure.

This analysis is an excellent survey of operational fuels. It does serve to identify problems such as lack of additives. 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 built into the design of the pump, rather than the result of the fuel used. A different approach must be taken to resolve the F100 fuel pump failure problem.

Since a lack of additives problem was identified in several fuels, it was recommended that the additive package be added to these fuels. Once the additive problem was identified, the proper authorities were immediately advised of the problem. It is the Fuel's Branch understanding that additives are now being used at all the problem Air Bases. It is again stressed that the recommended additives should continue to be used to prevent future potential operational problems.

APPENDIX A
SPECIFICATION ANALYSES

TABLE A-1
SAYBOLT COLOR

FUEL (JP-4)	SAYBOLT COLOR
-----	-----
Spec: No Limit	
1. Inshas, Egypt	N/A
2. Inshas, Egypt	N/A
3. Egypt	N/A
4. King Fahad, Saudi Arabia	30
5. King Aziz, Saudi Arabia	30
6. Japan	30
7. Pakistan	30
8. Beauvechain, Belgium	21
9. Kleine Brogen, Belgium	27
10. Skrydstru, Denmark	30
11. Bodo, Norway	30
12. Rygge, Norway	27
Mean:	28 +/- 3

FUEL (JP-8)	SAYBOLT COLOR
-----	-----
Spec: No Limit	
1. Egypt	26
2. Venezuela	N/A

TABLE A-2
TOTAL ACID NUMBER ANALYSES

FUEL (JP-4)	TOTAL ACID (mg KOH/gm)
Spec: 0.015 mg KOH/g maximum	
1. Inshas, Egypt	N/A
2. Inshas, Egypt	N/A
3. Egypt	N/A
4. King Fahad, Saudi Arabia	0.002
5. King Aziz, Saudi Arabia	0.001
6. Japan	0.006
7. Pakistan	0.003
8. Beauvechain, Belgium	0.003
9. Kleine Brogen, Belgium	0.005
10. Skrydstru, Denmark	0.002
11. Bodo, Norway	0.002
12. Rygge, Norway	0.004
Mean:	0.003 +/- 0.002

FUEL (JP-8)	TOTAL ACID (mg KOH/gm)
Spec: 0.015 mg KOH/gm maximum	
1. Egypt	0.005
2. Venezuela	N/A
3. Leeuwarden, Netherlands	0.004
4. Volkel, Netherlands	0.003

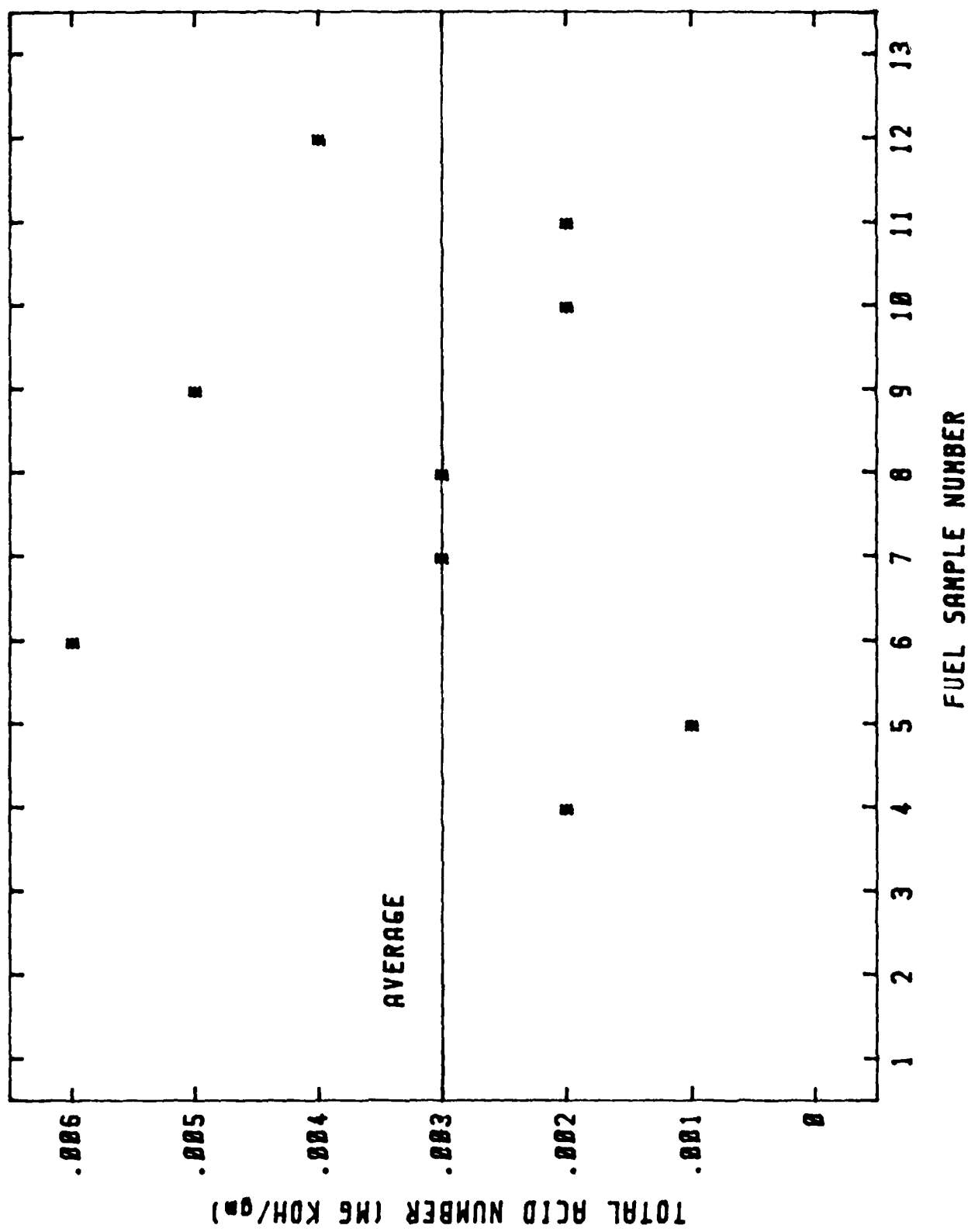


Figure A-1. Total Acid Number

TABLE A-3
VOLUME PERCENT AROMATICS ANALYSES

FUEL (JP-4)	VOL % AROMATICS
-----	-----
Spec: 25 vol % maximum	
1. Inshas, Egypt	N/A
2. Inshas, Egypt	N/A
3. Egypt	N/A
4. King Fahad, Saudi Arabia	13.5
5. King Aziz, Saudi Arabia	14.5
6. Japan	13.4
7. Pakistan	14.3
8. Beauvechain, Belgium	13.3
9. Kleine Brogen, Belgium	12.3
10. Skrydstru, Denmark	11.7
11. Bodo, Norway	14.4
12. Rygge, Norway	14.8
Mean:	13.6 +/- 1.0

FUEL (JP-8)	VOL % AROMATICS
-----	-----
Spec: 25.0 vol % maximum	
1. Egypt	16.3
2. Venezuela	N/A
3. Leeuwarden, Netherlands	15.6
4. Volkel, Netherlands	20.8

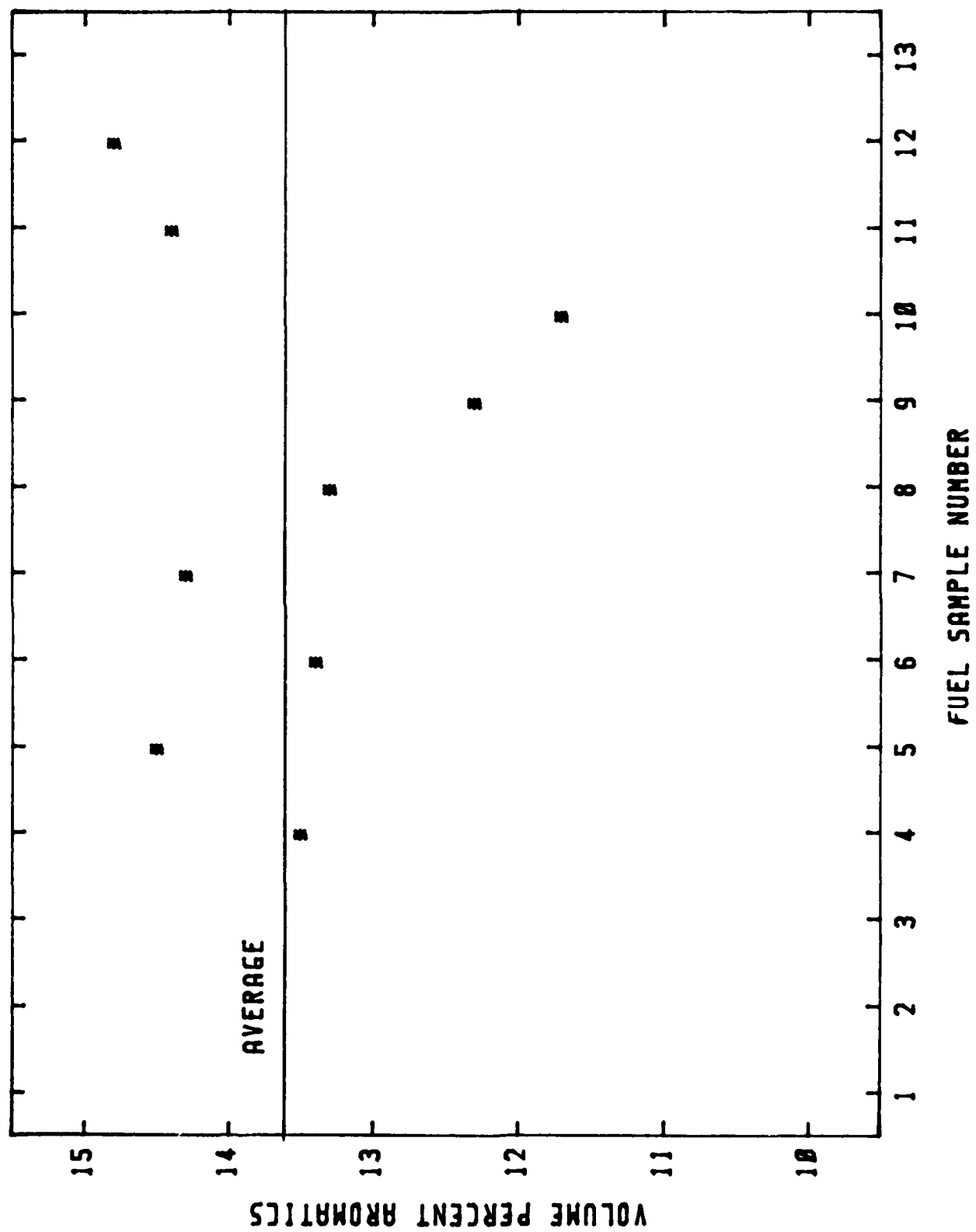


Figure A-2. Volume Percent Aromatics

TABLE A-4
VOLUME PERCENT OLEFINS ANALYSES

FUEL (JP-4)	VOL% OLEFINS
-----	-----
Spec: 5 vol % maximum	
1. Inshas, Egypt	N/A
2. Inshas, Egypt	N/A
3. Egypt	N/A
4. King Fahad, Saudi Arabia	0.5
5. King Aziz, Saudi Arabia	0.5
6. Japan	0.8
7. Pakistan	0.7
8. Beauvechain, Belgium	0.7
9. Kleine Brogen, Belgium	0.7
10. Skrydstru, Denmark	0.7
11. Bodo, Norway	0.7
12. Rygge, Norway	0.9
Mean:	0.7 +/- 0.1

FUEL (JP-8)	VOL% OLEFINS
-----	-----
Spec: 5 vol % maximum	
1. Egypt	0.8
2. Venezuela	N/A
3. Leeuwarden, Netherlands	0.7
4. Volkel, Netherlands	0.9

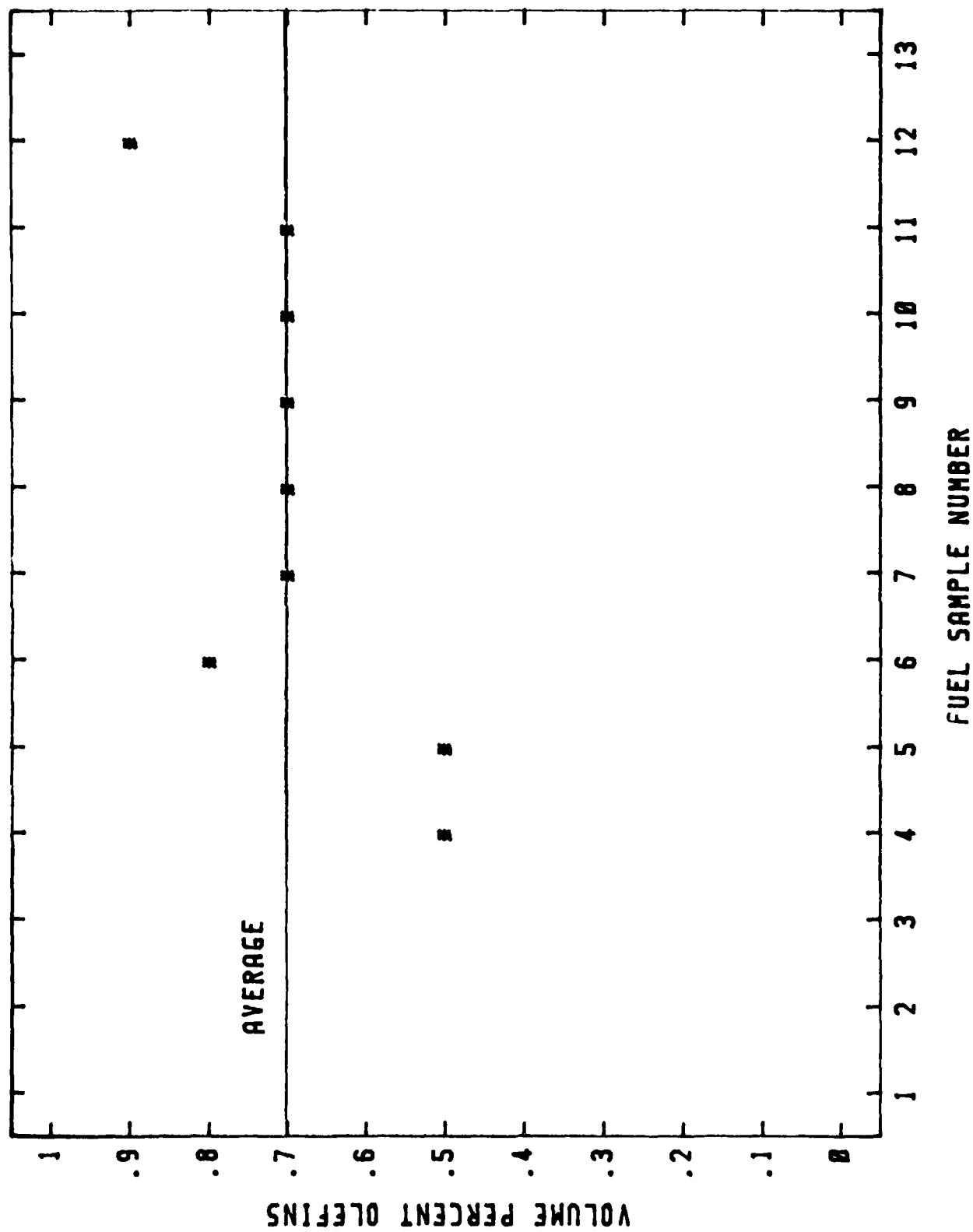


Figure A-3. Volume Percent Olefins

TABLE A-5
MERCAPTAN SULFUR ANALYSES

FUEL (JP-4)	MERCAPTAN SULFUR wt %
-----	-----
Spec: 0.001 wt % maximum	
1. Inshas, Egypt	N/A
2. Inshas, Egypt	N/A
3. Egypt	N/A
4. King Fahad, Saudi Arabia	0.0003
5. King Aziz, Saudi Arabia	0.0004
6. Japan	0.0000
7. Pakistan	0.0001
8. Beauvechain, Belgium	0.0002
9. Kleine Brogen, Belgium	0.0001
10. Skrydstru, Denmark	0.0000
11. Bodo, Norway	0.0001
12. Rygge, Norway	0.0000
Mean:	0.0001 +/- 0.0001

FUEL (JP-8)	MERCAPTAN SULFUR wt %
-----	-----
Spec: 0.001 wt % maximum	
1. Egypt	0.0000
2. Venezuela	N/A
3. Leeuwarden, Netherlands	0.0001
4. Volkel, Netherlands	0.0002

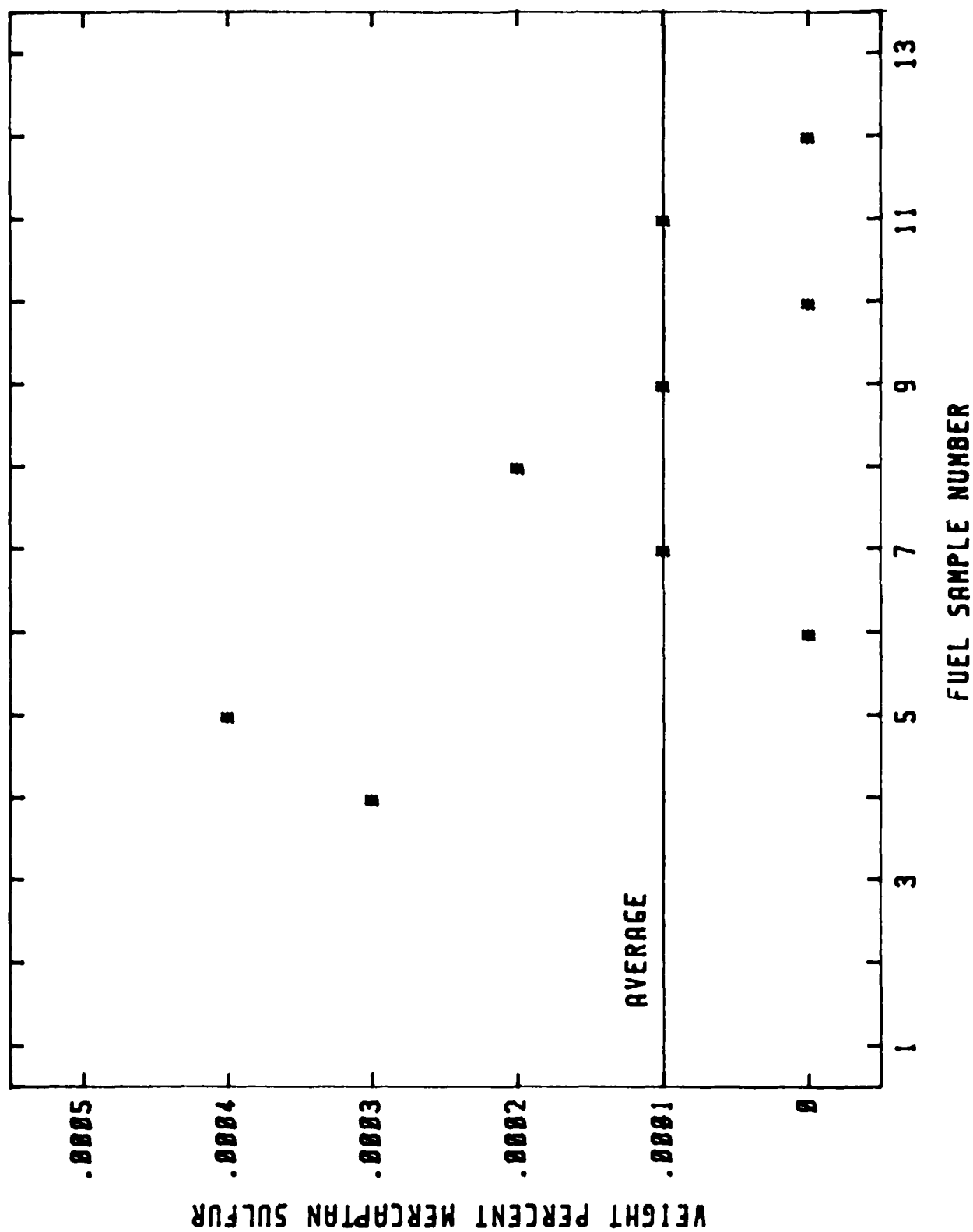


Figure A-4. Mercaptan Sulfur

TABLE A-6
TOTAL WEIGHT PERCENT SULFUR ANALYSES

FUEL (JP-4)	WT % SULFUR
-----	-----
Spec: 0.40 wt % maximum	
1. Inshas, Egypt	N/A
2. Inshas, Egypt	N/A
3. Egypt	N/A
4. King Fahad, Saudi Arabia	0.09
5. King Aziz, Saudi Arabia	0.13
6. Japan	0.02
7. Pakistan	0.05
8. Beauvechain, Belgium	0.03
9. Kleine Brogen, Belgium	0.03
10. Skrydstru, Denmark	0.01
11. Bodo, Norway	0.03
12. Rygge, Norway	0.00
Mean:	0.04 +/- 0.04

FUEL (JP-8)	WT % SULFUR
-----	-----
Spec: 0.3 wt % maximum	
1. Egypt	0.02
2. Venezuela	N/A
3. Leeuwarden, Netherlands	0.00
4. Volkel, Netherlands	0.00

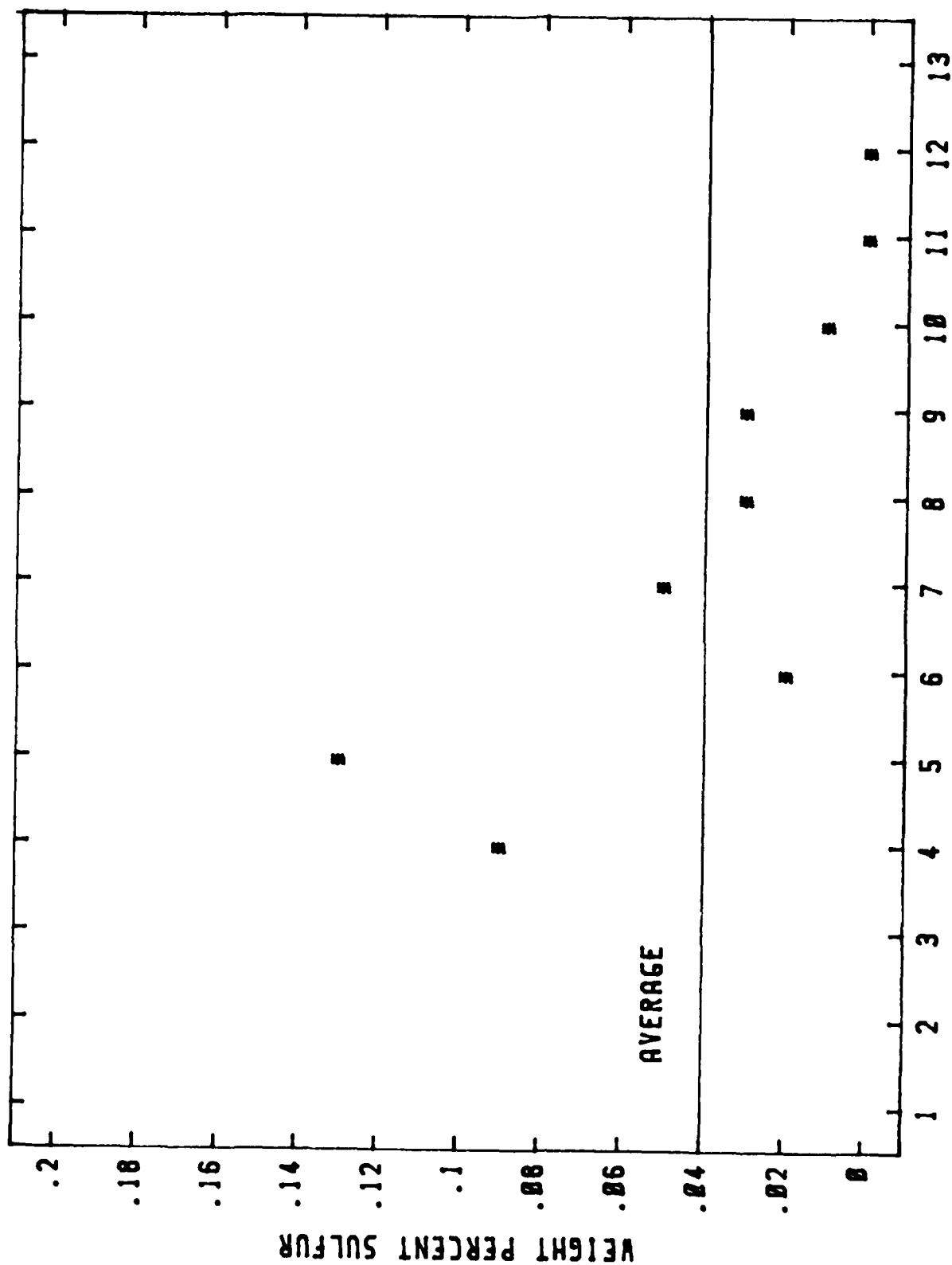


Figure A-5. Total Sulfur

TABLE A-7
 BOTLING RANGE DISTRIBUTION SPECIFICATIONS

ASTM D 2887 (JP-4)

SPECS: 20% recovered - 130 °C maximum
 50% recovered - 185 °C maximum
 90% recovered - 250 °C maximum
 FBP - 320 °C maximum

ASTM D 2887 (JP-8)

SPECS: 10% recovered - 186 °C maximum
 20% recovered - to be reported
 50% recovered - to be reported
 90% recovered - to be reported
 FBP - 330 °C maximum

TABLE A-8
SIMULATED DISTILLATION ANALYSES

FUEL (JP-4)	IBP ⁰ C		10 ⁰ C		20 ⁰ C	
	SFTLA	MONSANTO	SFTLA	MONSANTO	SFTLA	MONSANTO
1. Inshas, Egypt	N/A	98	N/A	149	N/A	161
2. Inshas, Egypt	N/A	98	N/A	149	N/A	160
3. Egypt	N/A	98	N/A	146	N/A	159
4. King Fahad, Saudi Arabia	24	31	68	70	98	100
5. King Aziz, Saudi Arabia	24	27	68	65	98	95
6. Japan	54	27	91	72	109	99
7. Pakistan	24	28	82	74	106	102
8. Beavechain, Belgium	24	29	73	57	99	14
9. Kleine Brogen, Belgium	26	29	70	66	92	91
10. Skrydstru, Denmark	-5	14	92	91	112	112
11. Bodo, Norway	-7	N/A	82	N/A	97	N/A
12. Rggve, Norway	24	37	82	87	116	119
					Mean:	130

FUEL (JP-8)	IBP ⁰ C		10 ⁰ C		20 ⁰ C	
	SFTLA	MONSANTO	SFTLA	MONSANTO	SFTLA	MONSANTO
1. Egypt	99	98	144	150	160	164
2. Venezuela	N/A	130	N/A	164	N/A	175
3. Leeuwarden, Netherlands	116	118	163	162	175	175
4. Volkel, Netherlands	93	92	150	149	169	166

TABLE A-8 (Concluded)

FUEL (JP-4)	50% °C		90% °C		FBP °C	
	SFTLA	MONSANTO	SFTLA	MONSANTO	SFTLA	MONSANTO
1. Inshas, Egypt	N/A	189	N/A	235	N/A	264
2. Inshas, Egypt	N/A	189	N/A	235	N/A	268
3. Egypt	N/A	189	N/A	243	N/A	345
4. King Fahad, Saudi Arabia	173	177	231	236	279	275
5. King Aziz, Saudi Arabia	174	171	232	231	279	284
6. Japan	163	157	232	230	273	275
7. Pakistan	149	150	227	230	265	278
8. Beavechain, Belgium	159	157	236	233	267	263
9. Kleine Brogen, Belgium	163	158	233	231	270	271
10. Skrydstrup, Denmark	164	162	234	232	283	268
11. Bodo, Norway	127	N/A	186	N/A	251	N/A
12. Rggve, Norway	186	187	226	225	286	264
Mean:	162		226		273	

FUEL (JP-8)	50% °C		90% °C		FBP °C	
	SFTLA	MONSANTO	SFTLA	MONSANTO	SFTLA	MONSANTO
1. Egypt	193	196	240	239	270	279
2. Venezuela	N/A	207	N/A	262	N/A	310
3. Leeuwarden, Netherlands	205	204	248	251	293	298
4. Volkel, Netherlands	196	194	244	241	284	272

TABLE A-9
VAPOR PRESSURE ANALYSES

FUEL (JP-4)	VAPOR PRESSURE (psi)
-----	SFTLA
Spec: 2 psi minimum; 3 psi maximum	
1. Inshas, Egypt	N/A
2. Inshas, Egypt	N/A
3. Egypt	N/A
4. King Fahad, Saudi Arabia	2.7
5. King Aziz, Saudi Arabia	2.6
6. Japan	2.5
7. Pakistan	2.6
8. Beauvechain, Belgium	2.7
9. Kleine Brogen, Belgium	2.6
10. Skrydstru, Denmark	2.5
11. Bodo, Norway	2.5
12. Rygge, Norway	2.2
Mean:	2.5 +/- 0.15

FUEL (JP-8)	VAPOR PRESSURE (psi)
-----	MONSANTO
Spec: Not Applicable	
1. Egypt	.35
2. Venezuela	.48
3. Leeuwarden, Netherlands	.42
4. Volkel, Netherlands	.82

TABLE A-10
API GRAVITY ANALYSES

FUEL (JP-4)	API GRAVITY
-----	-----
Spec Limits: 45.0 and 57.0	
1. Inshas, Egypt	N/A
2. Inshas, Egypt	N/A
3. Egypt	N/A
4. King Fahad, Saudi Arabia	55.3
5. King Aziz, Saudi Arabia	55.4
6. Japan	55.6
7. Pakistan	55.8
8. Beauvechain, Belgium	53.4
9. Kleine Brogen, Belgium	54.6
10. Skrydstru, Denmark	52.9
11. Bodo, Norway	55.6
12. Rygge, Norway	51.5
Mean:	54.5 +/- 1.5

FUEL (JP-8)	API GRAVITY
-----	-----
Spec: 37.0 and 51.0	
1. Egypt	47.0
2. Venezuela	N/A
3. Leeuwarden, Netherlands	45.6
4. Volkel, Netherlands	45.0

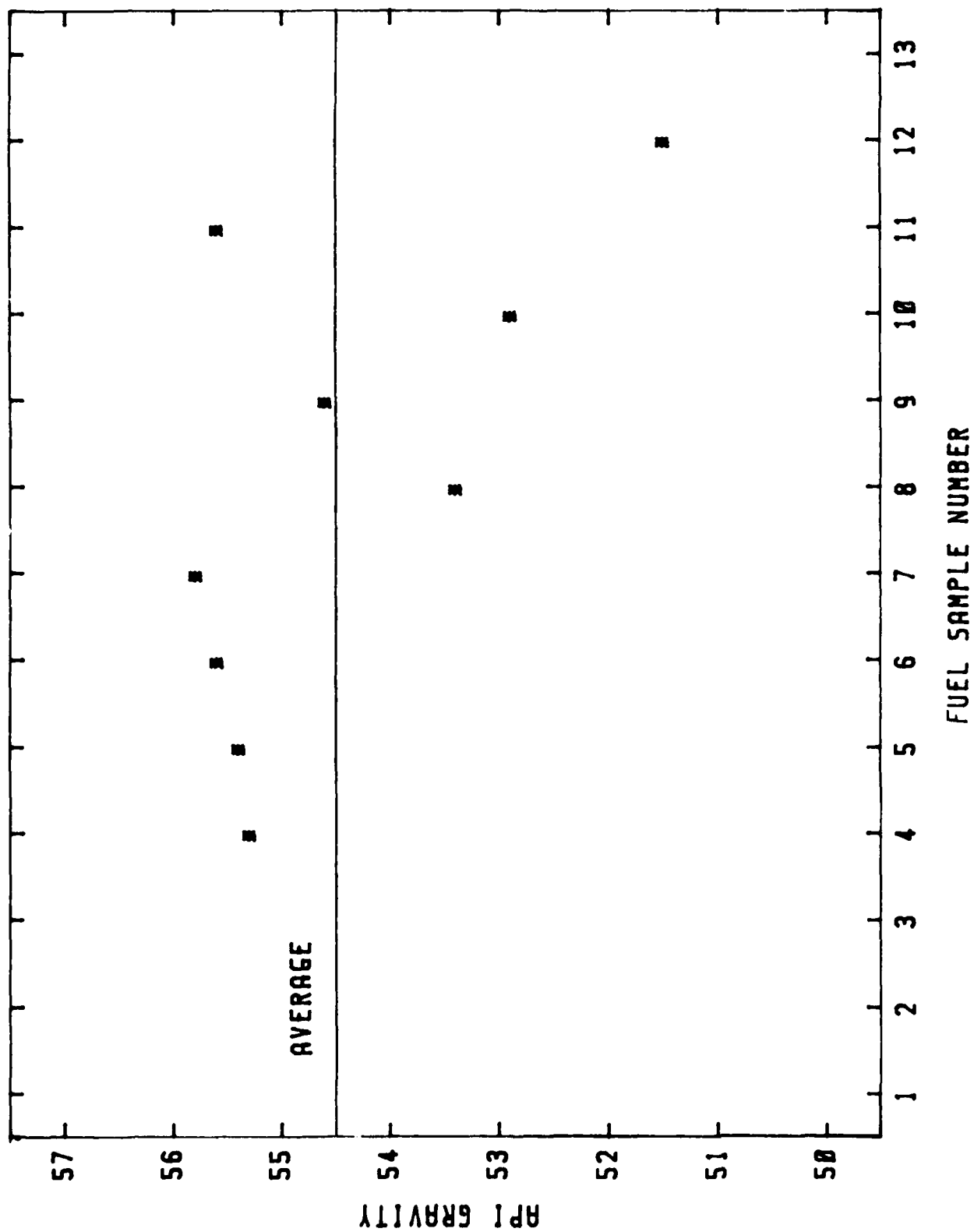


Figure A-6. API Gravity

TABLE A-11
FREEZING POINT ANALYSES

FUEL (JP-4)	FREEZING POINT (°C)
-----	-----
Spec: -58°C maximum	
1. Inshas, Egypt	N/A
2. Inshas, Egypt	N/A
3. Egypt	N/A
4. King Fahad, Saudi Arabia	-60
5. King Aziz, Saudi Arabia	-60
6. Japan	-63
7. Pakistan	-62
8. Beauvechain, Belgium	-65
9. Kleine Brogen, Belgium	-62
10. Skrydstru, Denmark	-60
11. Bodo, Norway	-73
12. Rygge, Norway	-63
Mean:	-63 +/- 4

FUEL (JP-8)	FREEZING POINT (°C)
-----	-----
Spec: -50°C maximum	
1. Egypt	-53
2. Venezuela	N/A
3. Leeuwarden, Netherlands	-56
4. Volkel, Netherlands	-67

TABLE A-12
VISCOSITY ANALYSES

FUEL (JP-4)	VISCOSITY SFTLA	(Cs @ -20°C) MONSANTO
Spec: No limit		
1. Inshas, Egypt	N/A	3.18
2. Inshas, Egypt	N/A	3.12
3. Egypt	N/A	1.73
4. King Fahad, Saudi Arabia	2.09	1.85
5. King Aziz, Saudi Arabia	1.95	1.81
6. Japan	1.80	1.70
7. Pakistan	1.89	1.80
8. Beauvechain, Belgium	2.01	1.77
9. Kleine Brogen, Belgium	1.84	1.76
10. Skrydstru, Denmark	2.28	1.98
11. Bodo, Norway	1.42	1.38
12. Rygge, Norway	2.24	2.19

Mean: 1.9 +/- 0.3

FUEL (JP-8)	VISCOSITY SFTLA	(Cs @ -20°C) MONSANTO
Spec: 8.0 maximum		
1. Egypt	3.50	3.40
2. Venezuela	N/A	4.20
3. Leeuwarden, Netherlands	4.46	4.10
4. Volkel, Netherlands	3.73	3.44

TABLE A-13
HEAT OF COMBUSTION ANALYSES

FUEL (JP-4) -----	NET HEAT OF COMBUSTION (MJ/kg)	
	SFTLA -----	MONSANTO -----
Spec: 42.8 MJ/kg minimum		
1. Inshas, Egypt	N/A	43.7
2. Inshas, Egypt	N/A	43.3
3. Egypt	N/A	43.3
4. King Fahad, Saudi Arabia	43.6	43.4
5. King Aziz, Saudi Arabia	43.6	43.4
6. Japan	43.6	43.6
7. Pakistan	43.6	43.6
8. Beauvechain, Belgium	43.5	43.3
9. Kleine Brogen, Belgium	43.6	43.5
10. Skrydstrup, Denmark	43.6	43.6
11. Bodo, Norway	43.6	43.4
12. Rygge, Norway	43.6	43.6
Mean:	43.6 +/- .03	43.3 +/- 0.14

FUEL (JP-8) -----	NET HEAT OF COMBUSTION (MJ/kg)	
	SFTLA -----	MONSANTO -----
Spec: 42.8 MJ/kg minimum		
1. Egypt	43.4	43.3
2. Venezuela	N/A	43.4
3. Leeuwarden, Netherlands	43.4	43.4
4. Volkel, Netherlands	43.3	43.2

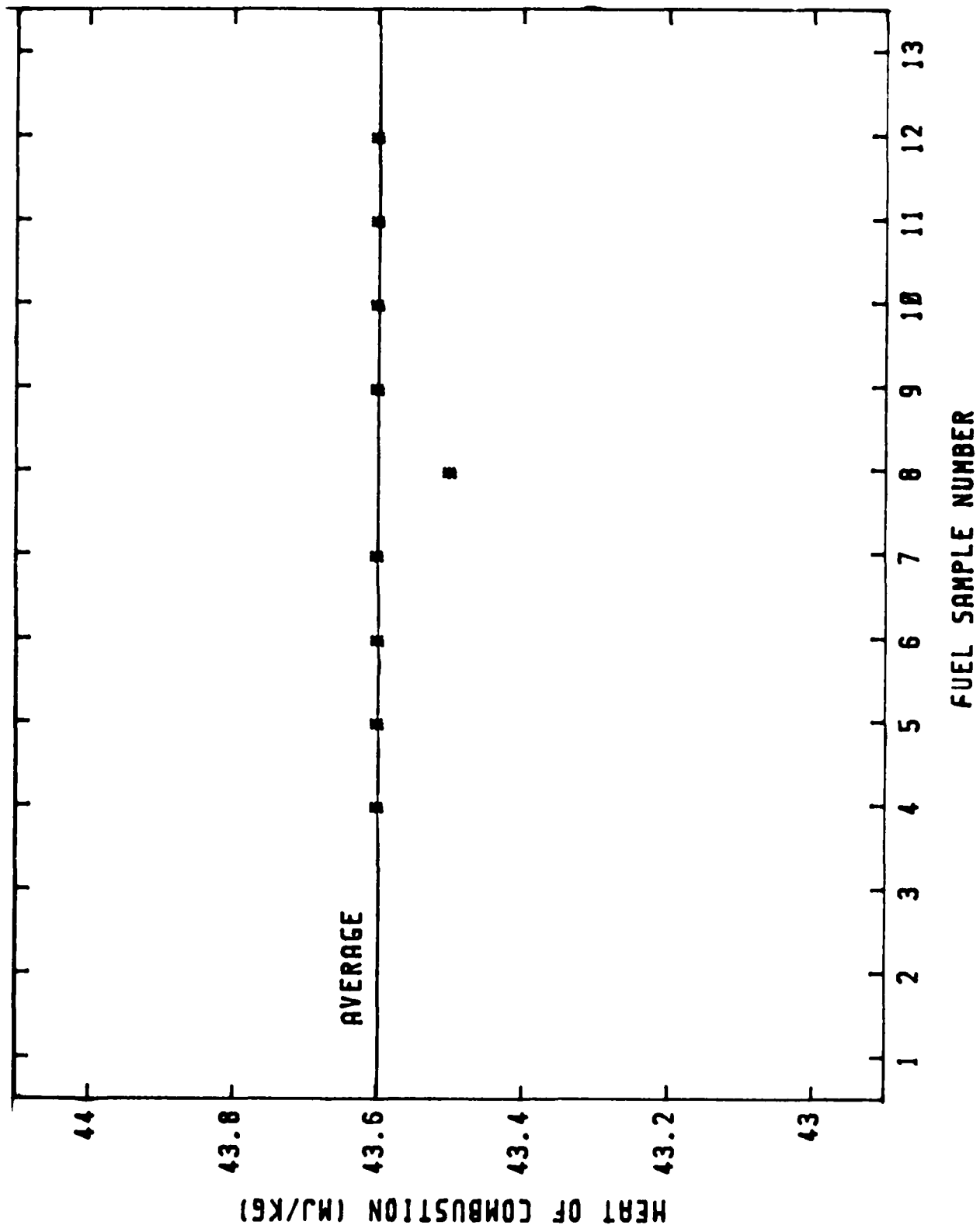


Figure A-7. Heat of Combustion

TABLE A-14
SMOKE POINT ANALYSES

FUEL (JP-4)	SMOKE POINT, mm
Spec: 20 mm minimum	
1. Inshas, Egypt	N/A
2. Inshas, Egypt	N/A
3. Egypt	N/A
4. King Fahad, Saudi Arabia	26
5. King Aziz, Saudi Arabia	26
6. Japan	27
7. Pakistan	28
8. Beauvechain, Belgium	27
9. Kleine Brogen, Belgium	27
10. Skrydstru, Denmark	27
11. Bodo, Norway	23
12. Rygge, Norway	28
Mean:	27 +/- 1

FUEL (JP-8)	SMOKE POINT, mm
Spec: 19 mm minimum	
1. Egypt	22
2. Venezuela	N/A
3. Leeuwarden, Netherlands	25
4. Volkel, Netherlands	22

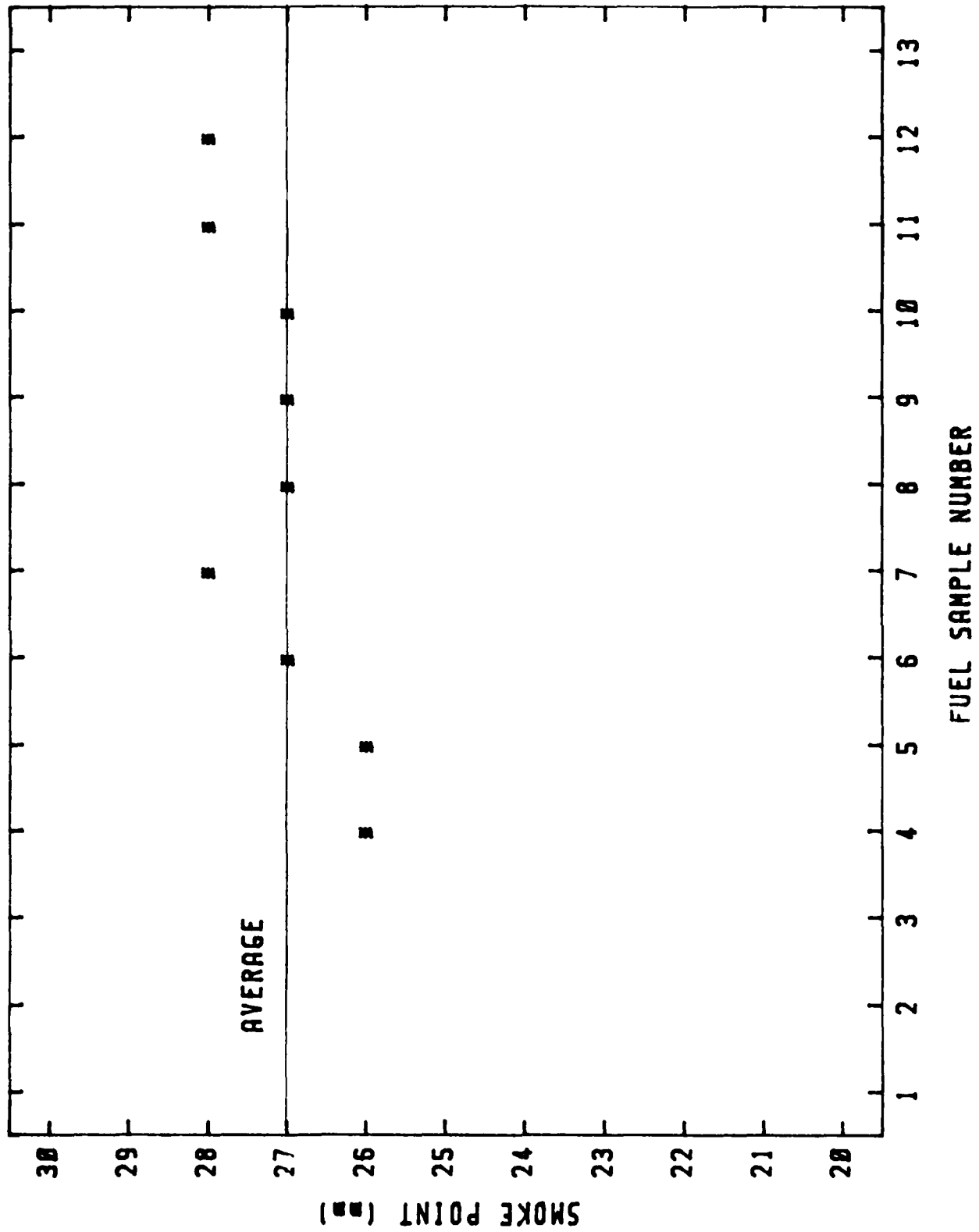


Figure A-8. Smoke Point.

TABLE A-15
HYDROGEN CONTENT ANALYSES

FUEL (JP-4)	SFTLA	POSF
-----	wt% H	wt% H
-----	-----	-----
Spec: 13.6 wt% minimum		
1. Inshas, Egypt	N/A	N/A
2. Inshas, Egypt	N/A	N/A
3. Egypt	N/A	14.0
4. King Fahad, Saudi Arabia	14.4	14.5
5. King Aziz, Saudi Arabia	14.4	14.5
6. Japan	14.5	14.4
7. Pakistan	14.4	14.4
8. Beauvechain, Belgium	14.3	14.3
9. Kleine Brogen, Belgium	14.4	14.4
10. Skrydstru, Denmark	14.4	14.3
11. Bodo, Norway	14.2	14.1
12. Rygge, Norway	14.3	14.2
Mean:	14.4 +/- .001	

FUEL (JP-8)	SFTLA	POSF
-----	wt% H	wt% H
-----	-----	-----
Spec: 13.5 wt% minimum		
1. Egypt	14.0	14.10
2. Venezuela	N/A	13.75
3. Leeuwarden, Netherlands	14.0	14.03
4. Volkel, Netherlands	13.8	13.74

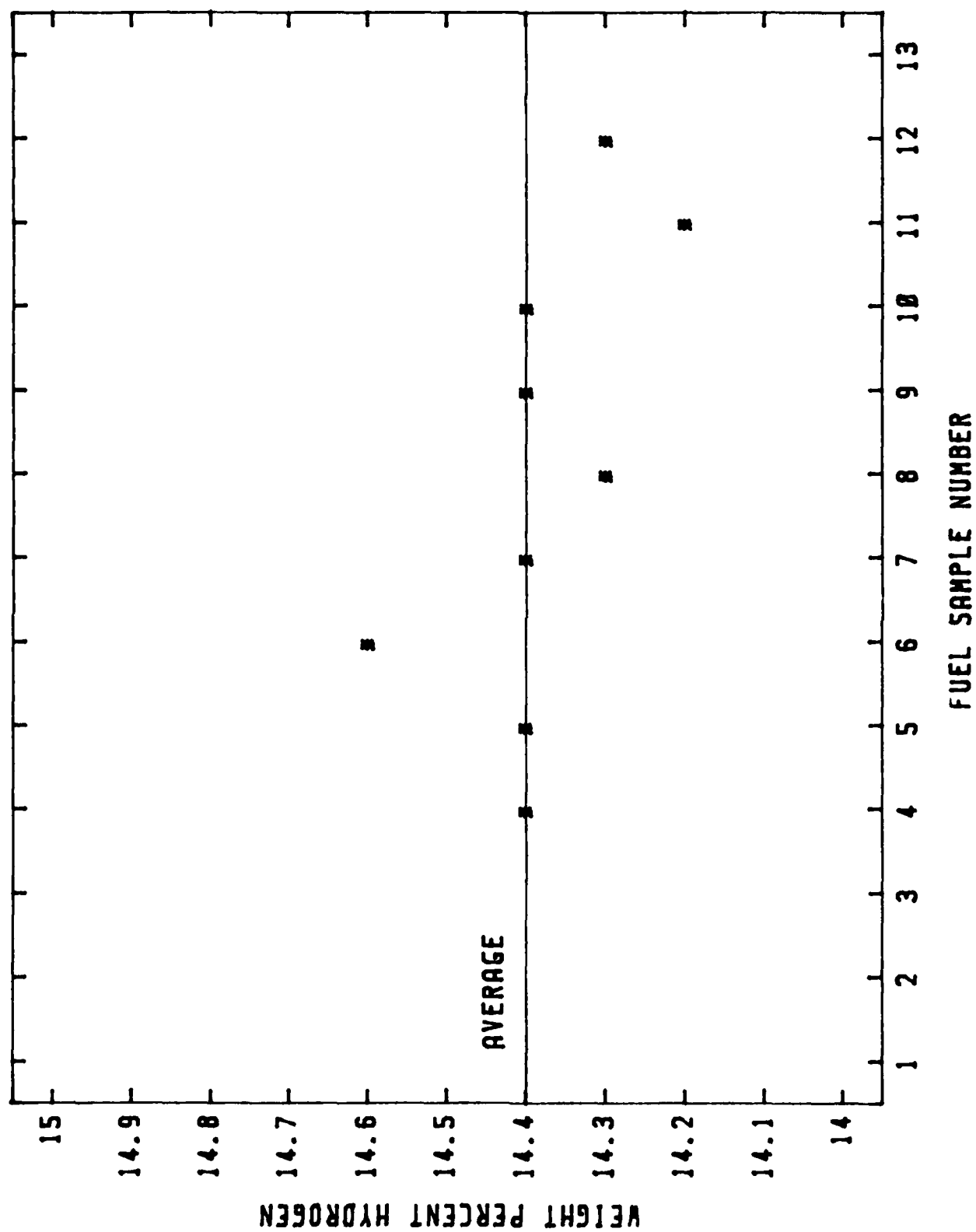


Figure A-9. Hydrogen Content

TABLE A-16
COPPER STRIP CORROSION ANALYSES

FUEL (JP-4)	COPPER STRIP CORROSION
-----	-----
Spec: 1B maximum	
1. Inshas, Egypt	N/A
2. Inshas, Egypt	N/A
3. Egypt	N/A
4. King Fahad, Saudi Arabia	1A
5. King Aziz, Saudi Arabia	1A
6. Japan	1A
7. Pakistan	1A
8. Beauvechain, Belgium	1A
9. Kleine Brogen, Belgium	1A
10. Skrydstru, Denmark	1A
11. Bodo, Norway	1A
12. Rygge, Norway	1A

FUEL (JP-8)	COPPER STRIP CORROSION
-----	-----
Spec: 1B maximum	
1. Egypt	1B
2. Venezuela	N/A
3. Leeuwarden, Netherlands	1A
4. Volkel, Netherlands	1A

TABLE A-17
THERMAL STABILITY ANALYSES

FUEL (JP-4)	ΔP mm Hg	PDC
Spec: $\Delta P = 25$ mm Hg maximum PDC < 3		
1. Inshas, Egypt	N/A	N/A
2. Inshas, Egypt	N/A	N/A
3. Egypt	N/A	1
4. King Fahad, Saudi Arabia	0	1
5. King Aziz, Saudi Arabia	0	1
6. Japan	0	1
7. Pakistan	0	1
8. Beauvechain, Belgium	0	1
9. Kleine Brogen, Belgium	0	1
10. Skrydstru, Denmark	0	1
11. Bodo, Norway	0	1
12. Rygge, Norway	0	1
Mean:	0	< 1

FUEL (JP-8)	ΔP mm Hg	PDC
Spec: $\Delta P = 25$ mm Hg maximum PDC < 3		
1. Egypt	N/A	N/A
2. Venezuela	N/A	N/A
3. Leeuwarden, Netherlands	0	1
4. Volkel, Netherlands	0	1

TABLE A-18
EXISTENT GUM ANALYSES

FUEL (JP-4)	EXISTENT GUM (mg/ml)
-----	-----
Spec: 7.0 mg/100 ml maximum	
1. Inshas, Egypt	N/A
2. Inshas, Egypt	N/A
3. Egypt	N/A
4. King Fahad, Saudi Arabia	0.0
5. King Aziz, Saudi Arabia	0.0
6. Japan	0.4
7. Pakistan	1.0
8. Beauvechain, Belgium	0.6
9. Kleine Brogen, Belgium	1.4
10. Skrydstru, Denmark	0.4
11. Bodo, Norway	0.2
12. Rygge, Norway	0.6

Mean: 0.5 +/- 0.5

FUEL (JP-8)	EXISTENT GUM (mg/ml)
-----	-----
Spec: 7.0 mg/100 ml maximum	
1. Egypt	0.0
2. Venezuela	N/A
3. Leeuwarden, Netherlands	0.4
4. Volkel, Netherlands	2.6

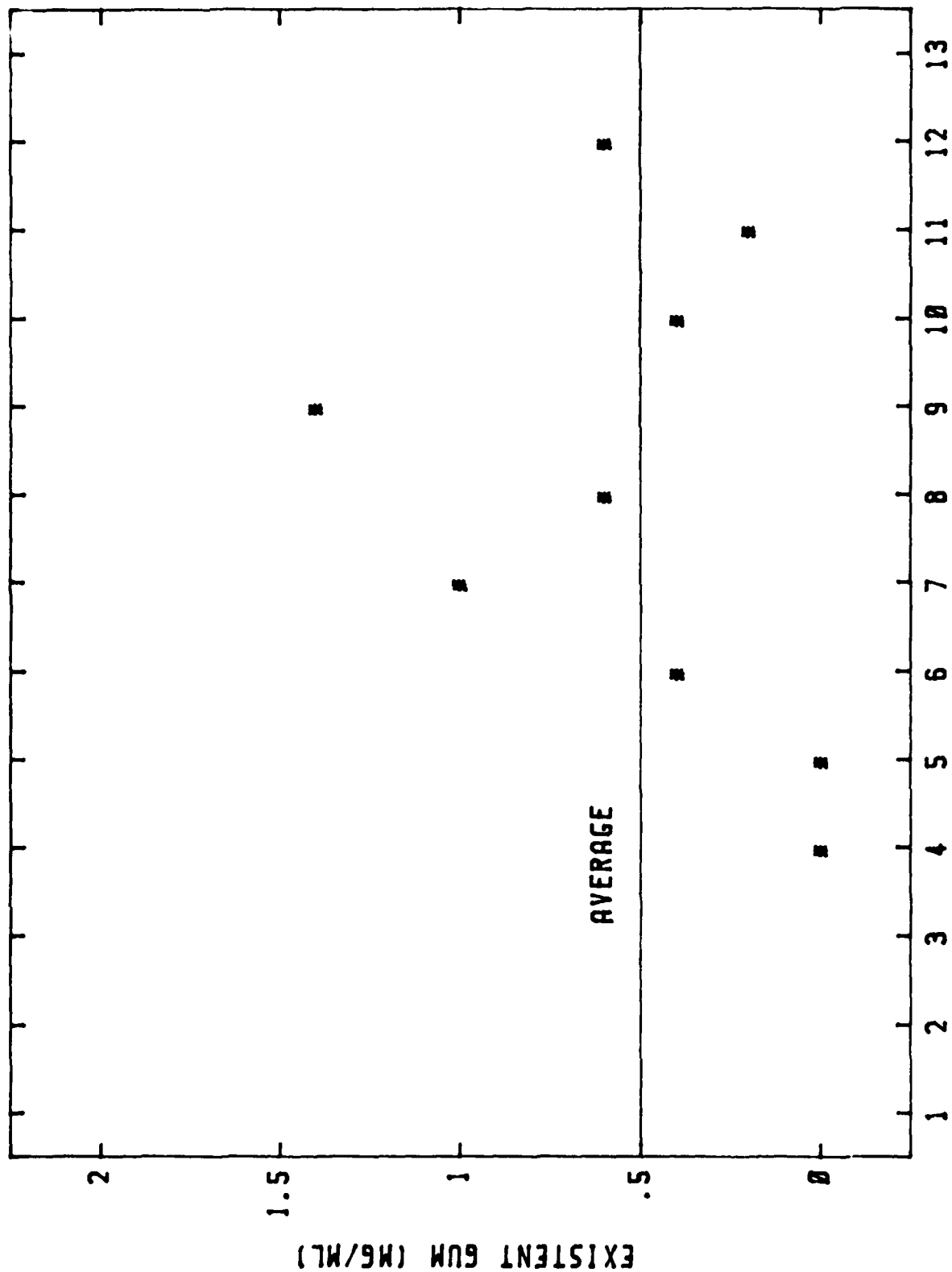


Figure A-10. Existent Gum

TABLE A-19
VOLUME PERCENT FUEL SYSTEM KING INHIBITOR ANALYSES

FUEL (JP-4)	VOL % FSII
-----	-----
Spec: 0.10 minimum, 0.15 maximum	
1. Inshas, Egypt	N/A
2. Inshas, Egypt	N/A
3. Egypt	N/A
4. King Fahad, Saudi Arabia	0.00
5. King Aziz, Saudi Arabia	0.00
6. Japan	0.16
7. Pakistan	0.01
8. Beauvechain, Belgium	0.16
9. Kleine Brogen, Belgium	0.14
10. Skrydstru, Denmark	0.15
11. Bodo, Norway	0.17
12. Rygge, Norway	0.17
Mean: 0.11 +/- 0.08	

FUEL (JP-8)	VOL % FSII
-----	-----
Spec: 0.10 minimum, 0.15 maximum	
1. Egypt	0.00
2. Venezuela	N/A
3. Leeuwarden, Netherlands	0.13
4. Volkel, Netherlands	0.14

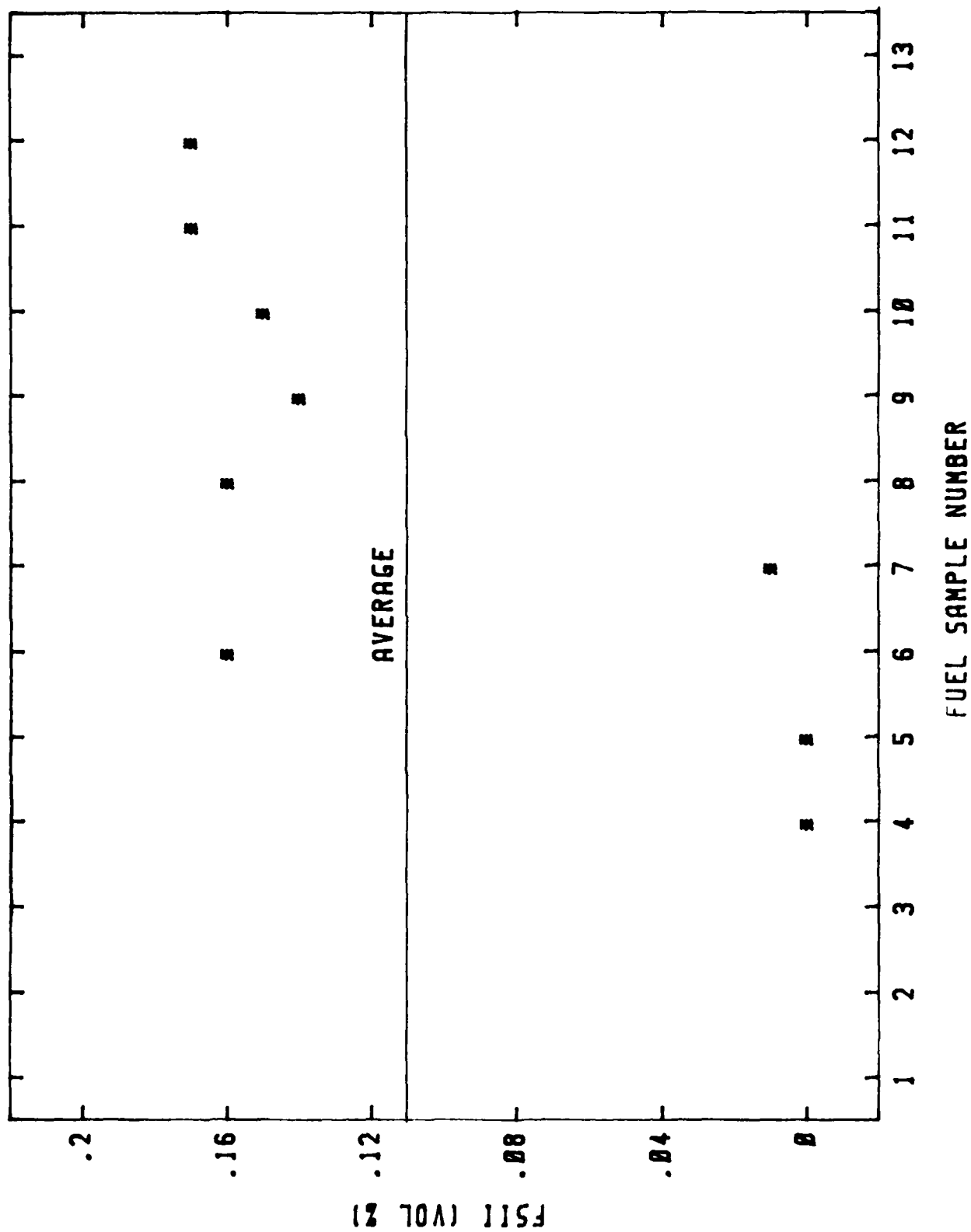


Figure A-11. Fuel System Icing Inhibitor

APPENDIX B
CHARACTERIZATION ANALYSES

TABLE R-1
PHYSICAL PROPERTIES AS A FUNCTION OF TEMPERATURE

	Vapor pressure (mm Hg)	Kinematic viscosity (centistokes)	Density (g/cm ³)	Surface tension (dynes/cm)
INSHAS #1				
-30.1 F	- ^a	-	-	- ^b
-20 F	2	4.040	0.8244	30.4
- 4 F	-	-	-	-
32 F	7	2.096	0.8020	27.9
59 F	-	-	0.7905	-
70 F	13	1.460	0.7857	25.9
100 F	21	1.152	0.7728	24.4
140 F	38	0.877	0.7557	22.5
INSHAS #2				
-30.1 F	- ^a	-	-	- ^b
-20 F	1.2	3.923	0.8210	30.1
- 4 F	-	-	-	-
32 F	5	2.046	0.8004	27.7
59 F	-	-	0.7898	-
70 F	10	1.436	0.7855	25.9
100 F	17	1.128	0.7736	24.4
140 F	33	0.865	0.7578	22.7
EGYPT JP-4				
-30.1 F	- ^a	4.425	-	- ^b
-20 F	0.7	3.775	0.8200	29.9
- 4 F	-	2.937	-	-
32 F	3.3	1.996	0.7993	27.4
59 F	-	-	0.7885	-
70 F	8.2	1.395	0.7839	25.8
100 F	15.5	1.129	0.7713	24.3
140 F	34	0.853	0.7546	22.4

^a Value determined by extrapolation of log P versus 1/T vapor pressure relationship.

^b Obtained by linear regression extrapolation of data.

TABLE B-1 (Continued)

	Vapor pressure (mm Hg)	Kinematic viscosity (centistokes)	Density (g/cm ³)	Surface tension (dynes/cm)
KING FAHAD				
-30.1 F	- ^a	2.4557	-	- ^b
-20 F	8.3	2.1669	0.7920	28.9
- 4 F	-	1.8133	-	-
32 F	35.5	1.3327	0.7696	26.1
59 F	-	-	0.7580	-
70 F	80	0.9968	0.7533	24.0
100 F	144	0.8234	0.7404	22.4
140 F	296	0.6587	0.7232	20.2
KING AZIZ				
-30.1 F	- ^a	2.4995	-	- ^b
-20 F	7.4	2.2111	0.7901	28.9
- 4 F	-	1.8464	-	-
32 F	38	1.3503	0.7689	26.2
59 F	-	-	0.7579	-
70 F	82	1.0113	0.7534	24.2
100 F	155	0.8325	0.7412	22.6
140 F	335	0.6685	0.7249	20.5
JAPAN				
-30.1 F	- ^a	2.2620	-	- ^b
-20 F	9	2.0192	0.7892	28.3
- 4 F	-	1.6958	-	-
32 F	34	1.2640	0.7690	25.8
59 F	-	-	0.7577	-
70 F	76	0.9499	0.7530	24.0
100 F	132	0.7837	0.7395	22.6
140 F	262	0.6303	0.7217	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 B-1 (Continued)

	Vapor pressure (mm Hg)	Kinematic viscosity (centistokes)	Density (g/cm ³)	Surface tension (dynes/cm)
EGYPT				
-30.1 F	-	5.03	-	-
-20 F	1.5 ^a	4.360	0.8242	30.6 ^b
- 4 F	-	-	-	-
32 F	5.2	3.333	0.8038	28.0
59 F	-	2.123	0.7925	-
70 F	11	1.493	0.7881	26.1
100 F	18	1.172	0.7759	24.6
140 F	-	-	-	-
VENEZUELA				
-30.1 F	- ^a	2.2036	-	- ^b
-20 F	8.4	1.9598	0.7893	28.1
- 4 F	-	-	-	-
32 F	34	1.2327	0.7672	25.6
59 F	-	-	0.7559	-
70 F	76	0.9280	0.7510	23.7
100 F	136	0.7701	0.7382	22.3
140 F	269	0.6191	0.7212	20.3
LEEWARDEN				
-30.1 F	- ^a	6.4397	-	- ^b
-20 F	4.4	5.4077	0.8295	31.6
- 4 F	-	4.1337	-	-
32 F	9	2.6412	0.8098	28.8
59 F	-	-	0.7984	-
70 F	15	1.7432	0.7934	26.7
100 F	21.5	1.3587	0.7825	25.1
140 F	33.5	1.0246	0.7660	22.9

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

^b Obtained by linear regression extrapolation of data.

TABLE B-1 (Continued)

	Vapor pressure (mm Hg)	Kinematic viscosity (centistokes)	Density (g/cm ³)	Surface tension (dynes/cm)
PAKISTAN				
-30.1 F	-	7.6082	-	-
-20 F	5.8 ^a	6.1395	0.8432	32.5 ^b
- 4 F	-	-	-	-
32 F	12	2.8664	0.8229	29.7
59 F	-	-	0.8132	-
70 F	18	1.8852	0.8080	27.6
100 F	25	1.4388	0.7963	25.9
140 F	36	1.0752	0.7799	23.7
BEAUVECHAIN				
-30.1 F	-	2.3460	-	-
-20 F	8.2 ^a	2.1091	0.7993	29.0 ^b
- 4 F	-	1.7714	-	-
32 F	34	1.3080	0.7771	26.3
59 F	-	-	0.7656	-
70 F	78	0.9669	0.7609	24.3
100 F	138	0.8060	0.7481	22.7
140 F	277	0.6461	0.7310	20.6
KLEINE BROGEN				
-30.1 F	-	2.3508	-	-
-20 F	10.3 ^a	2.0976	0.7940	28.6 ^b
- 4 F	-	1.7578	-	-
32 F	32.5	1.2938	0.7720	25.9
59 F	-	-	0.7606	-
70 F	75	0.9678	0.7560	23.9
100 F	137	0.8054	0.7443	22.3
140 F	275	0.6466	0.7264	20.2

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

^b Obtained by linear regression extrapolation of data.

TABLE R-1 (Continued)

	Vapor pressure (mm Hg)	Kinematic viscosity (centistokes)	Density (g/cm ³)	Surface tension (dynes/cm)
SKRYDSTRU				
-30.1 F	- ^a	2.7255	-	- ^b
-20 F	15	2.4135	0.8009	29.0
- 4 F	-	1.9835	-	-
32 F	47.5	1.4392	0.7789	26.3
59 F	-	-	0.7675	-
70 F	95	1.0577	0.7628	24.3
100 F	152	0.8709	0.7502	22.7
140 F	272	0.6953	0.7333	20.6
BODO				
-30.1 F	N/A	1.7956	-	- ^b
-20 F	N/A	1.6354	0.7916	29.2
- 4 F	N/A	1.3768	-	-
32 F	N/A	1.0508	0.7687	26.3
59 F	N/A	-	0.7567	-
70 F	N/A	0.8178	0.7319	24.1
100 F	N/A	0.6751	0.7386	22.4
140 F	N/A	0.5555	0.7210	20.1
RYGGE				
-30.1 F	N/A	3.0575	-	- ^b
-20 F	N/A	2.6859	0.8066	29.6
- 4 F	N/A	2.1880	-	-
32 F	N/A	1.5555	0.7857	27.1
59 F	N/A	-	0.7740	-
70 F	N/A	1.1414	0.7694	25.3
100 F	N/A	0.9171	0.7570	23.9
140 F	N/A	0.7229	0.7405	22.0

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

^b Obtained by linear regression extrapolation of data.

TABLE B-1 (Concluded)

	Vapor pressure (mm Hg)	Kinematic viscosity (centistokes)	Density (g/cm ³)	Surface tension (dynes/cm)
VOLKEL				
-30.1 F	- ^a	6.4397	-	-
-20 F	10	5.4077	0.8295	31.6 ^b
- 4 F	-	4.1337	-	-
32 F	20.5	2.6412	0.8098	28.8
59 F	-	-	0.7984	-
70 F	15	1.7432	0.7934	26.7
100 F	21.5	1.3587	0.7825	25.1
140 F	33.5	1.0246	0.7660	22.9

^a Value determined by extrapolation of log P versus 1/T vapor pressure relationship.

^b Obtained by linear regression extrapolation of data.

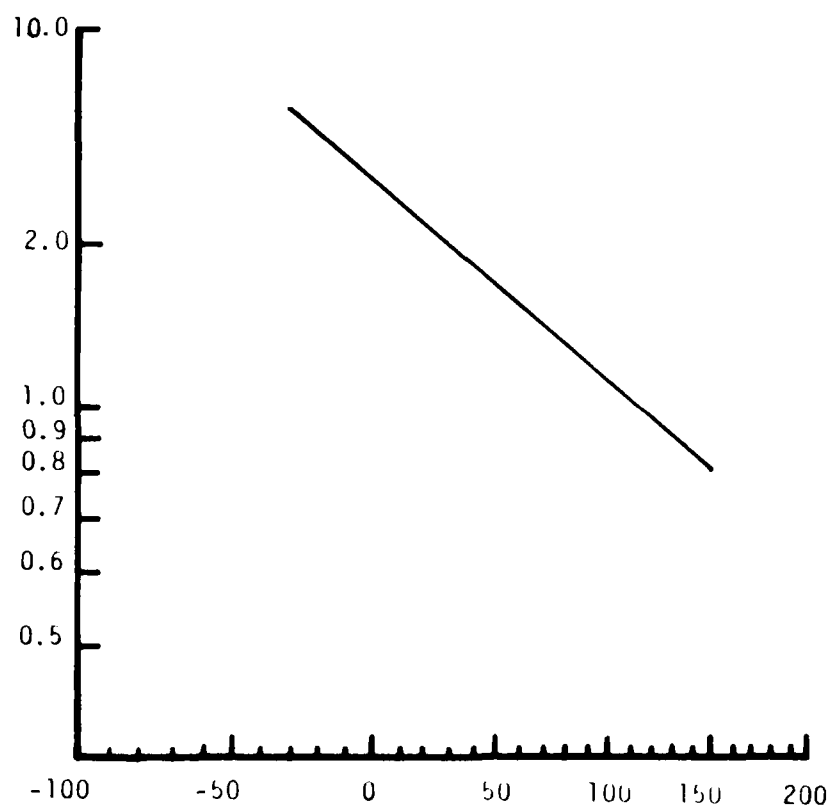


Figure B-1. Viscosity vs Temperature Plot for Inshas #1 Sample

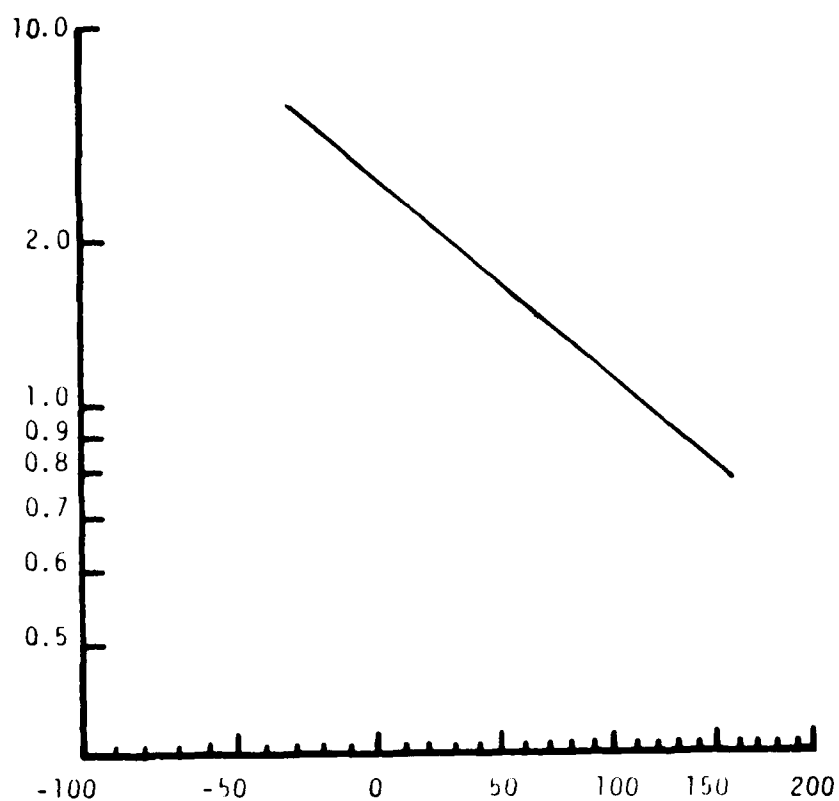


Figure B-2. Viscosity vs Temperature Plot for Inshas #2 Sample

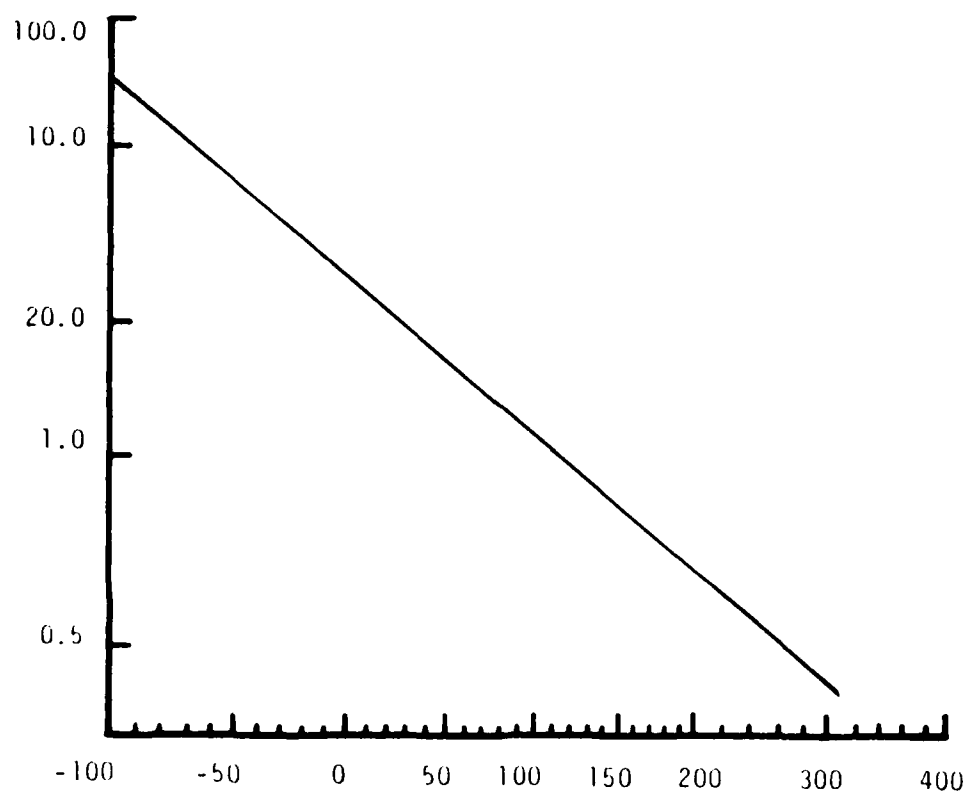


Figure B-3. Viscosity vs Temperature Plot for Egypt JP-4 Sample

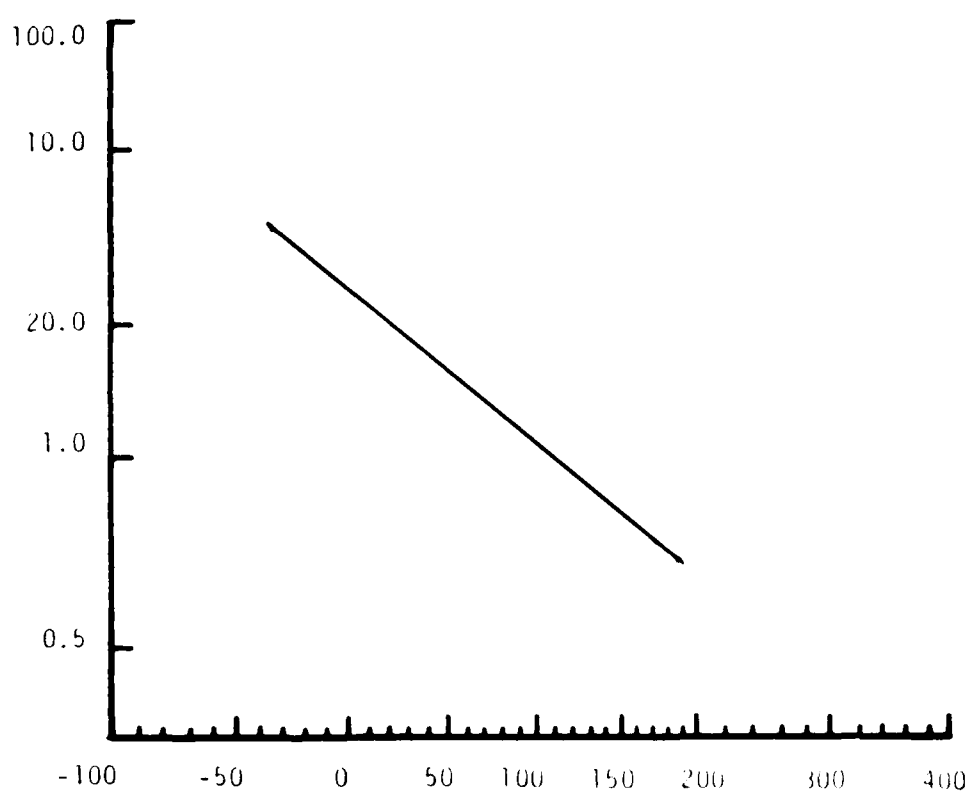


Figure B-4. Viscosity vs Temperature Plot for King Fahad Sample

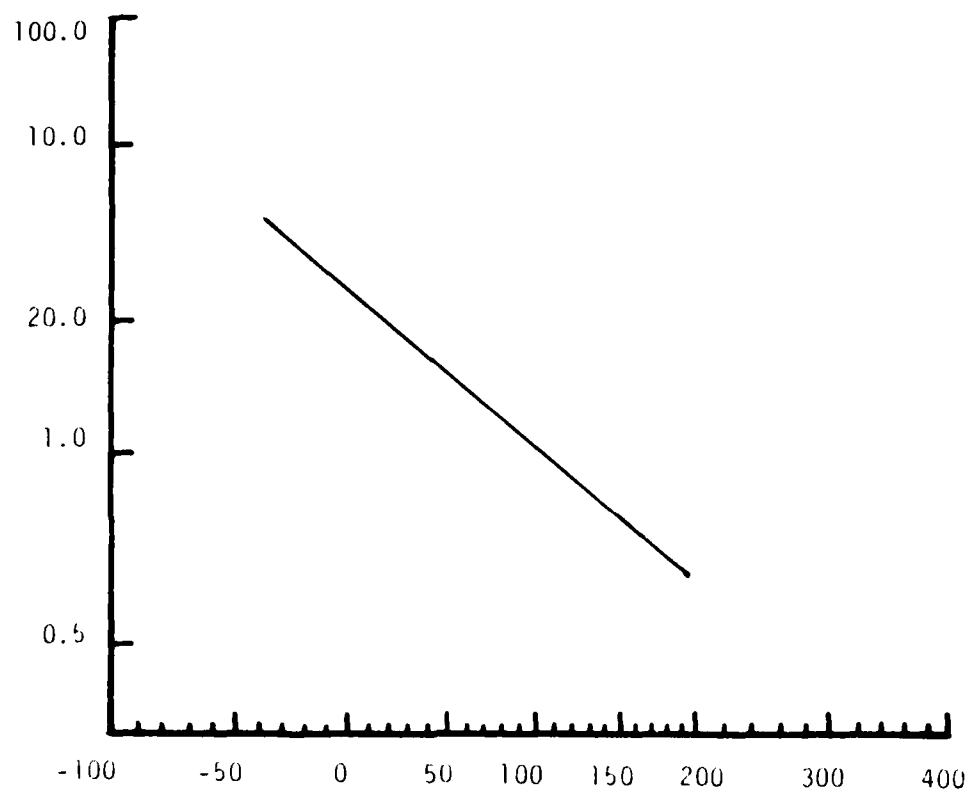


Figure B-5. Viscosity vs Temperature Plot for King Aziz Sample

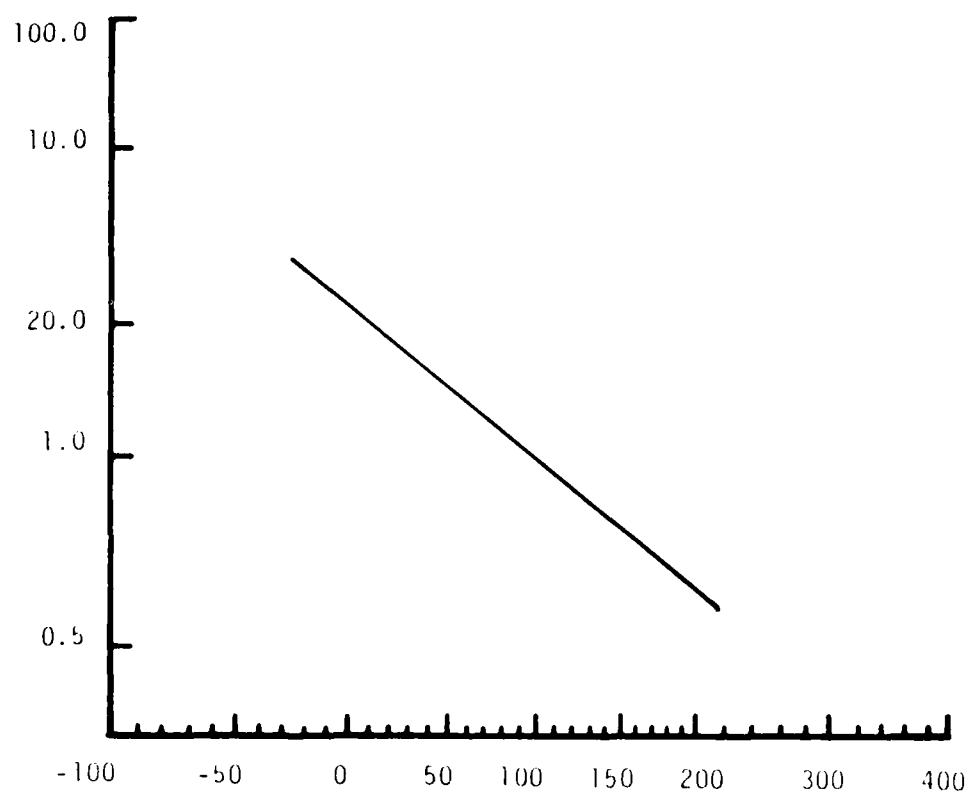


Figure B-6. Viscosity vs Temperature Plot for Japan Sample

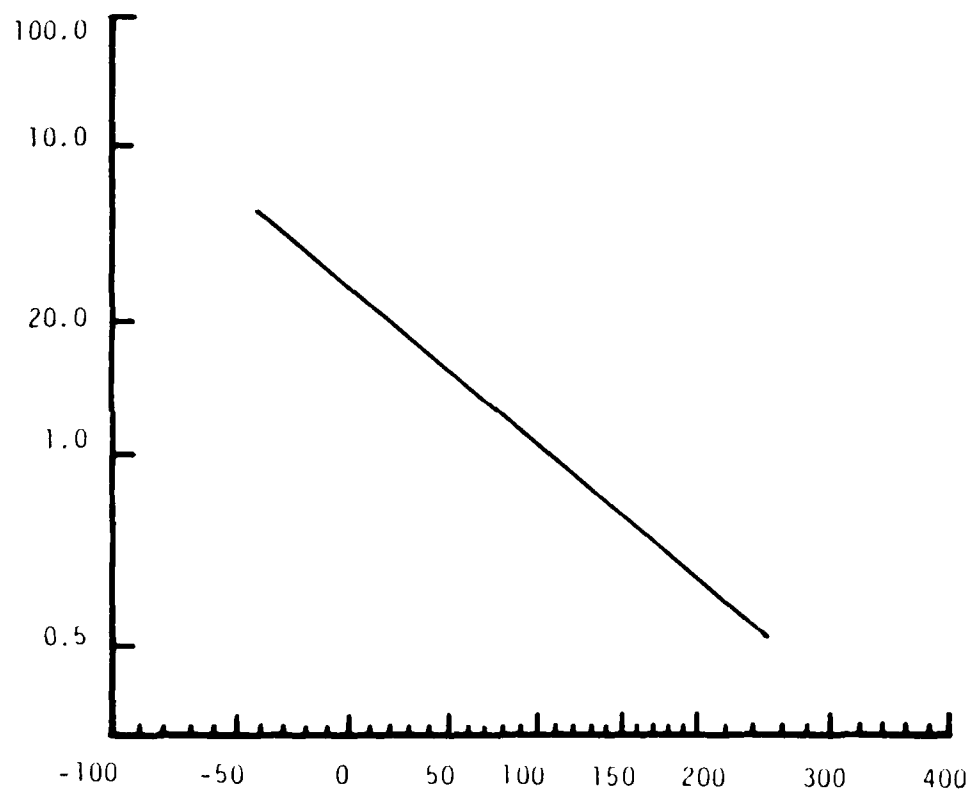


Figure B-7. Viscosity vs Temperature Plot for Beauvechain Sample

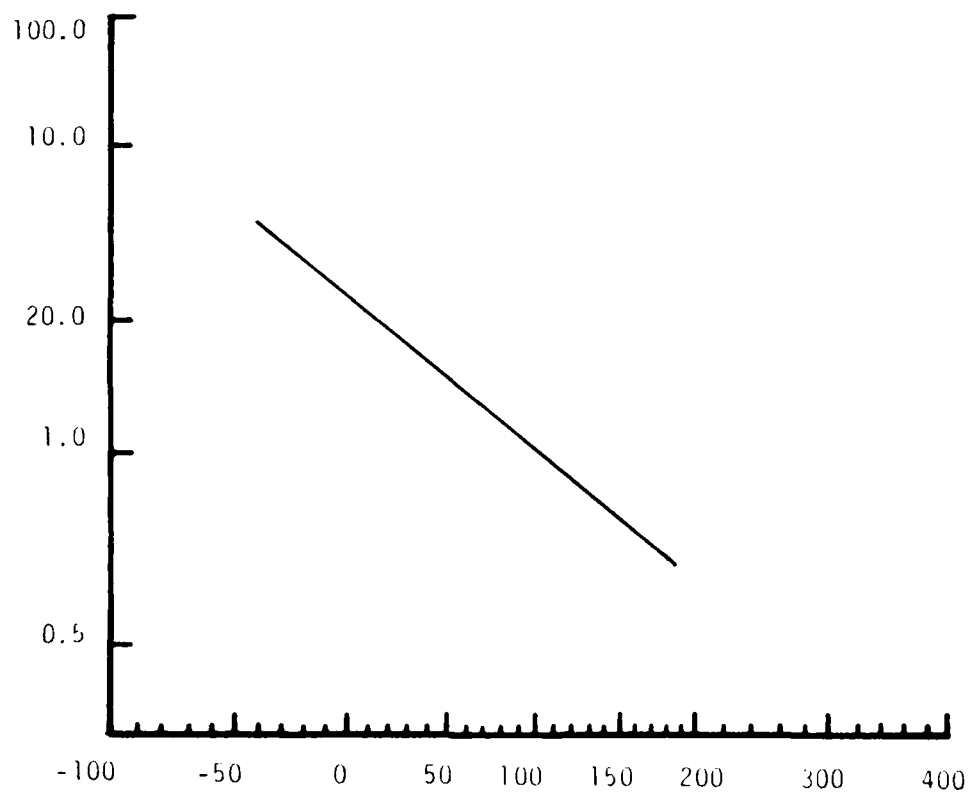


Figure B-8. Viscosity vs Temperature Plot for Kleine Brogen Sample

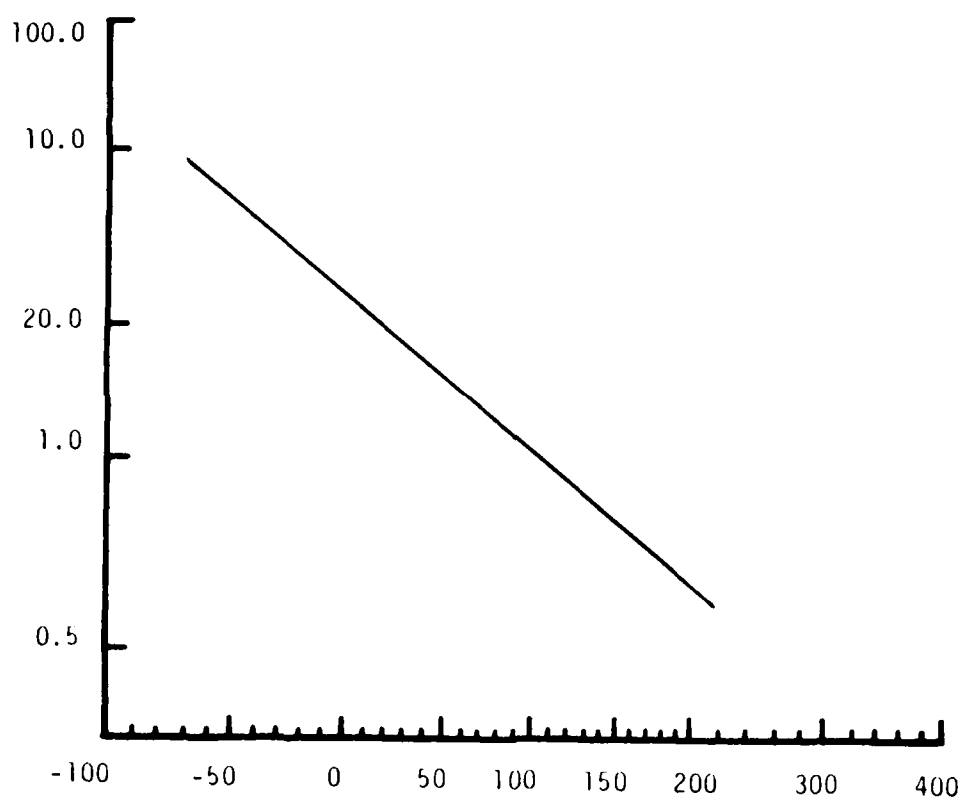


Figure B-9. Viscosity vs Temperature Plot for Skrydstru Sample

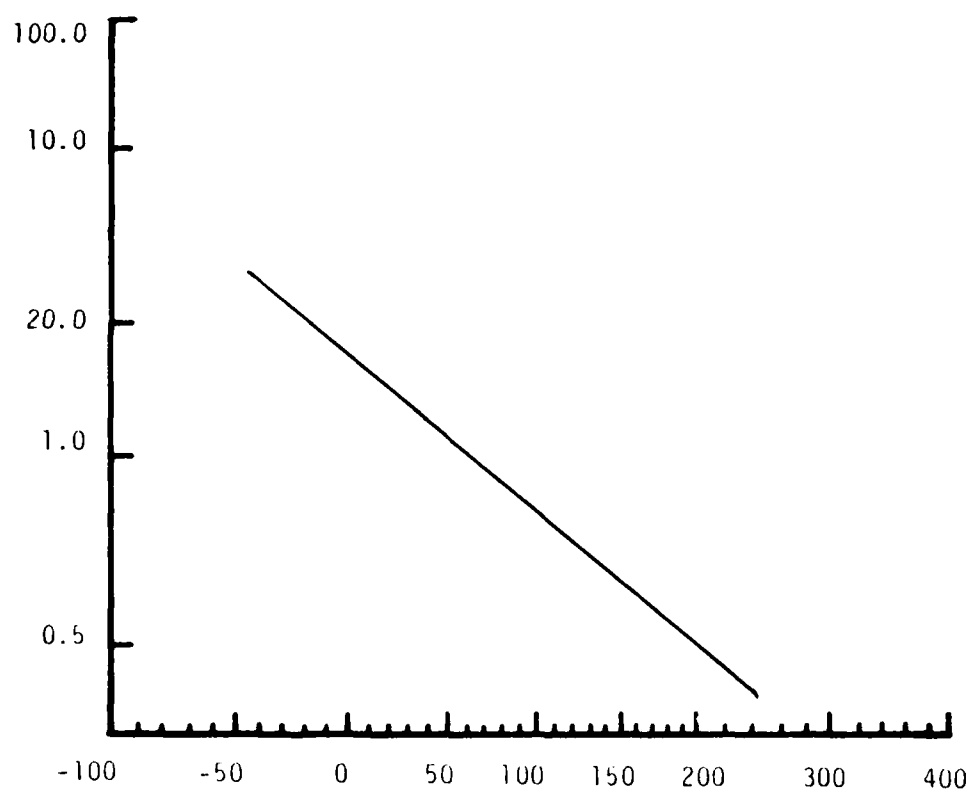


Figure B-10. Viscosity vs Temperature Plot for Bodo Sample

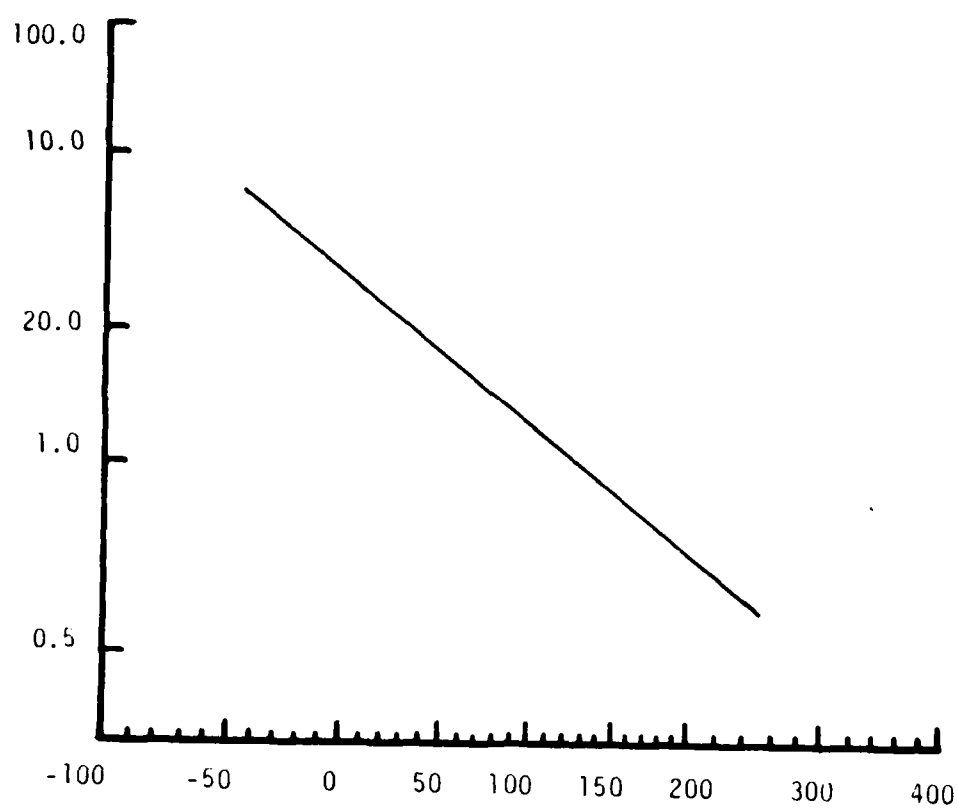


Figure B-11. Viscosity vs Temperature Plot for Rygge Sample

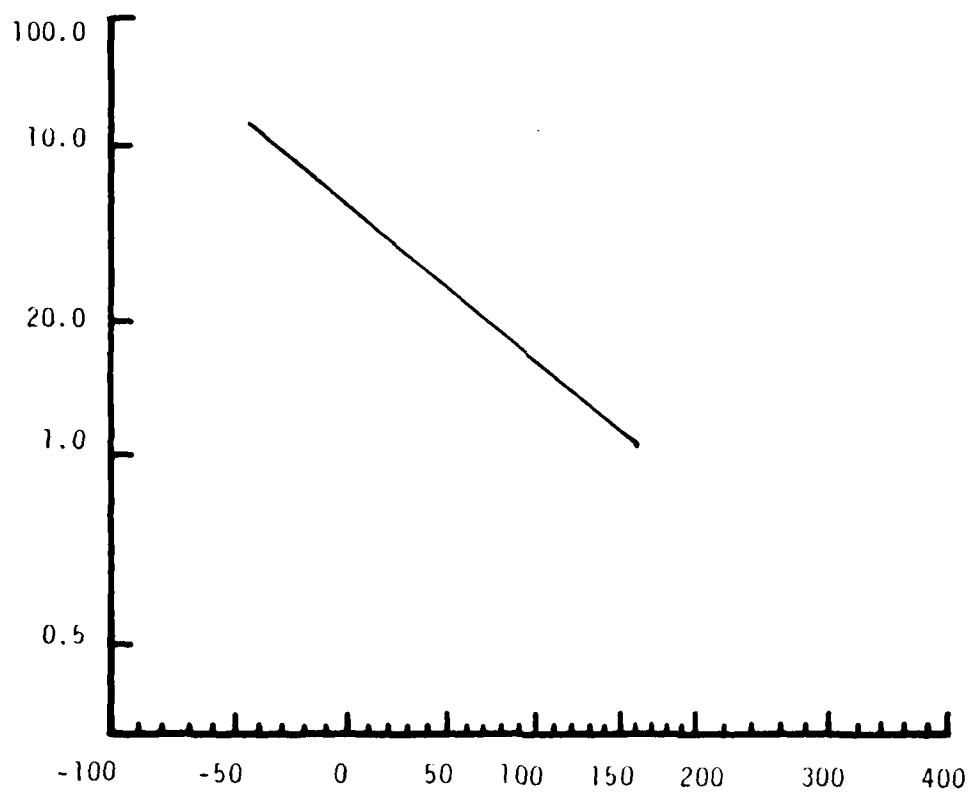


Figure B-12. Viscosity vs Temperature Plot for Egypt JP-8 Sample

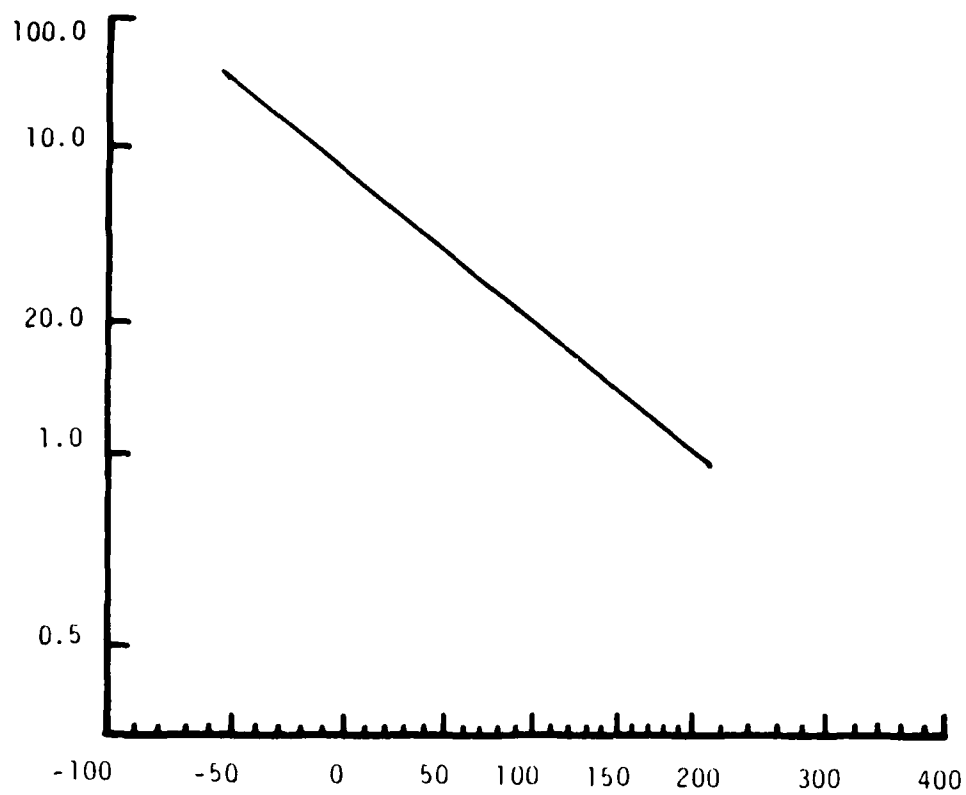


Figure B-13. Viscosity vs Temperature Plot for Leeuwarden Sample

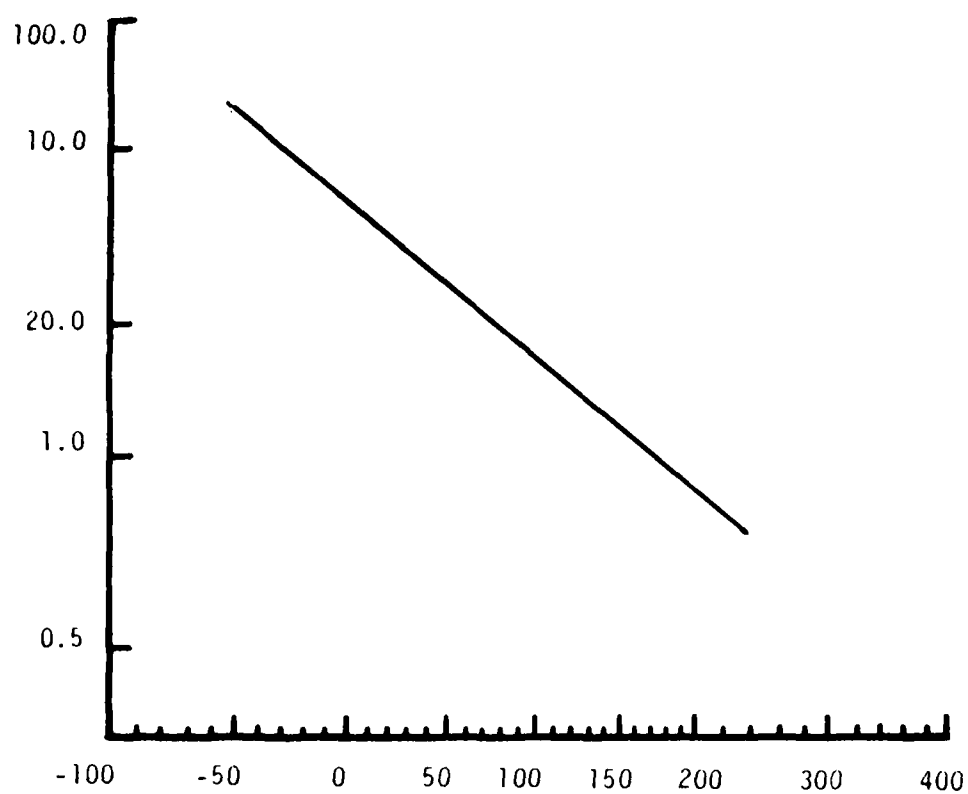


Figure B-14. Viscosity vs Temperature Plot for Volke¹ Sample

TABLE B-2

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

Temperature °F (°C)	Vapor Pressure (mm Hg)		
	Typical JP-4	F100 US	F100 Foreign
-20 (-28.9)	no data	7	6.79
32 (0)	23.25 ^a	30.8	24.88
70 (21.1)	81.01	72.6	53.52
100 (37.8)	126.00	133.0	93.65
140 (60)	283.50	276.9	185.80

^a Obtained by extrapolation

TABLE B-3

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

Temperature °F (°C)	Kinematic Viscosity Cs		
	Typical JP-4	F100 US	F100 Foreign
-30.1 (-34.5)	2.3	2.21	3.15
-20 (-28.8)	2.1	1.96	2.93
-4 (-20)	1.7	1.65	2.02
32 (0)	1.23	1.22	1.63
70 (21.1)	0.56	0.932	1.17
100 (37.8)	0.44	0.762	0.95
140 (60)	0.40	0.616	0.74

TABLE B-4

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

Temperature °F (°C)	Density (g/cm ³)		
	Typical JP-	F100 US	F100 Foreign
-20 (-28.8)	0.797	0.796	0.806
32 (0)	0.775	0.774	0.786
59 (15)	0.764	0.763	0.776
70 (21.1)	0.758	0.759	0.768
100 (37.8)	0.698	0.745	0.756
140 (60)	not avail.	0.727	0.739

^a Obtained by extrapolation

TABLE B-5

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

Temperature °F (°C)	Surface Tension (dyne/cm)		
	Typical JP-4	F100 US	F100 Foreign
-20 (-28.8)	25.9	28.3	29.5
- 4 (-20)	25.2	25.6	26.9
70 (21.1)	21.7	23.6	24.9
100 (37.8)	20.3	22.0	23.4
140 (60)	18.4	20.0	21.3

TABLE B-6

THERMAL CONDUCTIVITY ANALYSES

Sample	Thermal Conductivity (Watt/meter Kelvin)		
	0 °C	20 °C	40 °C
Inshas #1	0.123 +/- 2.36% ^b	0.121 +/- 2.48%	0.116 +/- 3.46%
Inshas #2	0.123 +/- 2.51%	0.120 +/- 3.00%	0.115 +/- 3.83%
Toluene (standard)	0.140 +/- 3.71%	0.1317 +/- 2.12%	0.1253 +/- 3.05%
Toluene (literature value ^a)	0.1366	0.1308	0.1250

^aLiterature values from Venart & Mani, Can. J. Chem. 49, 2468 (1971).^bStandard deviation of 6-8 measurements made at each temperature.

TABLE B-7

COMPARISON OF TYPICAL JP-4 AND EGYPTIAN F100 JP-4 SAMPLES THERMAL CONDUCTIVITY

Temperature °F (°C)	Thermal Conductivity (watt/meter °K)		
	Typical	US F100 Samples	Egyptian Samples
0	.1188	0.122	0.123
20	.1155	0.117	0.121
40	.1118	0.112	0.116

TABLE B-8

SPECIFIC HEAT ANALYSES

Sample	Specific Heat (cal/g/°C)				
	35°C	45°C	55°C	65°C	75°C
Inshas #1	0.496 +/- 0.004	0.505 +/- 0.003	0.512 +/- 0.003	0.521 +/- 0.005	0.529 +/- 0.005
Inshas #2	0.496 +/- 0.008	0.506 +/- 0.007	0.517 +/- 0.006	0.526 +/- 0.009	0.533 +/- 0.008
Diphenylether (Standard)	0.382	0.388	0.395	0.398	0.405
Diphenylether (Literature value) ^a	0.382	0.388	0.394	0.401	0.407
					0.412
					0.414

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

TABLE B-8 (Continued)
SPECIFIC HEAT ANALYSES

Sample	Specific Heat (cal/g/°C)		
	-15 °C	15 °C	40 °C
King Fahad (JP-4)	0.463 +/- 0.002	0.496 +/- 0.003	0.521 +/- 0.002
King Aziz (JP-4)	0.445 +/- 0.002	0.478 +/- 0.001	0.500 +/- 0.002
Beauvechain (JP-4)	0.442 +/- 0.002	0.473 +/- 0.000	0.495 +/- 0.004
Kleine Brogen (JP-4)	0.429 +/- 0.003	0.467 +/- 0.003	0.485 +/- 0.002
Skrydstru (JP-4)	0.423 +/- 0.003	0.451 +/- 0.001	0.479 +/- 0.002
Leeuwarden (JP-8)	0.416 +/- 0.004	0.450 +/- 0.001	0.475 +/- 0.000
Volkel (JP-8)	0.415 +/- 0.003	0.446 +/- 0.003	0.468 +/- 0.003
Heptane (>99% purity)	0.499 +/- 0.000	0.530 +/- 0.000	0.558 +/- 0.000
Heptane (Literature Value) ^a	0.505	0.528 +/- 0.000	0.550

^a API Project 44, Table 23-2-(1.202)-VC

TABLE B-9

COMPARISON OF TYPICAL JP-4 AND JP-8 AND EGYPTIAN F100 SAMPLES
SPECIFIC HEAT AS A FUNCTION OF TEMPERATURE

Temperature °F (°C)	Specific Heat (cal/g °C)		
	Typical	US F100 Samples	Egyptian Samples
-15 (JP-4)	N/A	-	0.441
15	N/A	-	0.473
35	0.507	0.499	0.496
40	0.512	-	0.496
45	0.517	0.510	0.506
55	0.528	0.521	0.515
65	0.538	0.532	0.524
75	0.547	0.541	0.532
85	0.559	0.550	0.539
-15 (JP-8)	N/A	-	0.416
15	N/A	-	0.448
40	0.486	-	0.472

TABLE B-10

TYPICAL JP-8 PROPERTIES AS A FUNCTION OF TEMPERATURE^a

Temperature °F (°C)	Vapor pressure (mm Hg)	Kinematic viscosity (centistokes)	Density (g/cm ³)	Surface tension (dynes/cm)
-30.1 (-34.5)	N/A	7.50	0.847	27.51
-20 (-28.9)	N/A	6.00	0.844	27.18
-4 (-20)	N/A	4.40	0.837	26.20
32 (0)	N/A	2.58	0.822	24.79
59 (15)	N/A	1.81	0.812	23.70
70 (21.1)	N/A	1.63	0.807	23.20
100 (37.8)	N/A	1.22	0.796	21.90
140 (60)	16.12	0.90	0.779	20.20

^aReference 8.

TABLE B-11

SIMULATED DISTILLATION DATA FOR INSHAS #1 SAMPLE

% Recovered	Temperature	
	°C	°F
0.5	98	208
1.0	103	217
5.0	137	279
10	149	300
20	161	322
30	170	338
40	178	352
50	189	372
60	198	388
70	211	412
80	221	430
90	235	455
95	244	471
99	259	498
99.5	264	507

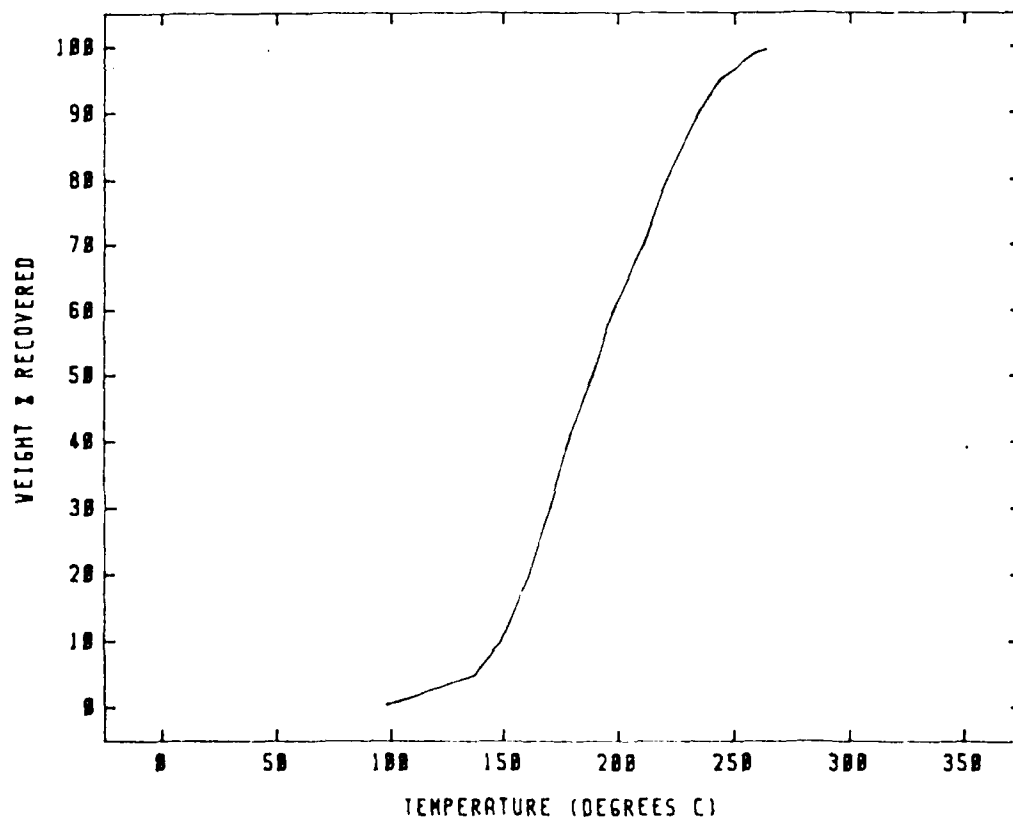


Figure B-15. Distillation Curve for Inshas #1 Sample

TABLE B-12

SIMULATED DISTILLATION DATA FOR INSHAS #2 SAMPLE

% Recovered	Temperature	
	°C	°F
0.5	98	208
1.0	104	219
5.0	137	279
10	149	300
20	160	320
30	169	336
40	177	351
50	188	370
60	198	388
70	210	410
80	220	428
90	235	455
95	244	471
99	260	500
99.5	268	514

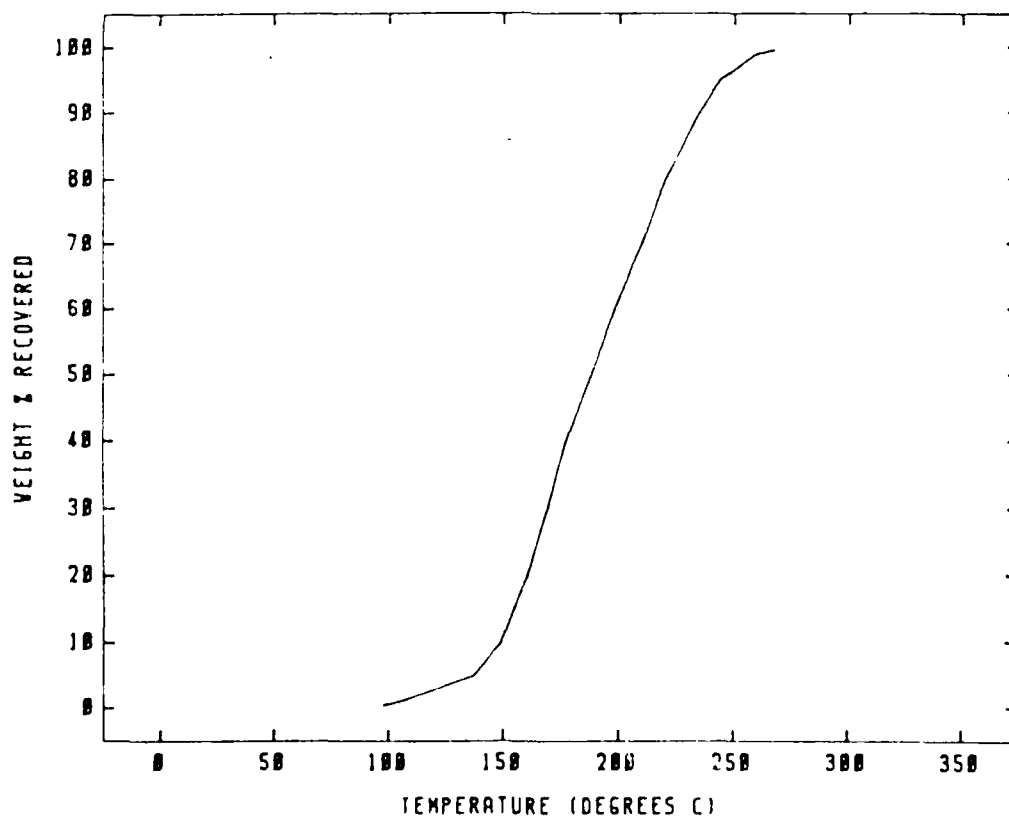


Figure B-16. Distillation Curve for Inshas #2 Sample

AD-A160 573

F100 FUEL SAMPLING ANALYSIS: FOREIGN SAMPLES(U) AIR
FORCE WRIGHT AERONAUTICAL LABS WRIGHT-PATTERSON AFB OH
L O MAURICE MAR 86 AFMAL-TR-85-2007

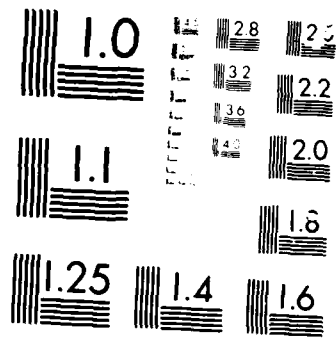
2/2

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M. R.

TABLE 13

SIMULATED DISTILLATION DATA FOR EGYPT JP-4 SAMPLE

% Recovered	Temperature	
	°C	°F
0.5	98	209
1.0	108	227
5.0	136	277
10	146	296
20	159	318
30	168	335
40	176	349
50	189	371
60	199	389
70	214	418
80	228	442
90	243	470
95	262	503
99	332	629
99.5	345	654

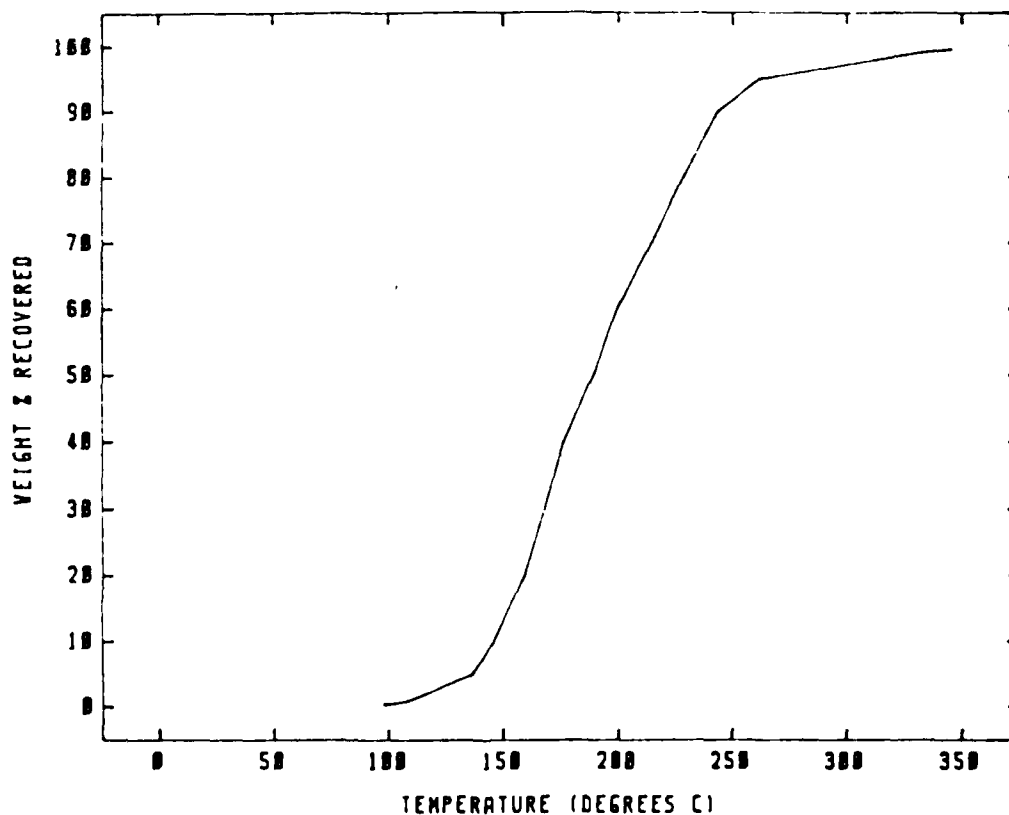


Figure B-17. Distillation Curve for Egypt JP-4 Sample

TABLE B-14

SIMULATED DISTILLATION DATA FOR KING FAHAD SAMPLE

% Recovered	Temperature	
	°C	°F
0.5	31	88
1.0	32	90
5.0	58	136
10	70	158
25	100	212
30	133	271
40	161	322
50	177	351
60	192	378
70	203	397
80	219	426
90	236	457
93	248	478
99	269	516
99.5	275	527

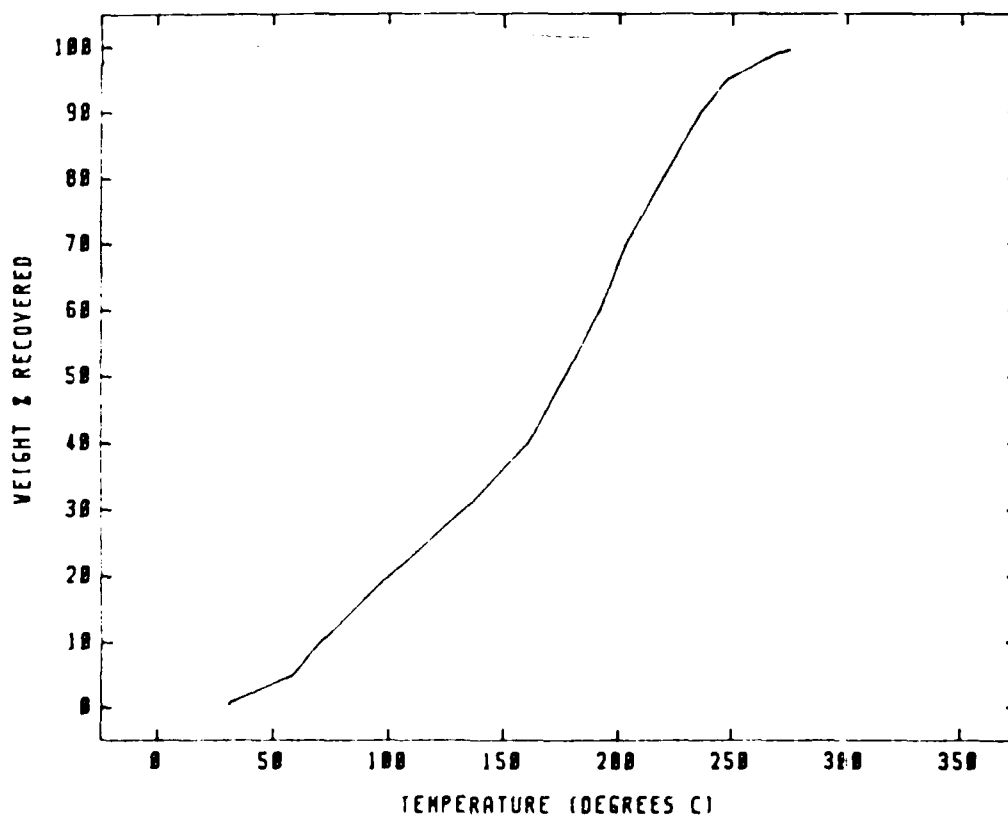


Figure B-1P. Distillation Curve for King Fahad Sample

TABLE B-15

SIMULATED DISTILLATION DATA FOR KING AZIZ SAMPLE

% Recovered	Temperature	
	$^{\circ}\text{C}$	$^{\circ}\text{F}$
0.5	27	81
1.0	29	84
5.0	54	129
10	65	149
20	95	203
30	127	261
40	153	307
50	171	340
60	185	365
70	196	385
80	213	415
90	231	448
95	244	471
99	270	518
99.5	284	543

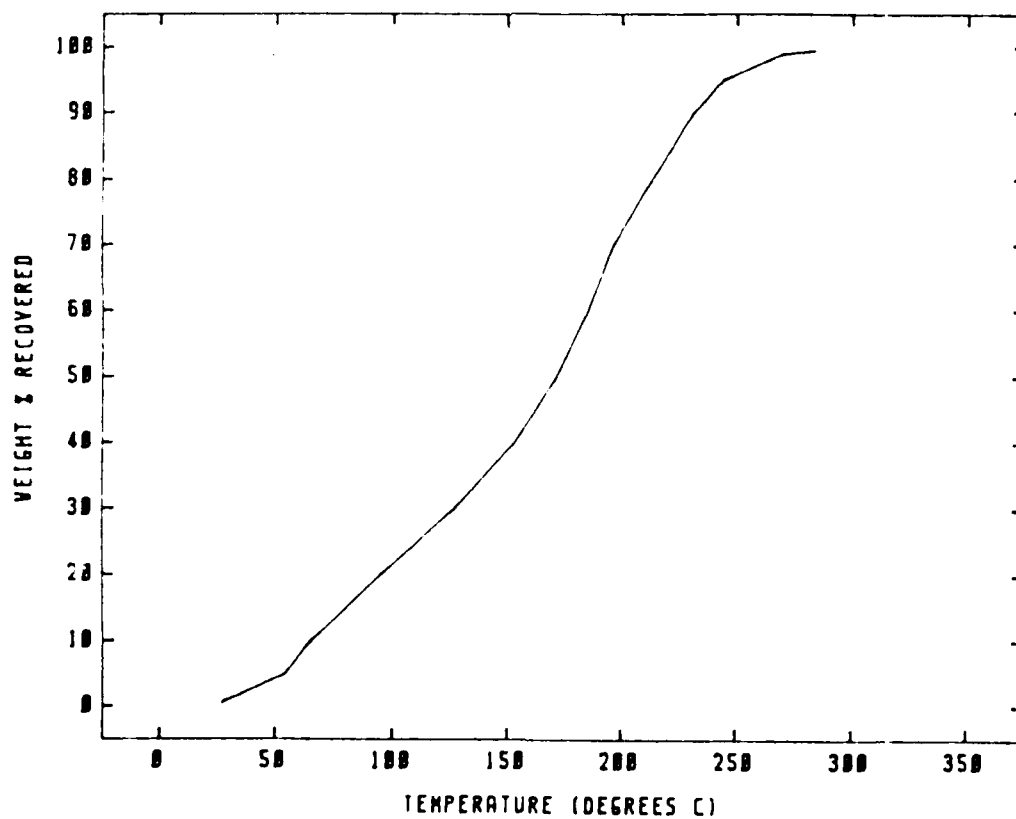


Figure B-19. Distillation Curve for King Aziz Sample

TABLE B-16

SIMULATED DISTILLATION DATA FOR JAPAN SAMPLE

% Recovered	Temperature	
	$^{\circ}\text{C}$	$^{\circ}\text{F}$
0.5	27	80
1.4	28	83
5.0	58	136
10	72	161
20	99	210
30	119	246
40	139	282
50	157	315
60	175	347
70	192	378
80	210	410
90	230	446
95	242	468
99	266	510
99.5	275	526

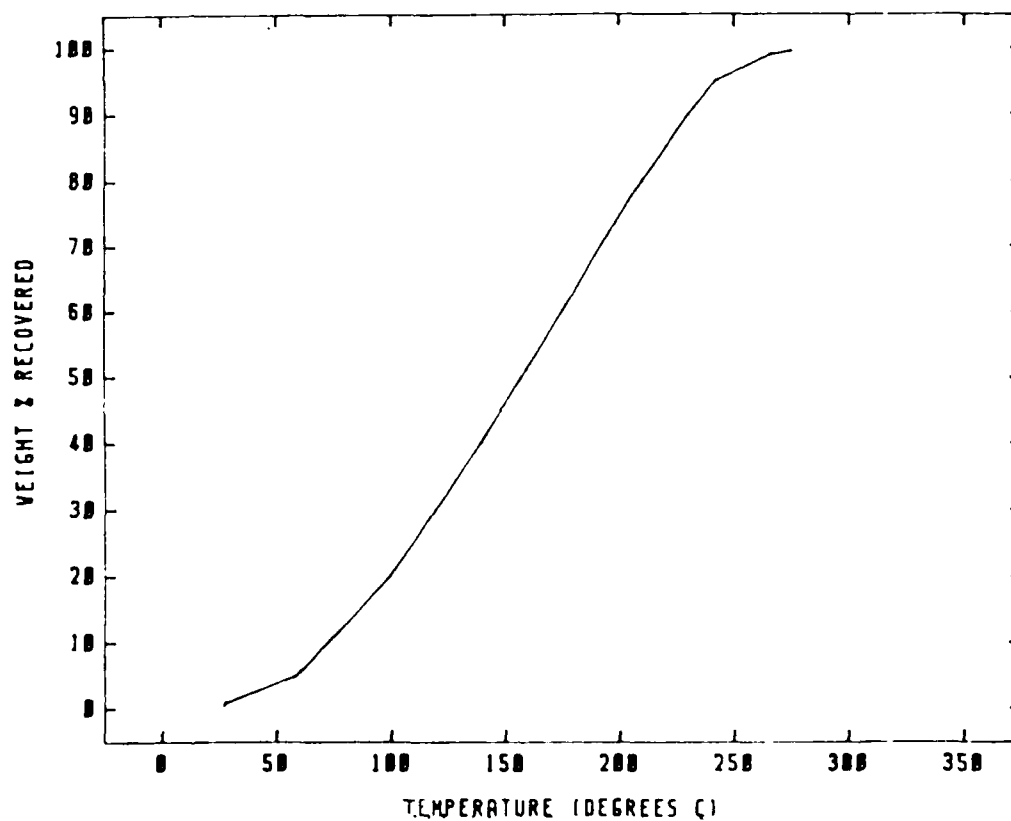


Figure B-20. Distillation Curve for Japan Sample

TABLE B-17
SIMULATED DISTILLATION DATA FOR PAKISTAN SAMPLE

% Recovered	Temperature	
	°C	°F
0.5	28	82
1.0	30	85
5.0	58	136
10	74	165
20	102	215
30	122	251
40	136	277
50	150	302
60	166	330
70	184	362
80	205	401
90	230	446
95	245	473
99	267	513
99.5	278	532

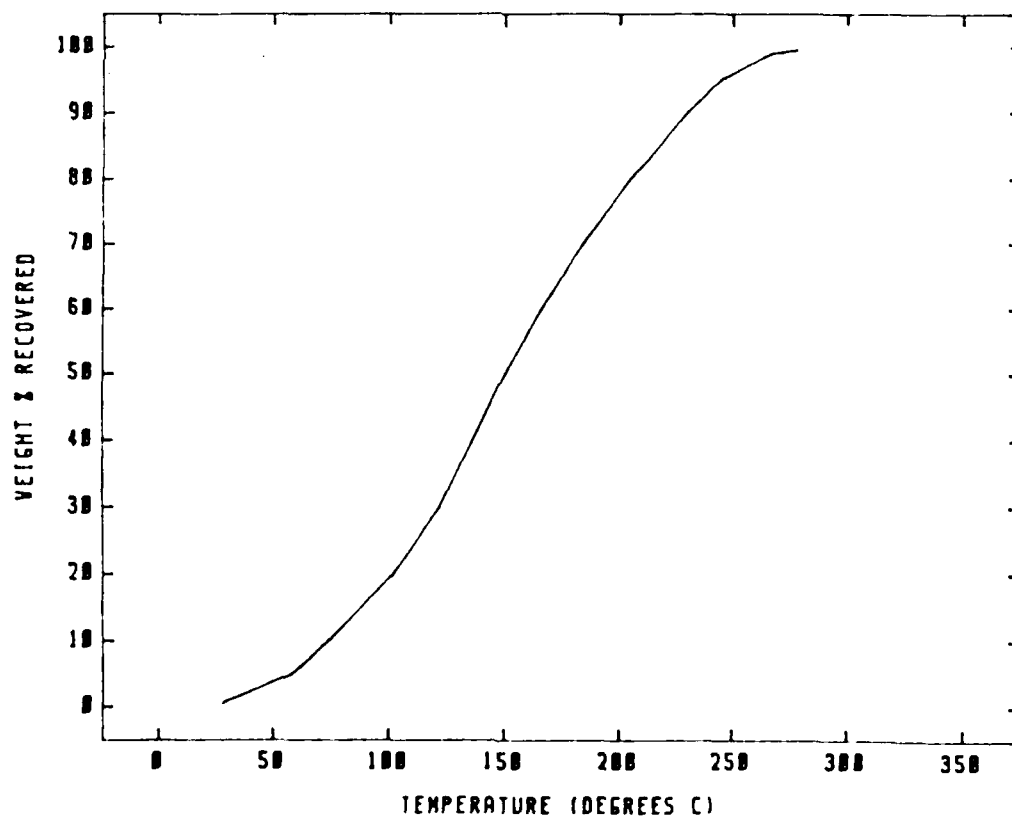


Figure B-21. Distillation Curve for Pakistan Sample

TABLE B-18

SIMULATED DISTILLATION DATA FOR BEAUVECHAIN SAMPLE

% Recovered	Temperature	
	°C	°F
0.5	29	84
1.0	30	86
5.0	36	96
10	57	135
20	90	193
30	110	230
40	130	266
50	151	304
60	171	339
70	187	369
80	204	399
90	223	434
95	235	456
99	256	493
99.5	263	505

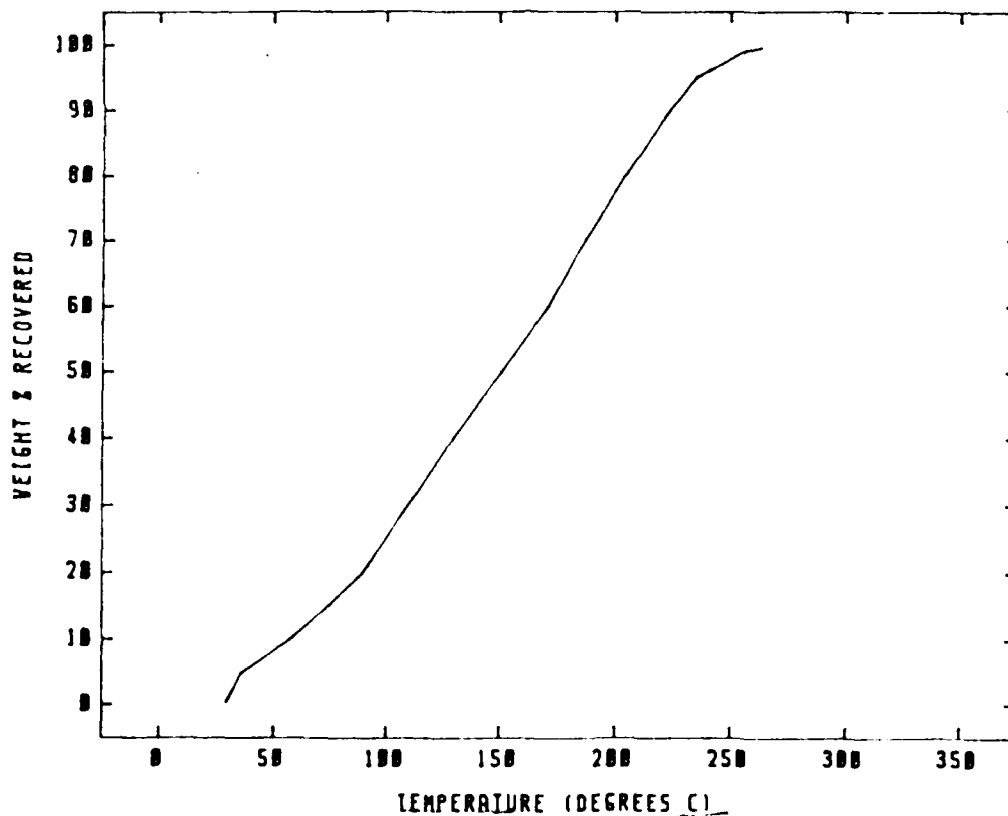


Figure B-22. Distillation Curve for Beauvechain Sample

TABLE B-19

SIMULATED DISTILLATION DATA FOR KLEINE BROGEN SAMPLE

% Recovered	Temperature	
	^o C	^o F
0.5	29	84
1.0	34	93
5.0	54	129
10	66	150
20	88	191
30	109	229
40	135	276
50	158	317
60	174	346
70	192	378
80	209	409
90	231	447
95	244	471
99	264	507
99.5	271	520

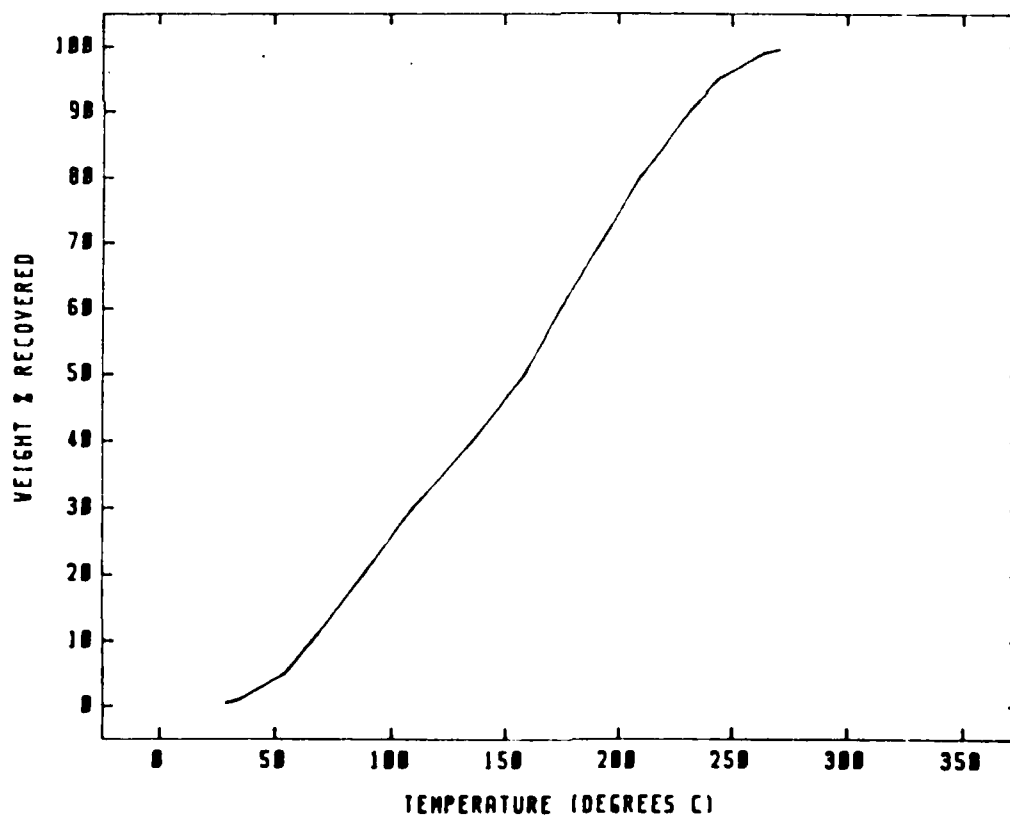


Figure B-23. Distillation Curve for Kleine Brogen Sample

TABLE B-20

SIMULATED DISTILLATION DATA FOR SKRYDSTRU SAMPLE

% Recovered	Temperature	
	$^{\circ}\text{C}$	$^{\circ}\text{F}$
0.5	14	58
1.0	16	61
5.0	79	174
10	91	195
20	112	234
30	128	263
40	145	292
50	162	324
60	177	350
70	195	383
80	213	415
90	232	449
95	244	471
99	263	505
99.5	268	515

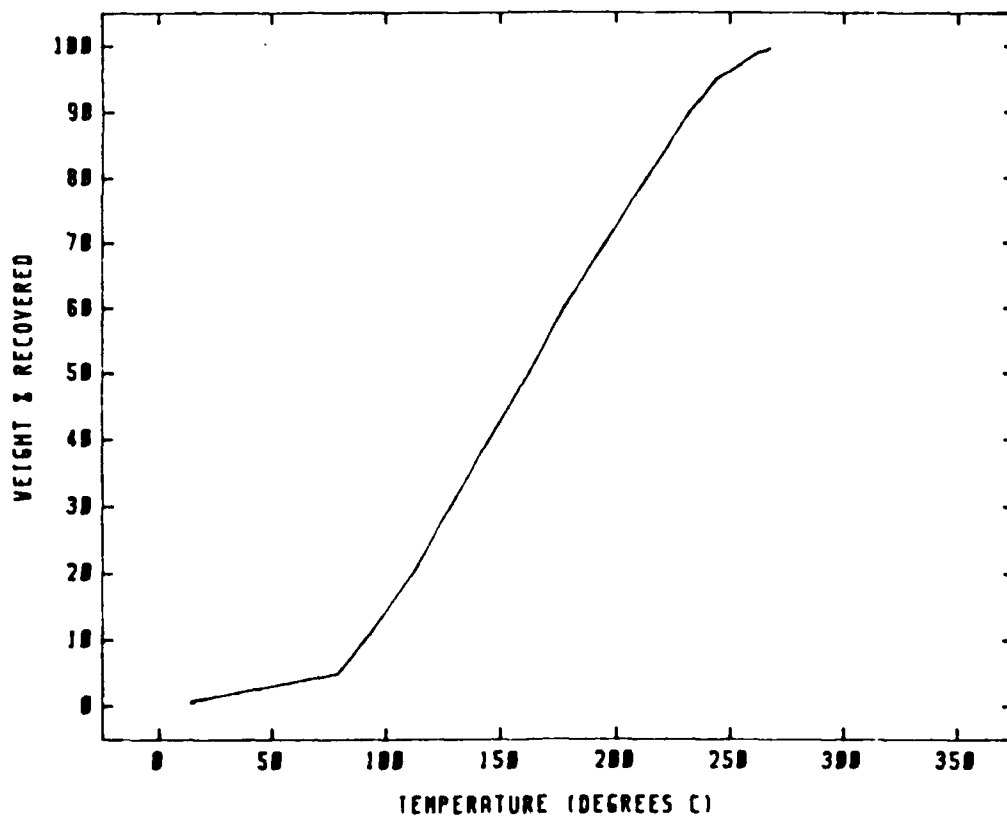


Figure B-24. Distillation Curve for Skrydstru Sample

TABLE B-21

SIMULATED DISTILLATION DATA FOR RYGGE SAMPLE

% Recovered	Temperature	
	°C	°F
0.5	37	99
1.0	52	126
5.0	63	145
10	87	189
20	119	246
30	158	316
40	175	347
50	187	369
60	196	385
70	203	397
80	214	417
90	225	437
95	235	455
99	255	419
99.5	264	507

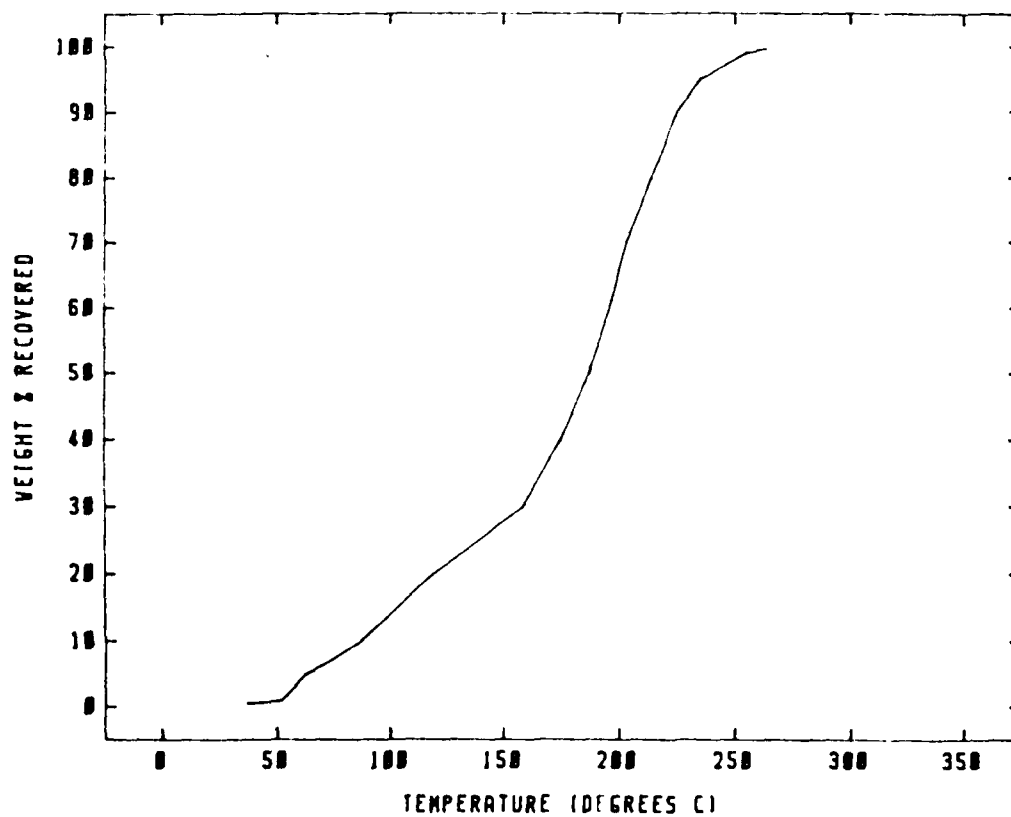


Figure B-25. Distillation Curve for Rygge Sample

TABLE B-22

SIMULATED DISTILLATION DATA FOR EGYPT JP-8 SAMPLE

% Recovered	Temperature	
	°C	°F
0.5	98	209
1.0	102	216
5.0	136	278
10	150	302
20	164	328
30	175	347
40	183	361
50	196	384
60	203	398
70	216	422
80	227	441
90	239	462
95	252	485
99	270	519
99.5	279	535

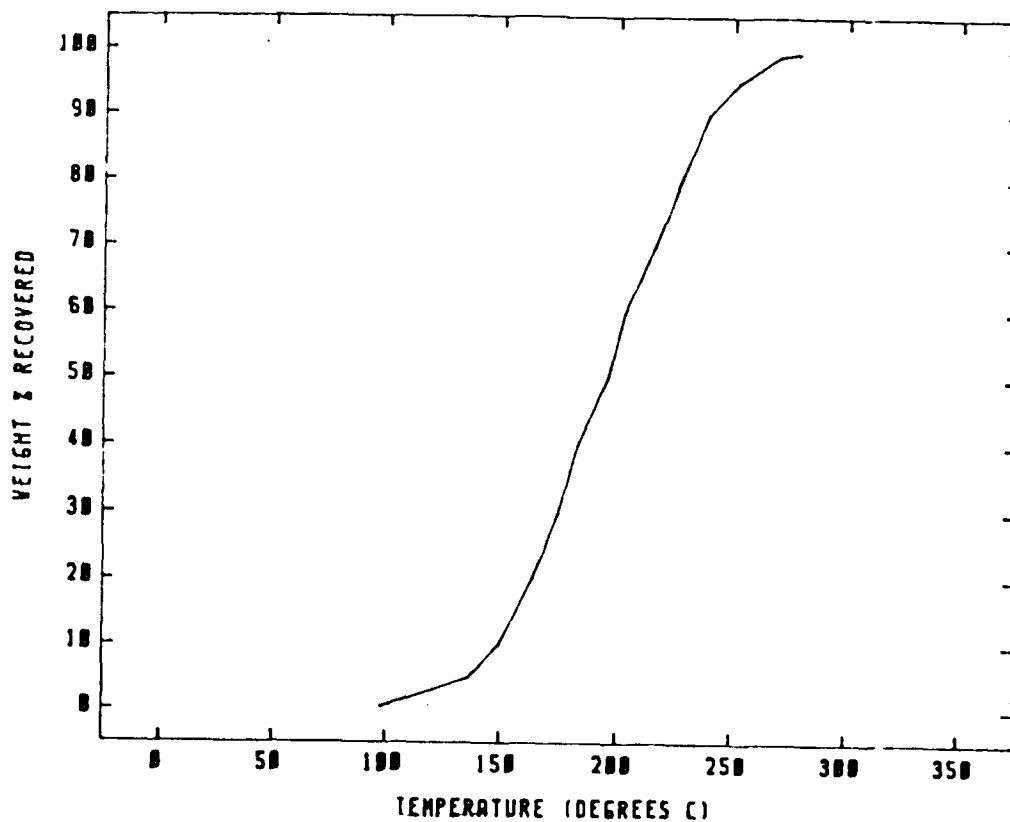


Figure B-26. Distillation Curve for Egypt JP-8 Sample

TABLE B-23

SIMULATED DISTILLATION DATA FOR VENEZUELA SAMPLE

% Recovered	Temperature	
	°C	°F
0.5	130	265
1.0	140	283
5.0	157	315
10	164	325
20	175	346
30	185	364
40	196	384
50	207	405
60	219	426
70	232	449
80	247	476
90	263	506
95	276	529
99	303	578
99.5	310	590

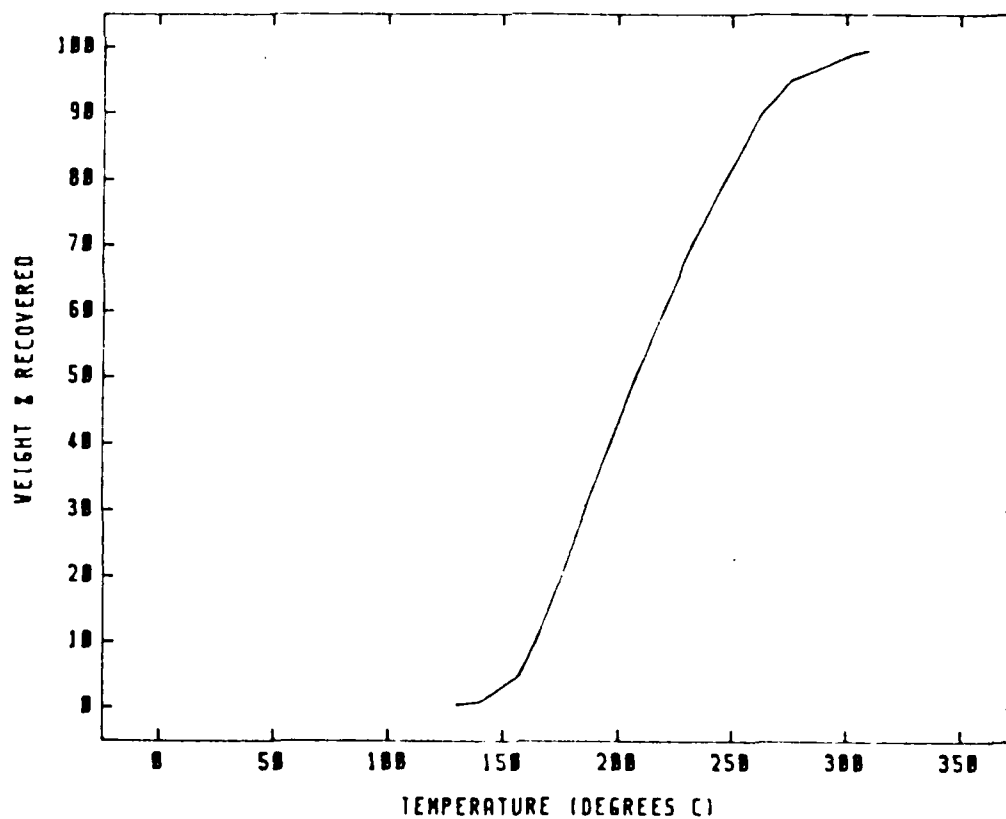


Figure B-27. Distillation Curve for Venezuela Sample

TABLE B-24

SIMULATED DISTILLATION DATA FOR LEEUWARDEN SAMPLE

% Recovered	Temperature	
	°C	°F
0.5	118	244
1.0	126	259
5.0	150	302
10	162	324
20	175	346
30	187	368
40	195	383
50	204	400
60	215	419
70	223	434
80	235	455
90	251	484
95	264	507
99	284	543
99.5	288	550

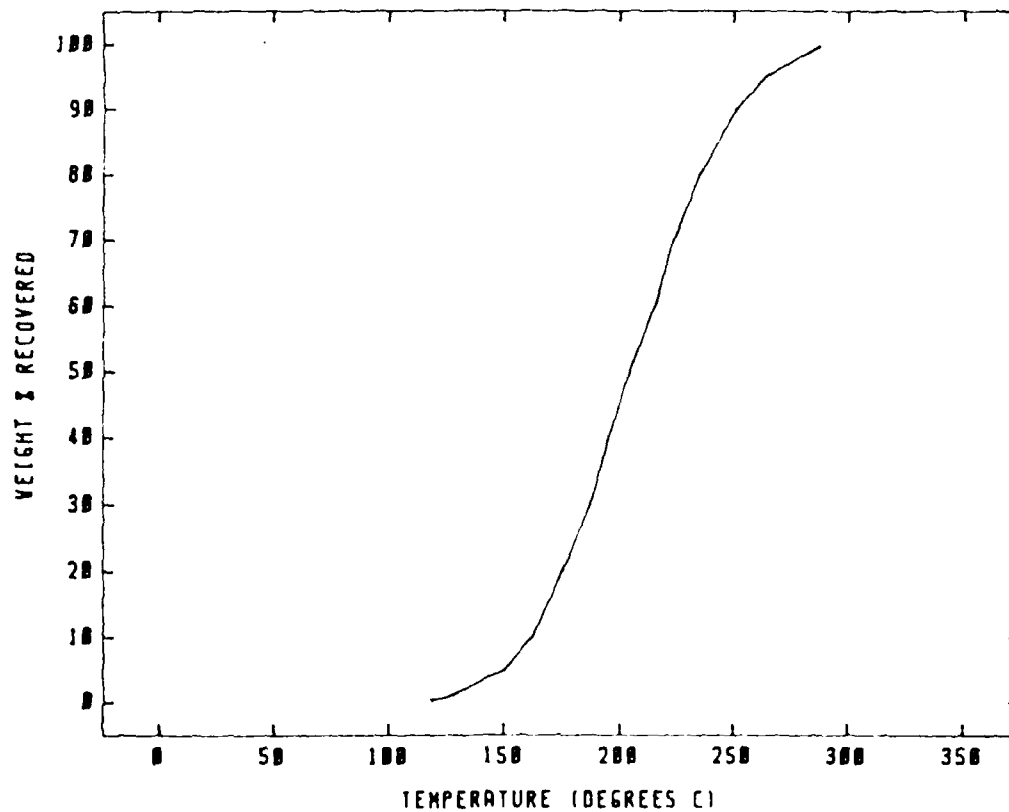


Figure B-28. Distillation Curve for Leeuwarden Sample

TABLE B-25

SIMULATED DISTILLATION DATA FOR VOLKEL SAMPLE

% Recovered	Temperature	
	$^{\circ}\text{C}$	$^{\circ}\text{F}$
0.5	92	197
1.0	99	211
5.0	131	267
10	149	300
20	166	330
30	175	346
40	184	364
50	194	382
60	202	396
70	214	417
80	226	438
90	241	465
95	253	488
99	269	516
99.5	272	521

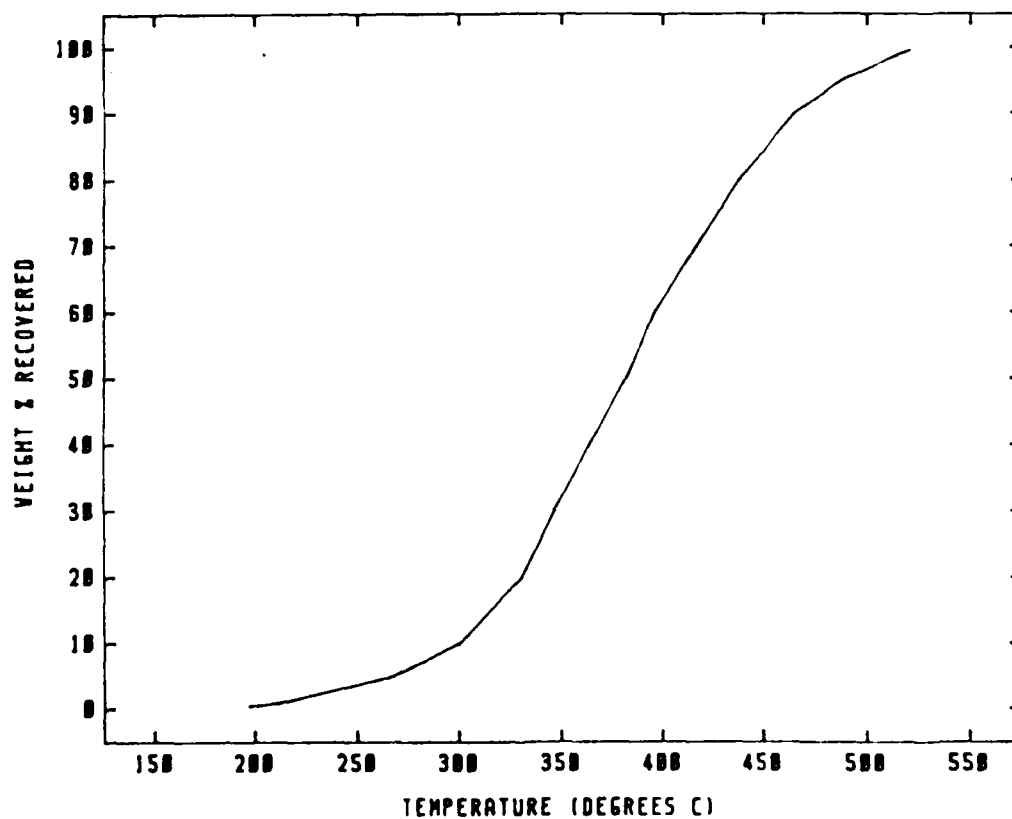


Figure R-29. Simulated Distillation Curve for Volkel Sample

TABLE B-26
HYDROCARBON TYPE ANALYSES

	INSHAS #1		INSHAS #2		EGYPT JP-4		KING FAHAD		KING AZIZ	
	ASTM ^a	Monsanto ^b	ASTM	Monsanto	ASTM	Monsanto	ASTM	Monsanto	ASTM	Monsanto
Paraffins	49.2	47.0	49.3	47.0	50.1	47.8	64.6	59.5	64.8	59.4
Cycloparaffins	33.2	- ^c	33.1	-	34.7	-	17.3	-	16.9	-
Dicycloparaffins	0	-	0	-	0	-	2.5	-	2.6	-
Total cyclo- paraffins	33.2 ^d	32.1	33.1	32.2	34.7	33.1	19.8	19.4	19.5	19.5
Alkylbenzenes	13.3	16.7	13.5	16.8	12.3	16.2	13.1	19.6	13.3	19.7
Indans and tetralins	2.1	2.0	2.0	1.9	1.5	1.6	1.7	1.5	1.6	1.4
Indenes and di- hydronaphthalenes	-	0	-	0	-	0	-	0	-	0
Naphthalenes	2.2	2.2	2.1	2.1	1.4	1.3	0.8	0	0.8	0
Average carbon no.	N/A		N/A		10.1		8.7		8.6	

^aModification of ASTM Method D 2789, values converted from volume percent using relative densities.

^bMonsanto Method 21-PQ-38-63.

^cDash: indicates method does not provide information on this compound category.

^dSum of two preceding values.

TABLE B-26 (Continued)

	JAPAN		PAKISTAN		BEAUVECHAIN		KLEINE BROGEN		SKRYDSTRU	
	ASTM	Monsanto	ASTM	Monsanto	ASTM	Monsanto	ASTM	Monsanto	ASTM	Monsanto
Paraffins	62.4	56.7	63.4	57.8	53.3	45.9	58.5	52.5	56.1	51.0
Cycloparaffins	20.9	^c -	19.0	-	27.9	-	24.8	-	27.5	-
Dicycloparaffins	2.5	-	2.1	-	4.9	-	4.0	-	5.3	-
Total cyclo- paraffins	23.4 ^d	23.3	21.1	21.0	38.8	35.3	28.8	30.0	32.8	33.6
Alkylbenzenes	12.1	18.4	13.4	20.5	11.1	16.7	10.3	15.8	9.5	13.7
Indans and tetralins	1.6	1.6	1.1	0.7	1.8	1.8	1.5	1.5	1.5	1.7
Indenes and di- hydronaphthalenes	-	0	-	0	-	0	-	0	-	0
Naphthalenes	0.5	0	1.0	0	1.0	0.3	0.9	0.2	0.1	0
Average carbon no.	8.7		8.5		8.6		8.7		9.0	

^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 B-26 (Continued)

	BODO		RYGGE		EGYPT JP-8		VENEZUELA		LEEWARDEN	
	ASTM ^a	Monsanto ^b	ASTM	Monsanto	ASTM	Monsanto	ASTM	Monsanto	ASTM	Monsanto
Paraffins	51.5	43.9	50.5	47.9	47.0	44.5	38.3	37.6	48.8	48.1
Cycloparaffins	29.2	- ^c	33.2	-	32.3	-	41.1	-	34.8	-
Dicycloparaffins	2.2	-	0	-	0.3	-	0.5	-	0	-
Total cyclo- paraffins	31.4 ^d	32.9	33.2	31.5	32.6	31.6	41.6	40.6	34.8	33.9
Alkylbenzenes	16.0	23.2	13.0	17.5	13.6	16.5	12.7	15.0	10.6	13.2
Indans and tetralins	0.4	0	3.0	2.8	2.5	2.3	4.4	3.8	4.7	3.9
Indenes and di- hydronaphthalenes	-	0	-	0	-	0	-	0	-	0
Naphthalenes	0.7	0	0.3	0.3	4.3	5.1	3.0	3.0	1.1	0.9
Average carbon no.	8.0		9.1		N/A		10.6		10.5	

Modification of ASTM Method D 2789, values converted from volume percent using relative densities.
Monsanto Method 21-PQ-38-63.

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

Sum of two preceding values.

TABLE B-26 (Concluded)

	VOLKEL	
	ASTM ^a	Monsanto ^b
Paraffins	43.7	41.9
Cycloparaffins	36.9	- ^c
Dicycloparaffins	0	-
Total cyclo- paraffins	36.9 ^d	36.1
Alkylbenzenes	13.6	16.8
Indans and tetralins	3.1	2.7
Indenes and di- hydronaphthalenes	-	0
Naphthalenes	2.7	2.5
Average carbon no.	10.1	-

^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 this specific compound category.

^d Sum of two preceding values.

TABLE B-27
AVERAGE HYDROCARBON TYPES

	US F100 JP-4	FOREIGN JP-4	FOREIGN JP-8
Paraffins	53.50	56.1	44.5
Cycloparaffins	27.40	26.5	36.3
Dicycloparaffins	4.01	2.2	0.2
Paraffin/cycloparaffins	84.90	84.8	81.0
Alkylbenzene	12.80	12.6	12.6
Indans and tetralins	1.50	1.7	4.0
Naphthalenes	0.80	1.0	2.8
Total aromatics	15.00	15.3	19.4

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7-86