Aviation Jet Fuel – Characteristics and Properties

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17.11.16

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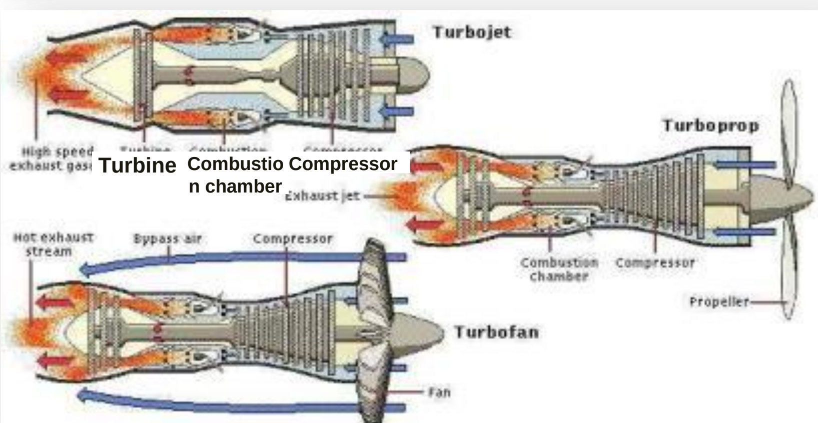
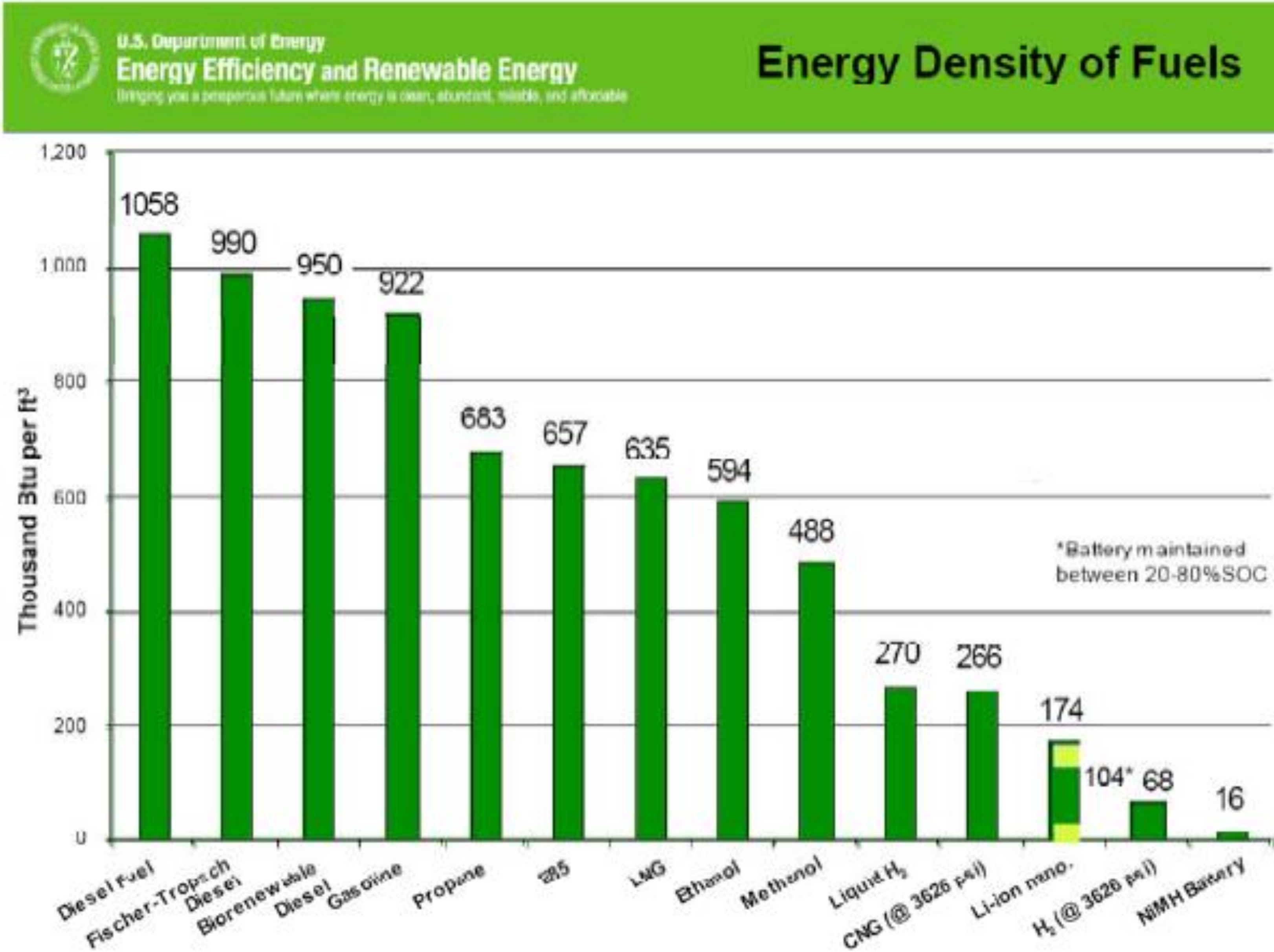
The Evolution of Jet Fuel

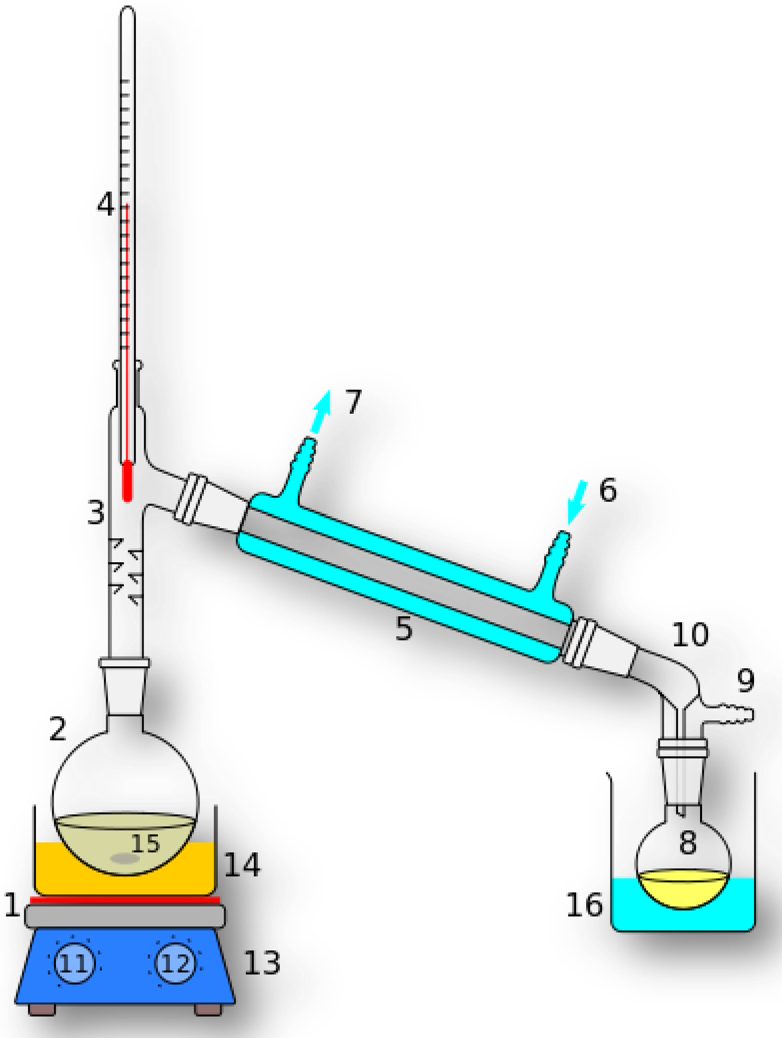


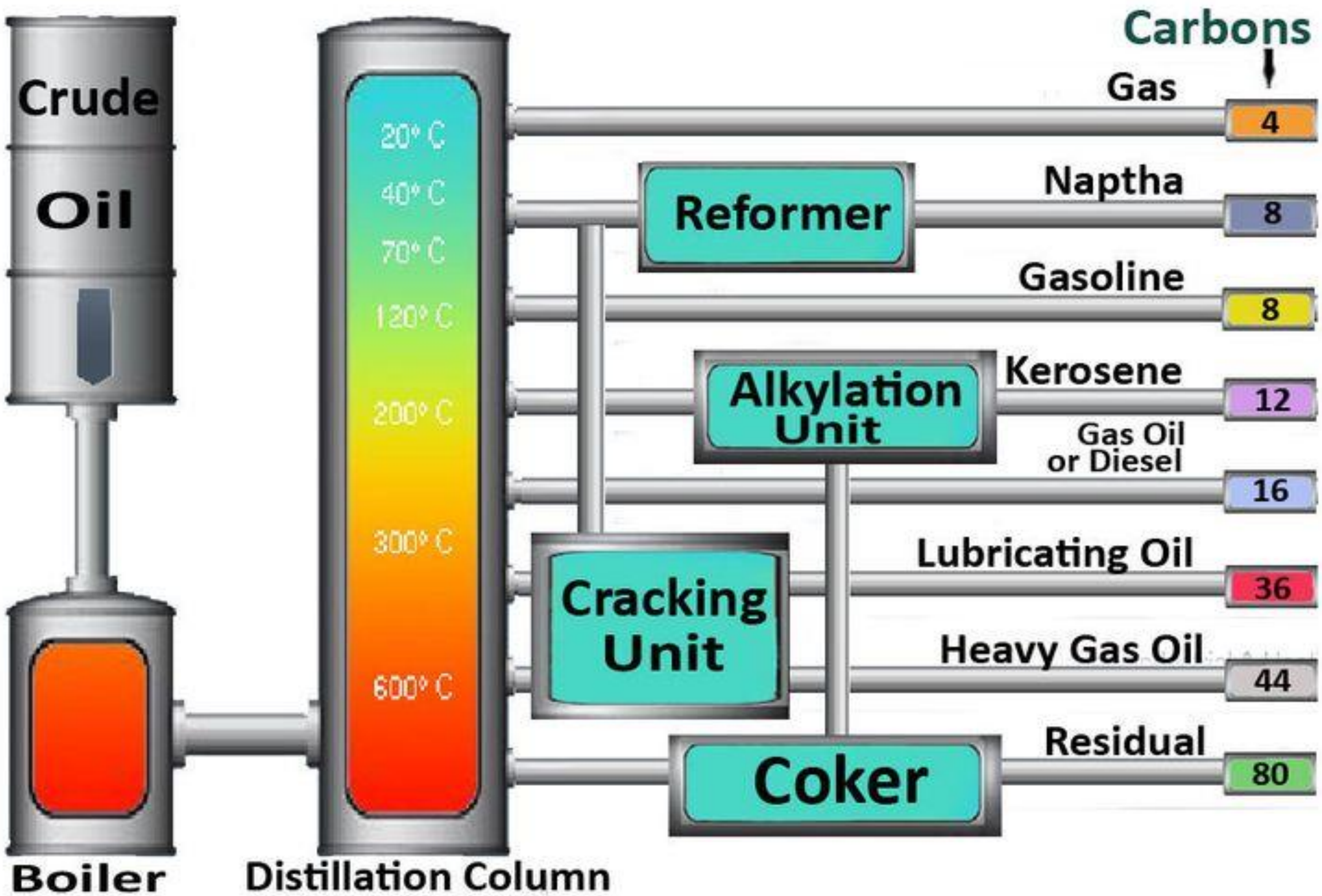
The Evolution of Jet Fuel

Liquid fuels have the highest energy density

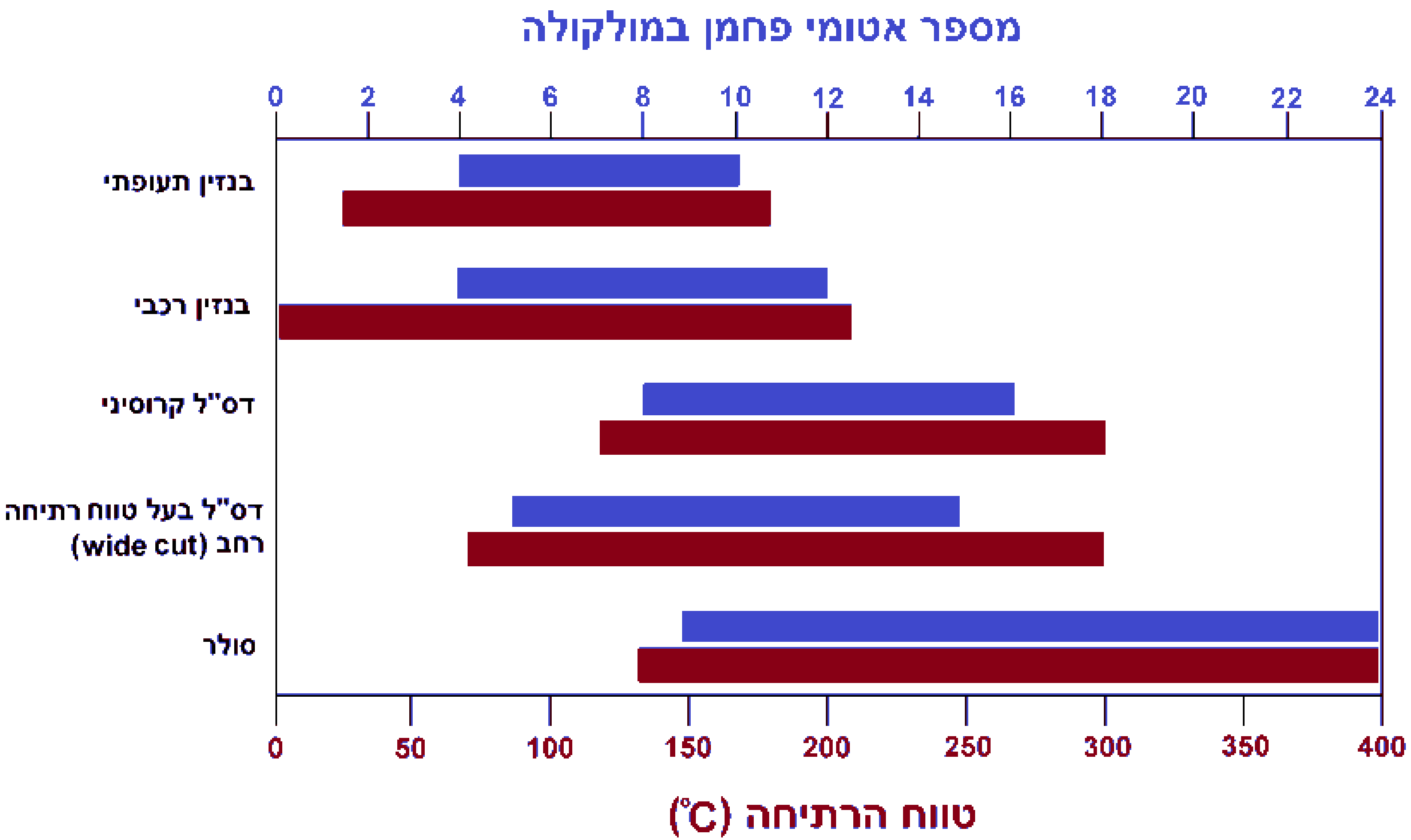



דס"ל
מים
מים בלבד
דס"ל בלבד
100
80
60
40
20
APPROX
Boro 3.3
100ml


4
3
7
6
5
10
9
2
15
14
8
1
16
11
12
13



Crude
Oil
Boiler
Distillation Column
20° C
40° C
70° C
120° C
200° C
300° C
600° C
Reformer
Alkylation Unit
Cracking Unit
Coker
Carbons
Gas
4
Naptha
8
Gasoline
8
Kerosene
12
Gas Oil or Diesel
16
Lubricating Oil
36
Heavy Gas Oil
44
Residual
80



מספר אטומי פחמן במולקולה
0
2
4
6
8
10
12
14
16
18
20
22
24
בנזין תעופתי
בנזין רכבי
דס"ל קרוסיני
דס"ל בעל טווח רתיחה רחב (wide cut)
סולר
0
50
100
150
200
250
300
350
400
טווח הרתיחה (°C)

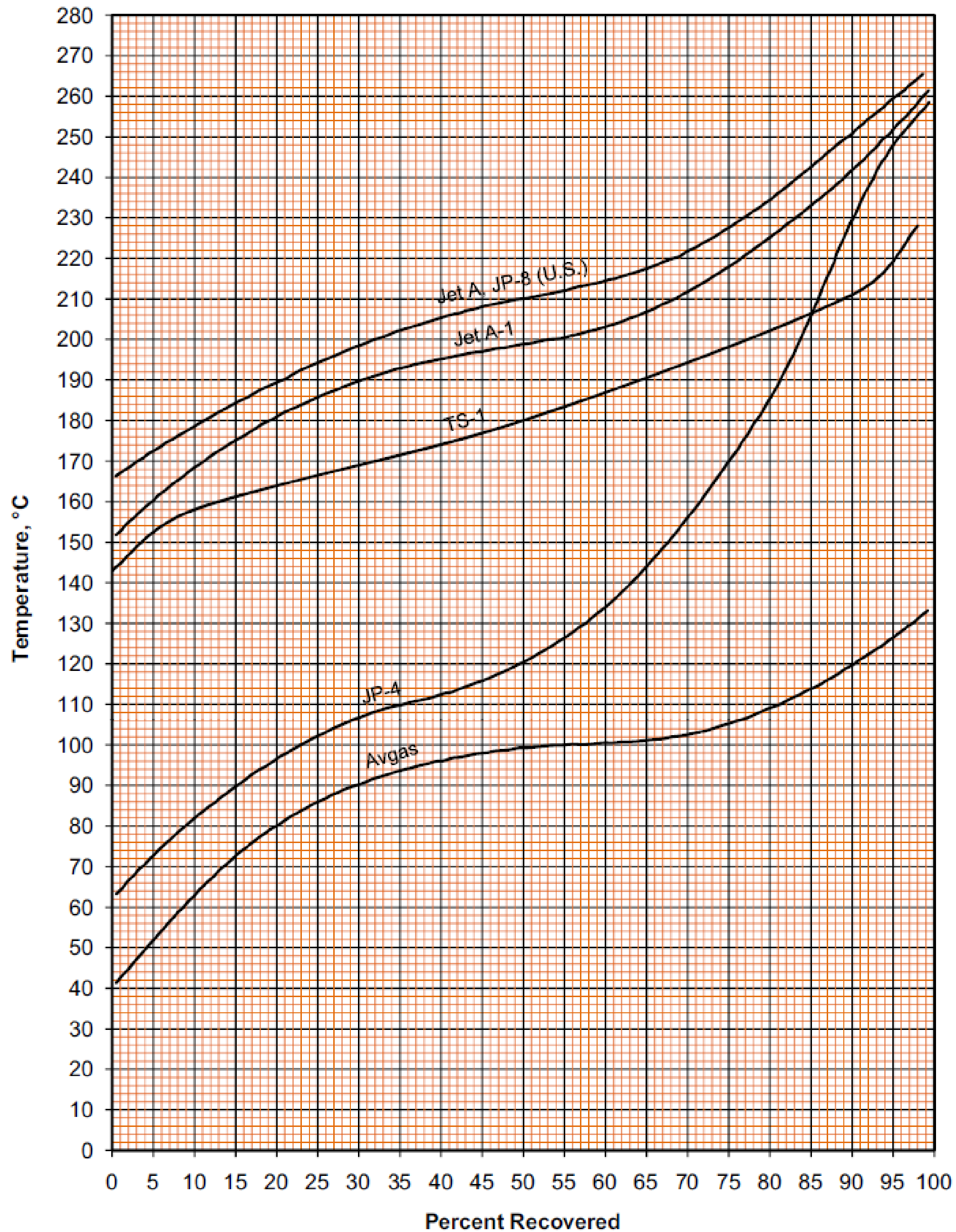
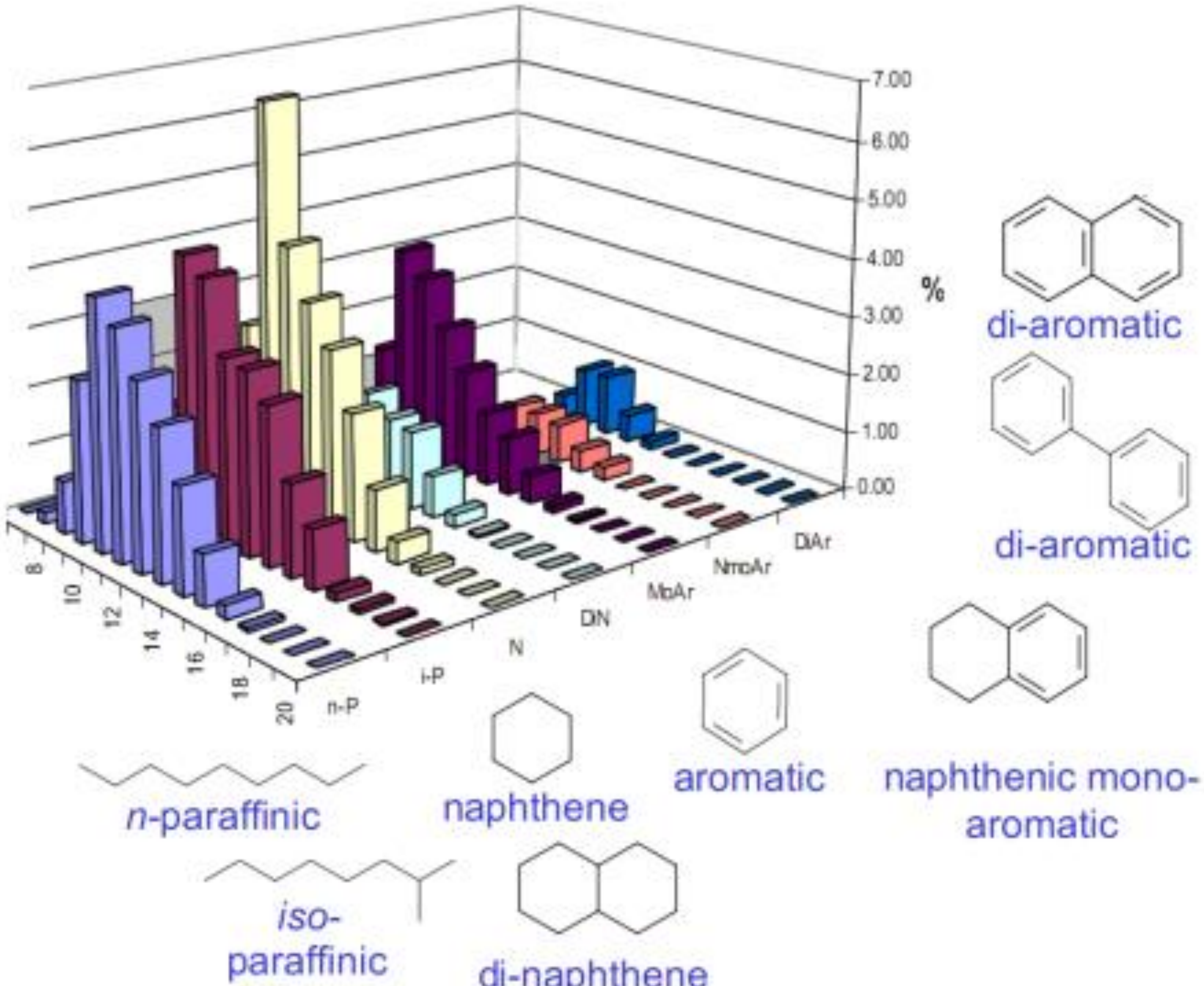


Figure 2-10. Distillation Curves for Typical Turbine Fuels and Avgas (ASTM D86 except for TS-1,GOST 2177)

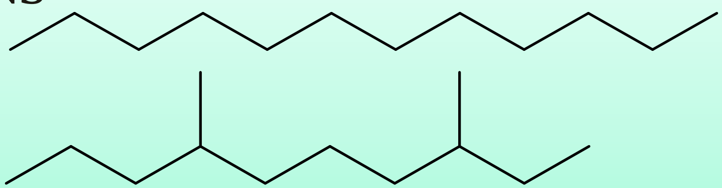
Conventional straight run kerosene type jet fuel

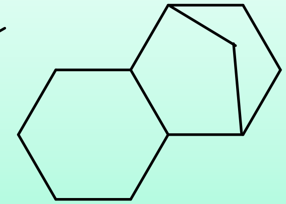


E4Tech, 2009.BiomassSupplyCurvesfortheUK,March2009

Composition

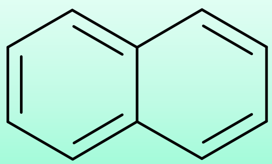
PARAFFINS
(75-80%)

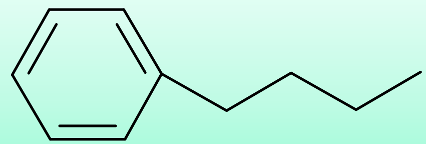




Normal and Iso-Paraffins **Cyclo&Polycyclo-Paraffins**

AROMATICS
(15-25%)

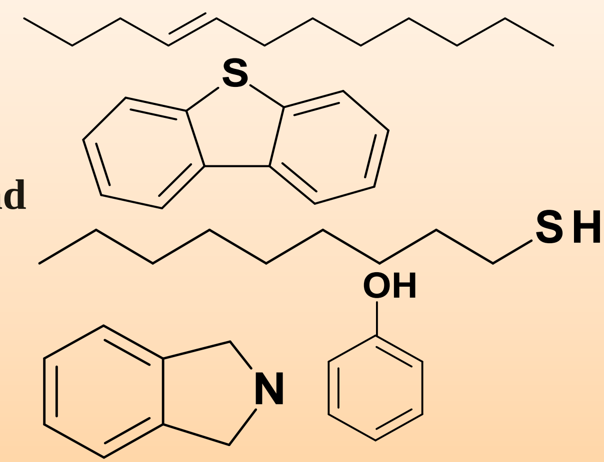




Energy content, combustion, density, and freezing point depend on the relative amount of bulk components.

TRACES:

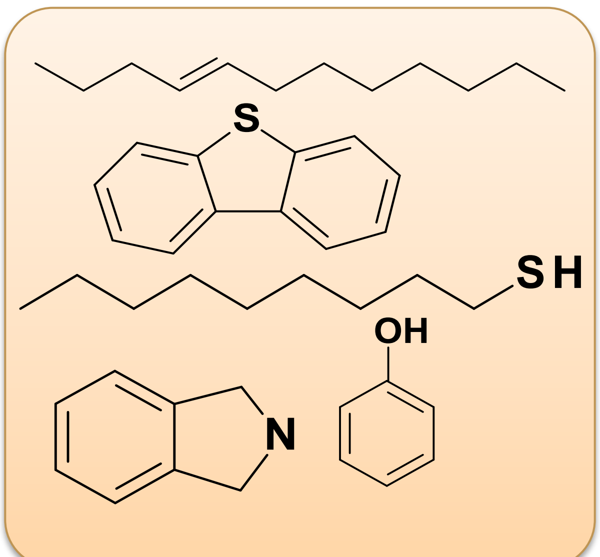
Olefins; Sulfur, Nitrogen and Oxygen-containing compounds

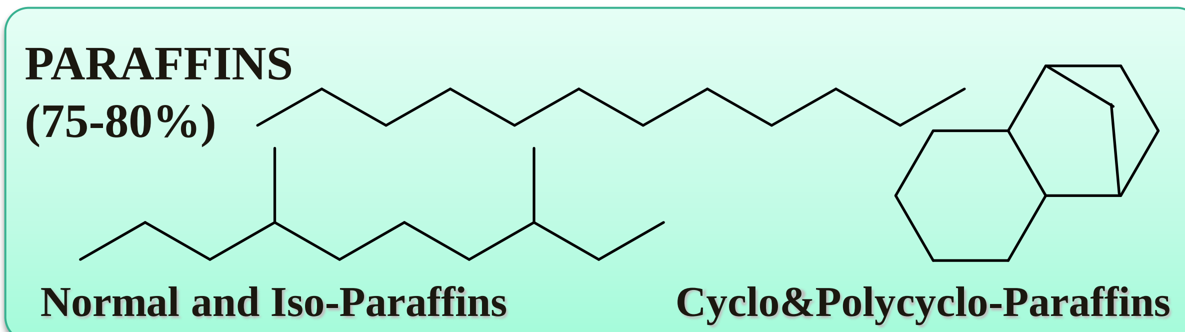


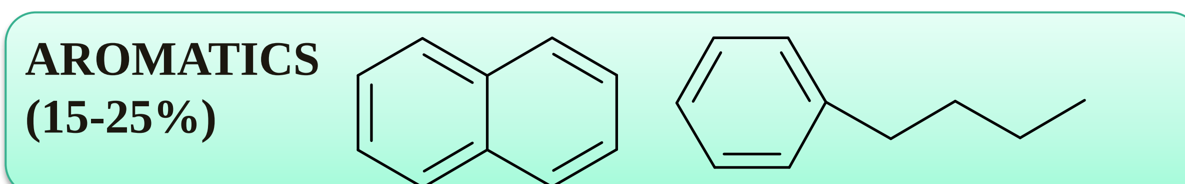
Lubricity, thermal and storage stability, and corrosivity are affected by just a few ppm's of traces in the fuel.
Sulfur compounds provide lubricity for jet fuel.
Alkenes , nitrogen and oxygen compounds decrease the storage and thermal stability.

Relationship of Jet Fuel Properties to Composition

Property	Relation to Composition	Property	Relation to Composition
Energy content	Bulk	Lubricity	Trace
Combustion characteristics	Bulk	Stability	Trace
Distillation range	Bulk	Corrosivity	Trace
Density	Bulk	Cleanliness	Trace
Fluidity	Bulk	Electrical conductivity	Trace







Composition - Gas Chromatography

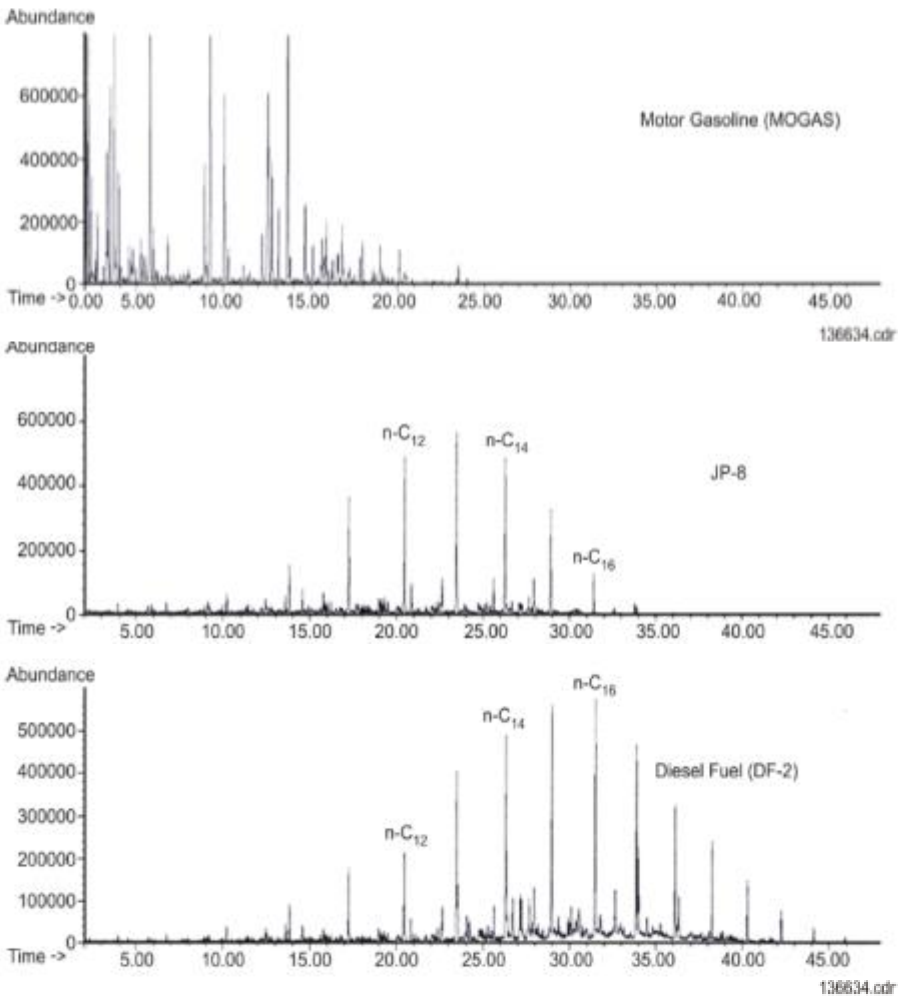


Figure 4-17. Gas Chromatograms of JP-8, Diesel Fuel, and Motor Gasoline

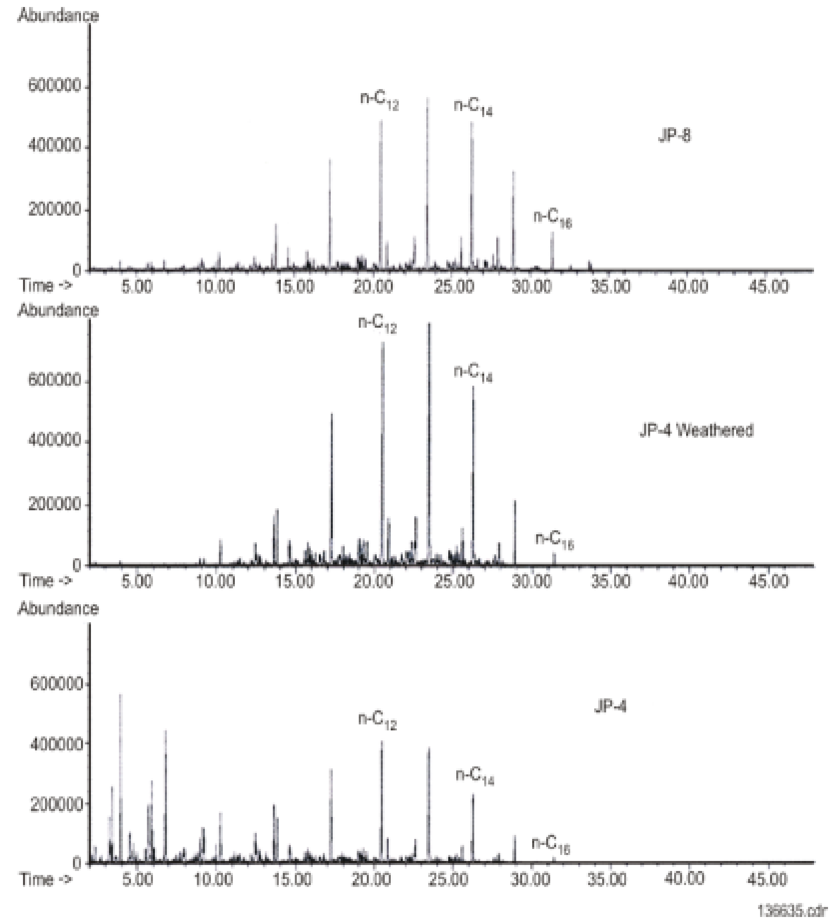
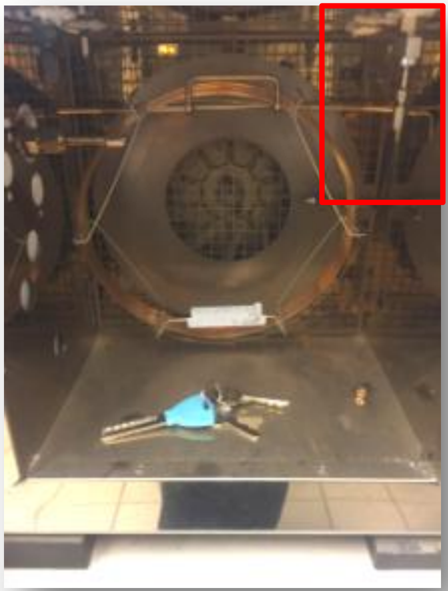


Figure 4-18. Comparison of Gas Chromatograms of Weathered JP-4, JP-8, and JP-4.



The Evolution of Jet Fuel

U.S. Military Jet Fuels

Fuel	Year Introduced	Freeze Point °C max	Flash Point °C min	Comments
JP-1	1944	−60	43	obsolete
JP-2	1945	−60		obsolete
JP-3	1947	−60		obsolete
JP-4	1951	−72		U.S. Air Force fuel
JP-5	1952	−46	60	U.S. Navy fuel
JP-6	1956	−54		XB-70 program, obsolete
JPTS	1956	−53	43	Higher thermal stability
JP-7	1960	−43	60	Lower volatility, higher thermal stability
JP-8	1979	−47	38	U.S. Air Force fuel

XB-70 Valkyrie

JP-6

JP-7

YF12A Interceptor photo taken from a refueling tanker.
The air refueling door is open to accept JP-7 fuel.

JP-7 (Jet Propellant 7) is a jet fuel developed by the U.S. Air Force for use in supersonic aircraft because of its high flash point and thermal stability. It is the fuel used in the Pratt & Whitney J58 engines, used in the Lockheed SR-71 Blackbird. The skin friction of the aircraft's surface with the atmosphere at Mach 3+ cruising flight generates very high skin temperatures; therefore this special fuel was needed.

The Evolution of Jet Fuel

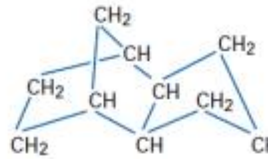
U.S. Military Jet Fuels

Fuel	Year Introduced	Freeze Point °C max	Flash Point °C min	Comments
JP-1	1944	−60	43	obsolete
JP-2	1945	−60		obsolete
JP-3	1947	−60		obsolete
JP-4	1951	−72		U.S. Air Force fuel
JP-5	1952	−46	60	U.S. Navy fuel
JP-6	1956	−54		XB-70 program, obsolete
JPTS	1956	−53	43	Higher thermal stability
JP-7	1960	−43	60	Lower volatility, higher thermal stability
JP-8	1979	−47	38	U.S. Air Force fuel

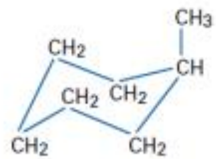
JP-8+100
JP-8+225
JP-9
JP-10

JP – 9

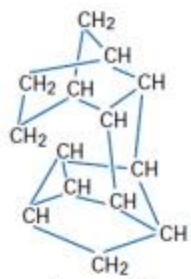
JP-9 is a mixture of these three compounds:



exo-tetrahydrodicyclopentadiene

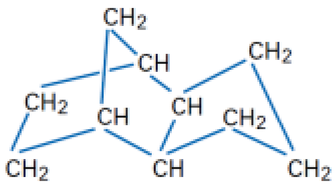


methylcyclohexane

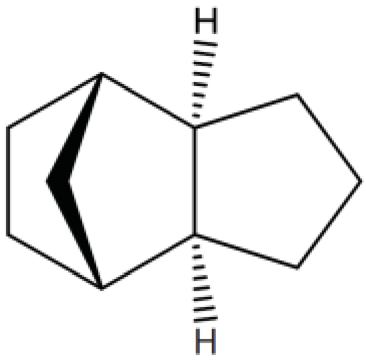


perhydronorbornadiene dimer

JP - 10



JP-10 exo-tetrahydrodicyclopentadiene



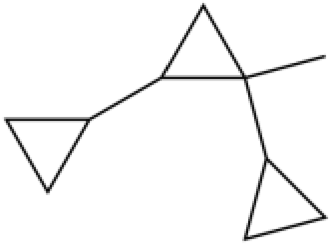
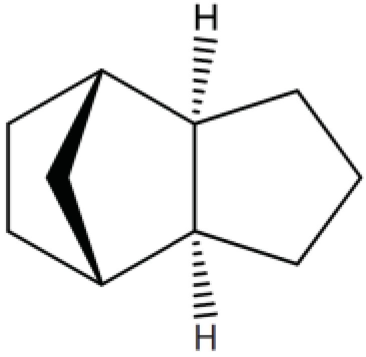


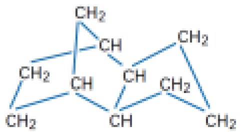
TABLE I. Chemical and physical requirements and test methods.

Property	Min	Max	ASTM Standards
Color, Saybolt	+25		D 156
Chemical Analysis, wt percent exo-tetrahydrodi (cyclopentadiene) other hydrocarbons	 98.5	 100.0 1.5	Note 1
Flash point, °C (°F)	54.4 (130)		D 93, D 3828
Density, 15 °C, kg/L (API)	0.935 (19.8)	0.943 (18.6)	D 1298
Freezing point, °C (°F)		-79 (-110)	D 2386 [2]
Viscosity, centistokes at °C (°F) -54 (-65) -18 (0)		 40 10	D 445
Net heat of combustion MJ/kg (Btu/lb) MJ/m (Btu/gallon)	 42.1 (18,100) 39,400 (141,500)		D 240, D 2382
Thermal stability change in pressure drop, mm Hg heater tube deposit visual rating		 10 less than code 3	D 3241 [3]
Existent gum, mg/100 mL		5.0	D 381
Particulate matter, mg/liter		1.0	D 2276

Notes
1. Test procedure and required equipment outlined in Appendix A.
2. This is for reference only, not a requirement.
3. See 4.5.1.1 for D 3241 test conditions and test limits.

JP-10

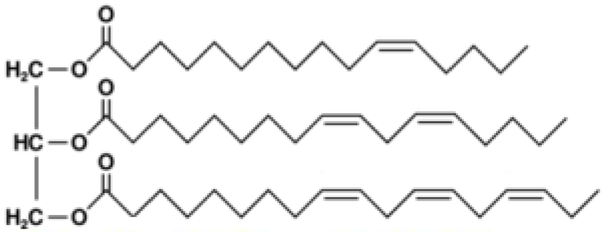




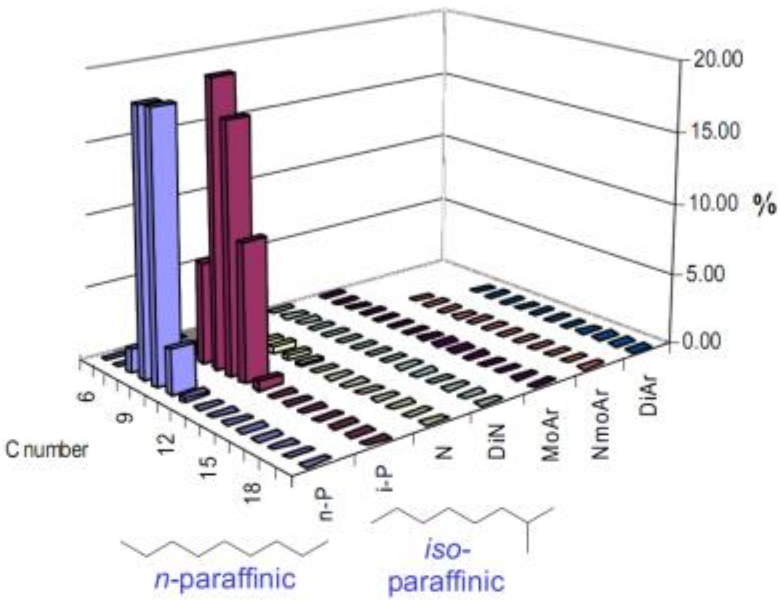
JP-10 exo-tetrahydrodicyclopentadiene

Type	Specification	Grade (NATO Code)	Country
Kerosene	ASTM D1655	Jet A1	USA Civil
		Jet A	USA Civil
	DEF STAN 91-91	AVTUR	United Kingdom
	MIL-DTL-83133H	JP-8 (F-34[1], F-35[2], F-37[3])	USA Military
	QAV-1		Brazil
	CAN/CGSB-3.23-02		Canada
	GB 6537-94		China
	GOST R 52050-2003		Russia
	GOST 10227-86	TS-1, T-1	Russia
	CAN/CGSB-3.22		Canadian
Wide Cut Type	ASTM D6615	Jet B	USA Civil
	MIL-DTL-5624	JP-4 (F-40[4])	USA Military
	DEF STAN 91-86	AVCAT/FSII	British Military
High flashpoint, kerosene type	MIL-DTL-5624	JP-5 (F-44[5])	USA Military (Navy)
	DEF STAN 91-88	AVTAG/FSII	British Military
	GOST 10227-86	T-1S, T-2, RT	Russia

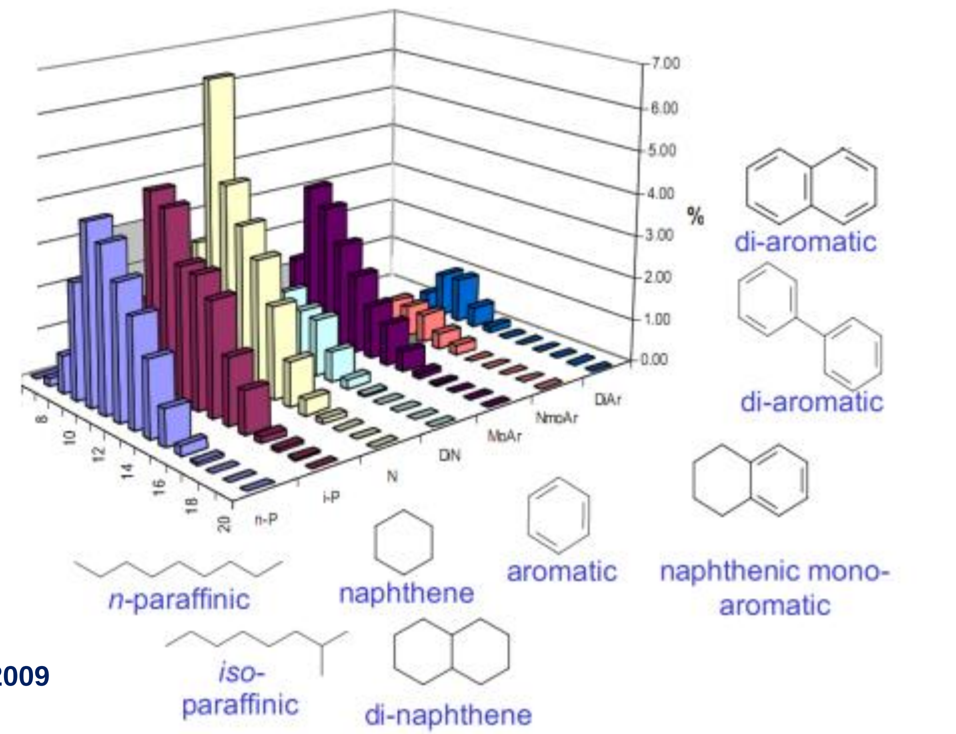
Jet Fuel Composition



Synthetic Paraffinic Kerosene



Conventional straight run kerosene type jet fuel



E4Tech, 2009.BiomassSupplyCurvesfortheUK,March2009

GTL

BTL

ATL

STJ

HEFA

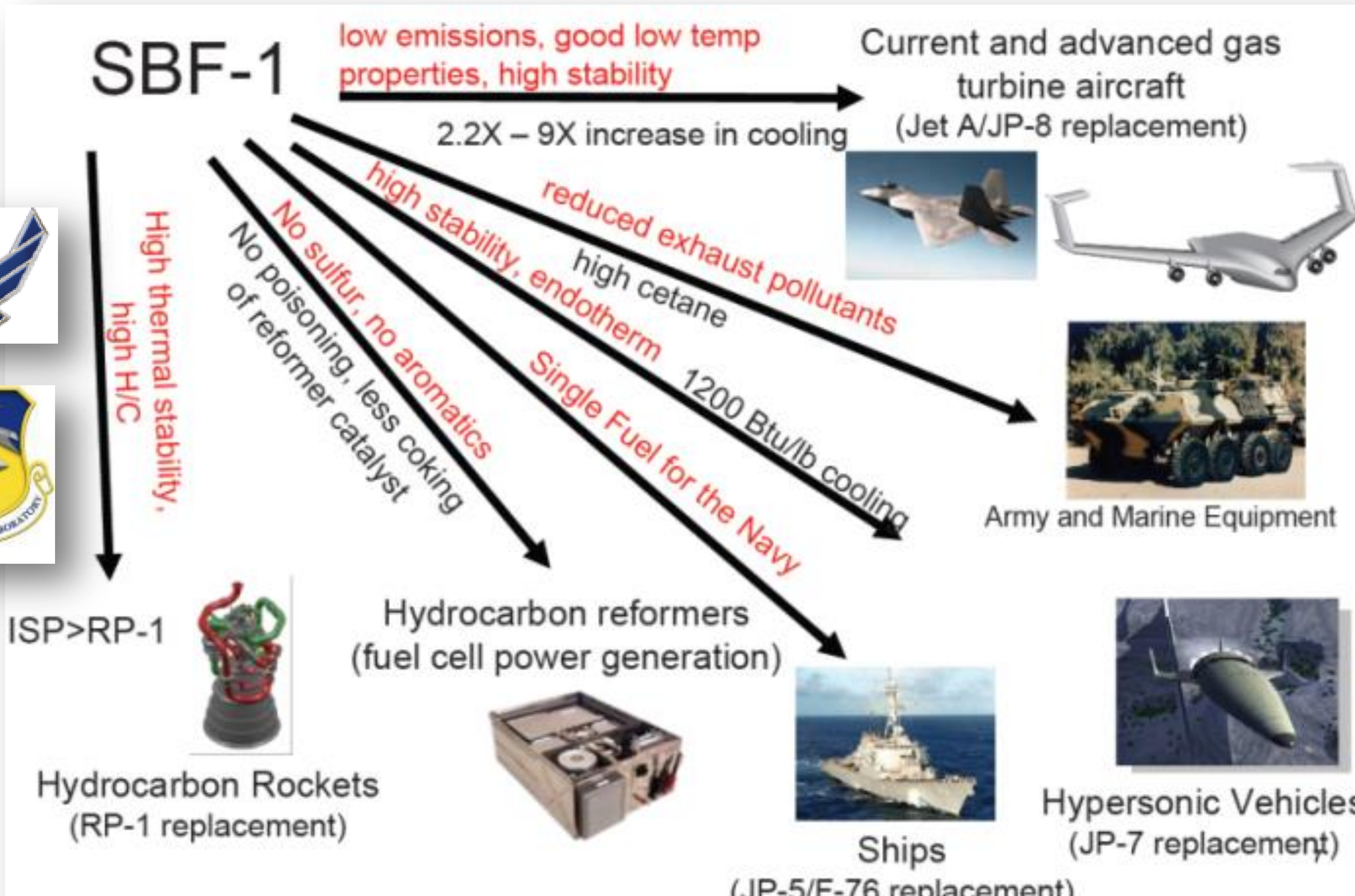
Tanker capacity in Port of Eilat is 150,000,000-250,000,000Liter

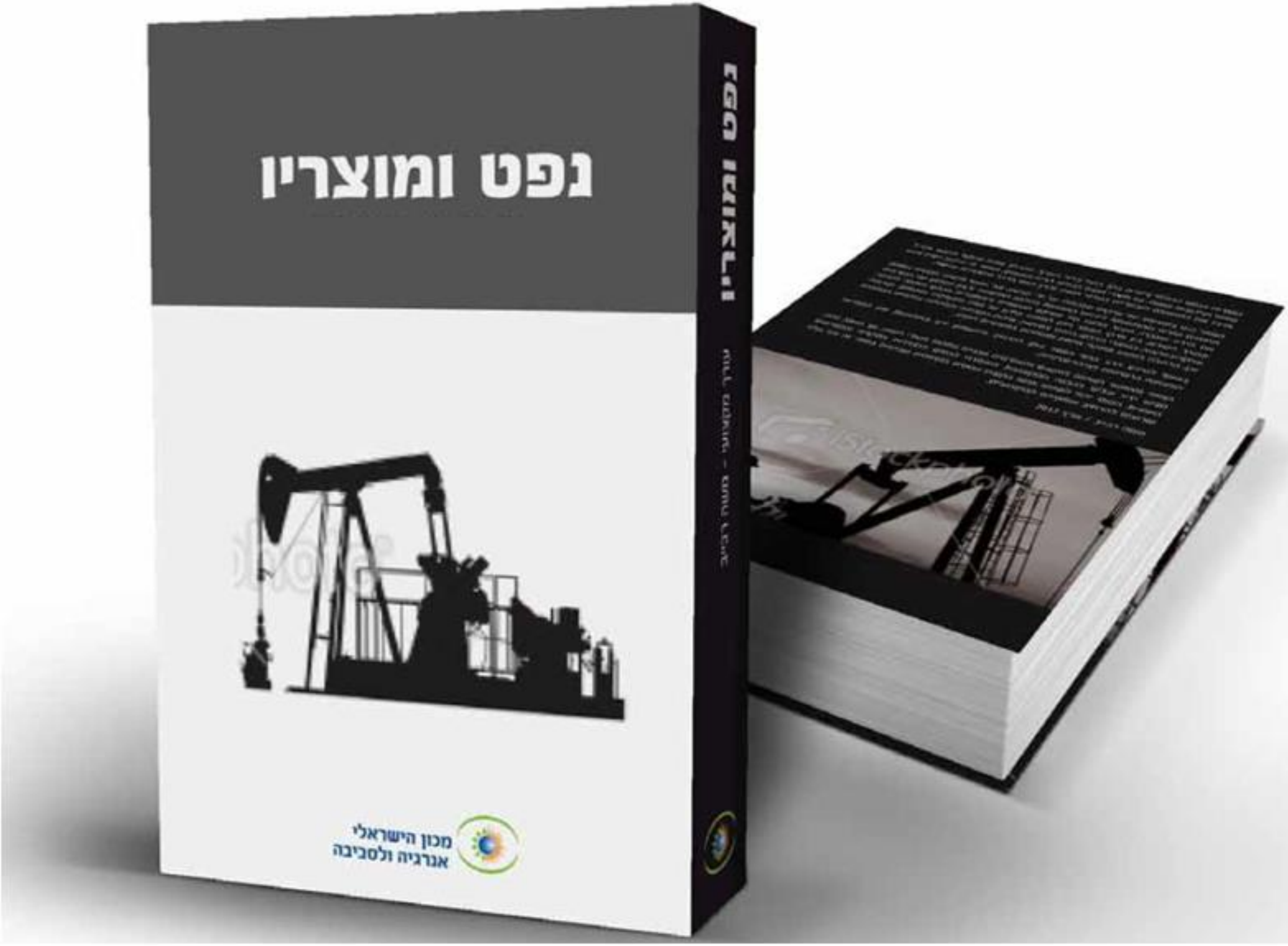
Airbus A380
Maximum range 15,000km
Maximum fuel capacity 360,000L

Attrage
3.75 -6.25 millions
refuelings

JP-8 SBF - Single Battlefield Fuel

Joint Battlespace Use Fuel of the Future (J-BUFF) Program





עתודות הנפט הידועות כיום יספיקו, לדעת מומחים, לכ-40 השנים הקרובות. עם זאת, חיפושי נפט מניבים מדי פעם מקורות חדשים. עליית מחיר הנפט עשויה להגדיל את העתודות, כי יהיה כדאי לחדש הפקה במרבצים שלא היו כדאיים להפקה בעבר. הם גם יכולים לתרום להאצת החיפושים באזורים שבהם הן הקידוחים והן ההפקה יקרים במיוחד - כמו קידוחים במים עמוקים, קידוחים יבשתיים לעומקים העולים על 6,000 מטר ועוד. יש לציין שכמות העתודות שנוספו למאגר העולמי הידוע כתוצאה מתגליות חדשות, ברמה הגבוהה מהתצרוכת השנתית העולמית. על כן, ההערכה שעתודות הנפט העולמיות תספקנה לכ-40 שנה לא השתנתה כבר מספר עשורים.

Defence Standard 91-91

Issue 7 Date: 18 February 2011

Incorporating Amendment 3 Date: 2 February 2015

Table 1 - Test Requirements

Test	Property	Units	Limits		Method
1	Appearance				
1.1	Visual Appearance		Clear, bright and visually free from solid matter and undissolved water at ambient fuel temperature		Visual (see Annex F)
1.2	Colour		Report		ASTM D156 or ASTM D6045 (see Note 1)
1.3	Particulate Contamination, at point of manufacture	mg/l	Max 1.0		IP423/ ASTM D5452 (see Note 2)
1.4	Particulate, at point of manufacture, cumulative channel particle counts	Individual channel counts & ISO Code	Channel Counts	ISO Code (see Note 3)	IP 564, IP 565 or IP 577 (see Note 4)
1.4.1	≥ 4 µm(c)		Report	Report	
1.4.2	≥6 µm(c)		Report	Report	
1.4.3	≥14 µm(c)		Report	Report	
1.4.4	≥21 µm(c)		Report	Report	
1.4.5	≥25 µm(c)		Report	Report	
1.4.6	≥30 µm(c)		Report	Report	
2	Composition				
2.1	Total Acidity	mg KOH/g	Max 0.015		IP 354/ ASTM D3242
2.2	Aromatic Hydrocarbon Types				
2.2.1	Aromatics	% v/v	Max 25.0		IP 156/ ASTM D1319
or					
2.2.2	Total Aromatics	% v/v	Max 26.5		IP 436/ ASTM D6379 (see Note 5)
2.3	Sulfur, Total	% m/m	Max 0.30		IP 336
2.4	Sulfur, Mercaptan	% m/m	Max 0.0030		IP 342/ ASTM D3227 (see Note 6)
or					
2.5	Doctor Test		Doctor Negative		IP 30

Continued on page 5

Table 1: Test Requirements (continued)

2.6	Refining Components, at point of manufacture			(see Note 7)
2.6.1	Non Hydroprocessed Components	% v/v	Report	
2.6.2	Mildly Hydroprocessed Components	% v/v	Report	
2.6.3	Severely Hydroprocessed Components	% v/v	Report	
2.6.4	Synthetic Components	% v/v	Report For limits see Annex D	(See Note 8 and Note 9)
3	Volatility:			
3.1	Distillation:			IP 123/ ASTM D86 (see Note 10)
3.1.1	Initial Boiling Point	°C	Report	
3.1.2	10% Recovery	°C	Max 205.0	
3.1.3	50% Recovery	°C	Report	
3.1.4	90% Recovery	°C	Report	
3.1.5	End Point	°C	Max 300.0	
3.1.6	Residue	% v/v	Max 1.5	
3.1.7	Loss	% v/v	Max 1.5	
3.2	Flash Point	°C	Min 38.0	IP 170
3.3	Density at 15 °C	kg/m^3	Min 775.0 Max 840.0	IP 365/ ASTM D4052
4	Fluidity:			
4.1	Freezing Point	°C	Max minus 47.0	IP 16/ ASTM D2386
4.2	Viscosity at minus 20 °C	mm^2/s	Max 8.000	IP 71/ ASTM D445
5	Combustion:			
5.1	Smoke Point	mm	Min 25.0	IP 598 / ASTM D1322 (see Note 11)
or				
5.2	Smoke Point and	mm	Min 19.0	IP 598 / ASTM D1322
	Naphthalenes	% v/v	Max 3.00	ASTM D1840
5.3	Specific Energy	MJ/kg	Min 42.80	(see Note 12)
6	Corrosion:			
6.1	Copper Strip	Class	Max 1	IP 154/ ASTM D130 (see Note 13)

Continued on page 6

Defence Standard 91-91

Issue 7 **Date: 18 February 2011**

Incorporating Amendment 3 **Date: 2 February 2015**

Table 1: Test Requirements (continued)

Test	Property	Units	Limits	Method
7	Thermal Stability, JFTOT			IP 323 /ASTM D3241 (See Note 14)
7.1	Test Temperature	°C	Min 260	
7.2	Tube Rating Visual		Less than 3. No Peacock (P) or Abnormal (A)	(See Note 15)
7.3	Pressure Differential	mm Hg	Max 25	
8	Contaminants:			
8.1	Existent Gum	mg/100ml	Max 7	IP 540
9	Water Separation Characteristics			
9.1	Microseparometer, at Point of Manufacture:			ASTM D3948 (See Note 16)
9.1.1	MSEP Without SDA	Rating	Min 85	
9.1.2	MSEP With SDA	Rating	Min 70	
10	Conductivity:			
10.1	Electrical Conductivity	pS/m	Min 50 Max 600	IP 274/ ASTM D2624 (See Note 17)
11	Lubricity: Wear Scar Diameter	mm	Max 0.85	ASTM D5001 (See Note 18)
12	Identified Incidental Materials			(See Note 19)
12.1	Fatty Acid Methyl Ester	mg/kg	Max 50	IP 585 (See Note 20)

Note 1: The requirement to report Saybolt Colour shall apply at point of manufacture, thus enabling a colour change during distribution to be quantified. Where the colour of the fuel precludes the use of the Saybolt Colour test method, then the visual colour shall be reported. Unusual or atypical colours should also be noted. For further information on the significance of colour see Annex E.

Note 2: Refer to the information on Particulate Contamination at Annex F.

Note 3: Both the number of particles and the number of particles as a scale number as defined by Table 1 of ISO 4406:1999 shall be reported.

Note 4: It is the Specification Authority's intention to replace Test 1.3 with Test 1.4 at the earliest opportunity.

Note 5: Round robin testing has demonstrated the correlation between total aromatics content measured by IP 156/ASTM D1319 and IP 436/ASTM D6379. Bias between the two methods necessitates different equivalence limits as shown. Testing laboratories are encouraged to measure and report total aromatics content by the two methods to assist verification of the correlation. In cases of dispute IP 156 will be the referee method. It is the intention of the Technical Authority to change the referee method to IP 436 at a later date.

Note 6: The alternative requirement 2.5 is a secondary requirement to 2.4. In the event of a conflict between Sulfur Mercaptan (2.4) and Doctor Test (2.5) results, requirement 2.4 shall prevail.

Note 7: Each refinery component used in the make-up of the batch shall be reported on the Refinery Certificate of Quality as a percentage by volume of the total fuel in the batch. Mildly hydroprocessed components are defined as those petroleum derived hydrocarbons that have been subjected to a hydrogen partial pressure of less than 7000 kPa (70 bar or 1015 psi) during manufacture. Severely hydroprocessed components are defined as those petroleum derived hydrocarbons that have been

Continued on Page 7

Table 1: Test Requirements (concluded)

subjected to a hydrogen partial pressure of greater than 7000 kPa (70 bar or 1015 psi) during manufacture. The total of non-hydroprocessed plus mildly hydroprocessed plus severely hydroprocessed plus synthetic components shall equal 100%.

Note 8: The volume percentage of each synthetic blending component type shall be recorded along with its corresponding release Specification and Annex number, product originator and originator's Certificate of Quality number.

Note 9: The aromatic content of the finished semi-synthetic Aviation Turbine Fuel shall not be less than 8.0% nor greater than 25.0% by volume when using method IP156, or not less than 8.4% nor greater than 26.5% by volume when using method IP436. Further, the boiling point distribution of the semi-synthetic Aviation Turbine Fuel shall have a minimum distillation slope as defined by the T50-T10 of ≥ 15°C and a T90-T10 of ≥ 40°C.

Note 10: In methods IP 123 and ASTM D86 all fuels certified to this specification shall be classed as group 4, with a condenser temperature of zero to 4°C.

Note 11: Alternative test requirements identified in Table 1; Test Requirements 5.1 or 5.2 are equal primary requirements. IP 598 includes both a manual and an automated method. The manual method in IP 598 is the referee method. It is the intention of the Specification Authority to make the automated method in IP 598 the referee method in January 2014.

Note 12: Specific Energy by one of the calculation methods listed at Annex C is acceptable. Where a measurement of Specific Energy is deemed necessary, the method to be used shall be agreed between the Purchaser and Supplier.

Note 13: The sample shall be tested in a pressure vessel at 100±1°C for 2 hours ± 5 minutes.

Note 14: Thermal Stability is a critical aviation fuel test and while competition among equipment manufacturers/suppliers is to be encouraged, aircraft safety must remain paramount. It is known that there are heater tubes being supplied by sources other than the original equipment manufacturer (OEM). Until the alternative manufacturers' tubes have been demonstrated to be equivalent to the OEM's test pieces, to the satisfaction of the AFC, they shall not be used. A list of manufacturers whose heater tubes have been found to be technically suitable is as follows: a) PAC – Alcor b) Falex

Note 15: Examination of the heater tube to determine the Visual Tube Rating using the Visual Tube Rator shall be carried out within 120 minutes of completion of the test.

Note 16: Where SDA is added at point of manufacture the MSEP limit of 70 shall apply. No precision data are available for fuels containing SDA; if MSEP testing is carried out during downstream distribution no specification limits apply and the results are not to be used as the sole reason for rejection of a fuel. A protocol giving guidelines on possible actions to be taken following failed MSEP testing can be found in the Joint Inspection Group's Bulletin Number 14, MSEP Protocol at 'www.jigonline.com' under 'fuel quality'. Where SDA is added downstream of point of manufacture, it is acknowledged that MSEP results may be less than 70.

Note 17: The conductivity limits are mandatory for product to meet this specification. However it is acknowledged that in some manufacturing and distribution systems it is more practical to inject SDA further downstream. In such cases the Certificate of Quality for the batch should be annotated thus: "Product meets requirements of Defence Standard 91-91 except for electrical conductivity". The Specification Authority is also aware of situations where conductivity can decrease rapidly and the fuel can fail to respond to additional dosing of Stadis 450 (see Annex H for more information).

Note 18: The requirement to determine lubricity applies only to fuels whose composition is made up of a) less than 5% non hydroprocessed components **and** at least 20% severely hydroprocessed components (see Note 8) or b) includes synthesised fuel components. The limit applies only at the point of manufacture.

Note 19: See Clause 5.5 and 5.6 for additional information on identified incidental materials and FAME.

Note 20: Post manufacture a risk assessment shall be undertaken to quantify the potential risk of FAME carryover in all supply chains. Where such assessments indicate that there could be a potential risk in jet fuel supplies, additional quality assurance procedures shall be introduced to increase control in order to mitigate the risk. Where the risk of FAME carryover exists and it is not possible to control with additional quality assurance procedures, testing shall be instigated. Further guidance on how to verify compliance with this requirement is contained in Annex G.

HANDBOOK OF AVIATION FUEL PROPERTIES

2014 Fourth Edition

COORDINATING RESEARCH COUNCIL, INC.

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Dr. Thomas Smagala and Linda Gallaher of Chevron Aviation digitized the data points, developed equations of the lines, and generated the preliminary graphs. Dr. Clifford Moses, Consultant, digitized data points, resolved problems and inconsistencies in plotted data, and generated the finished graphs. Dr. Moses incorporated Russian TS-1 and RT data into the handbook plots from his CRC-funded program AV-12-10, *Properties of Russian Fuels*. Mr. Ben Coon designed the handbook cover. Margaret Adamson, Jamey Tatro, Margaret Fiore, and Jessica Fisher of Pratt & Whitney were responsible for putting the text and graphics of the document in publishable form. The draft review team was composed of the following experts:

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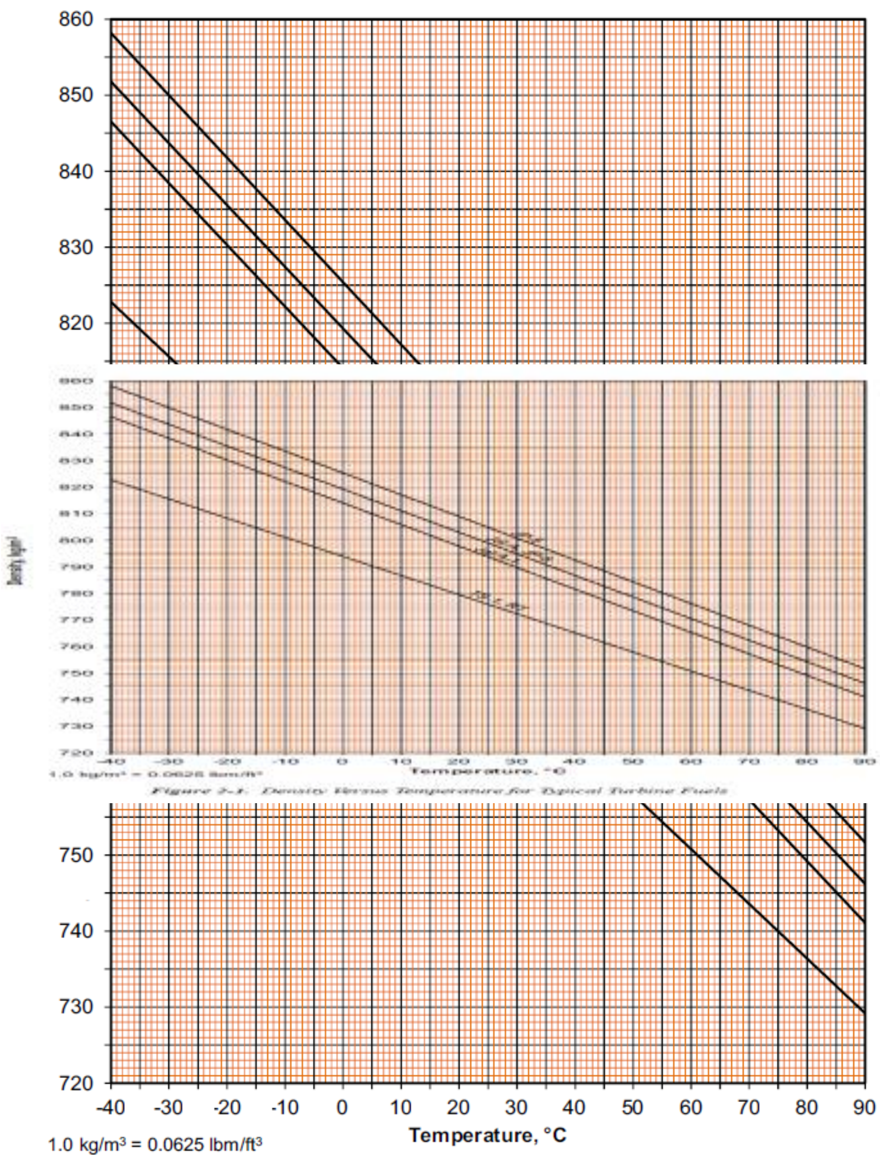


Figure 2-1. Density Versus Temperature for Typical Turbine Fuels

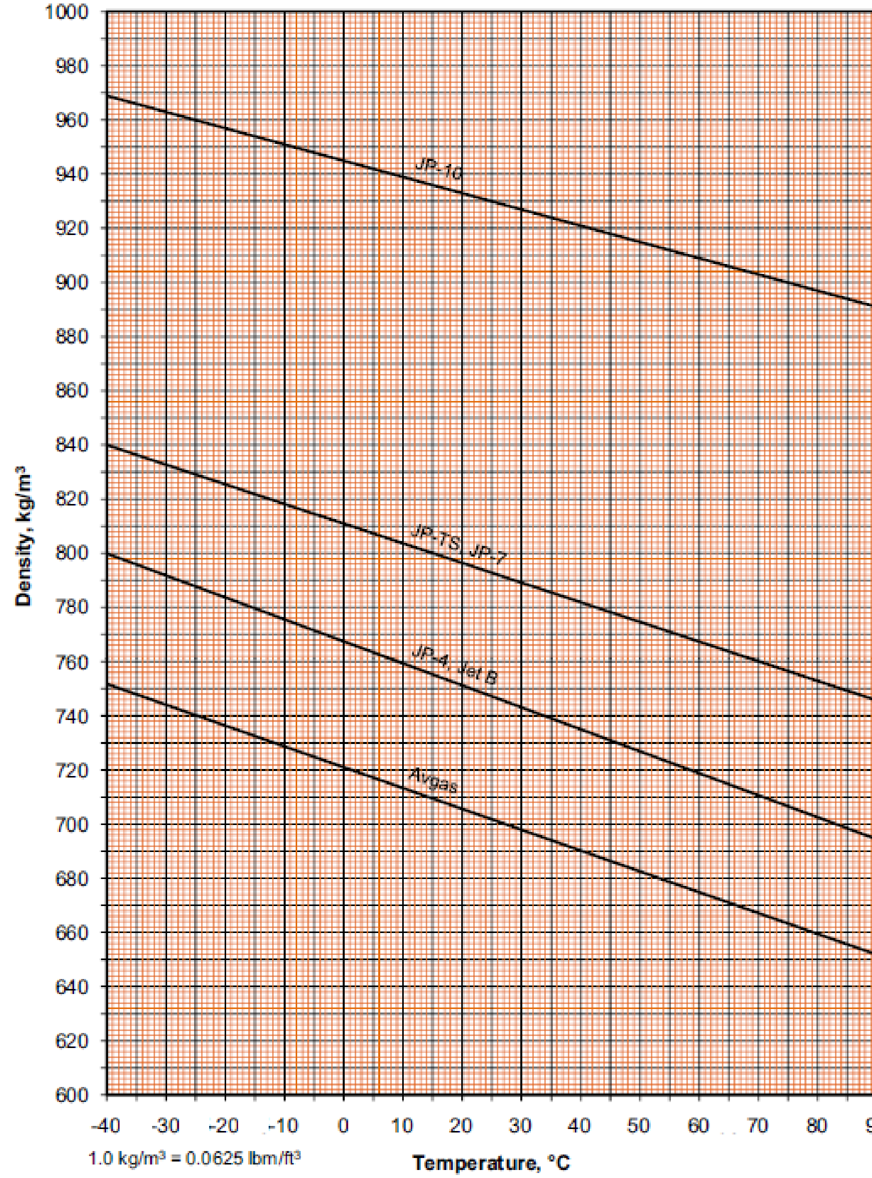


Figure 2-2. Density Versus Temperature for Typical Turbine Fuels, Avgas, and JP-10

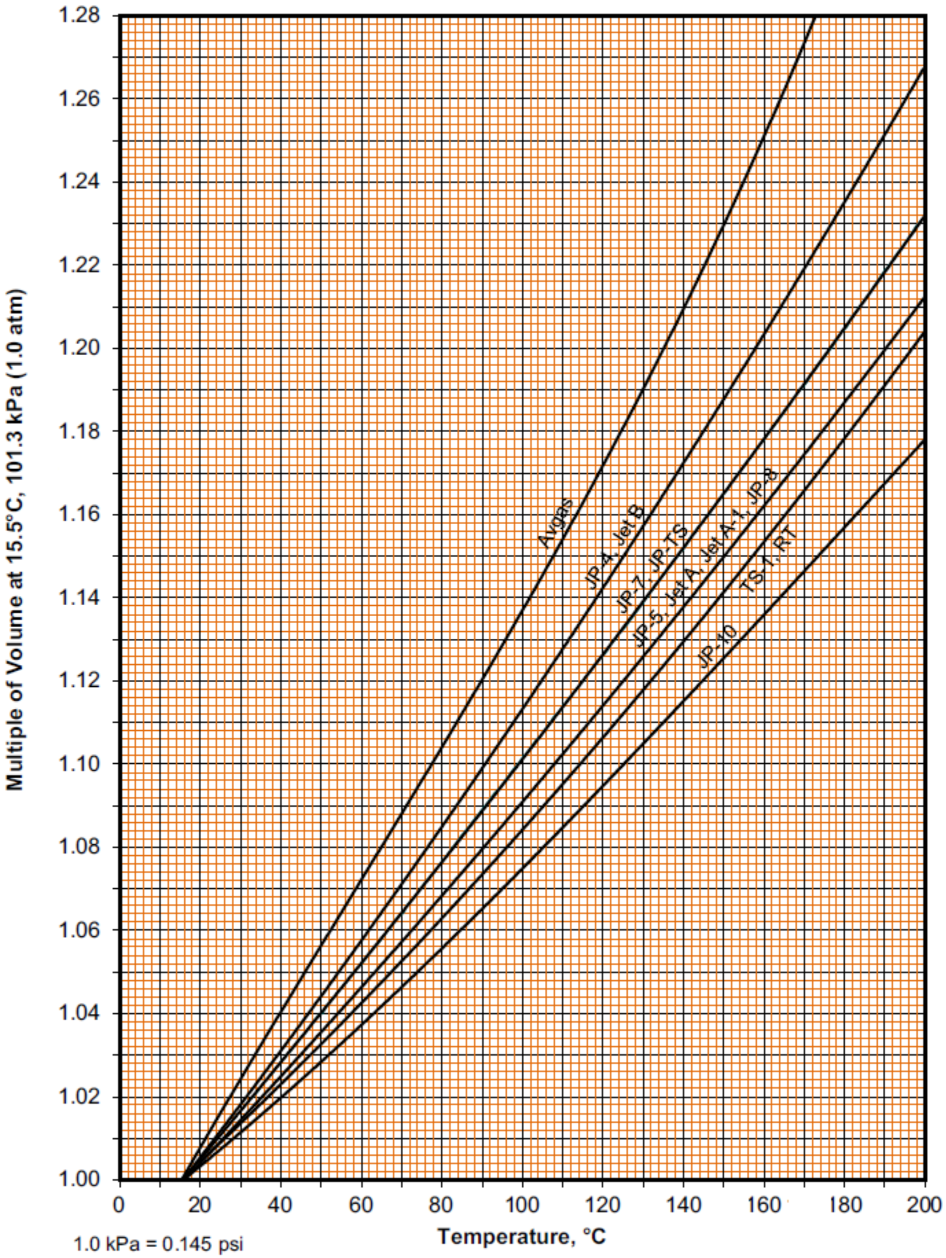


Figure 2-5. *Thermal Expansion of Typical Aviation Fuels and JP-10*

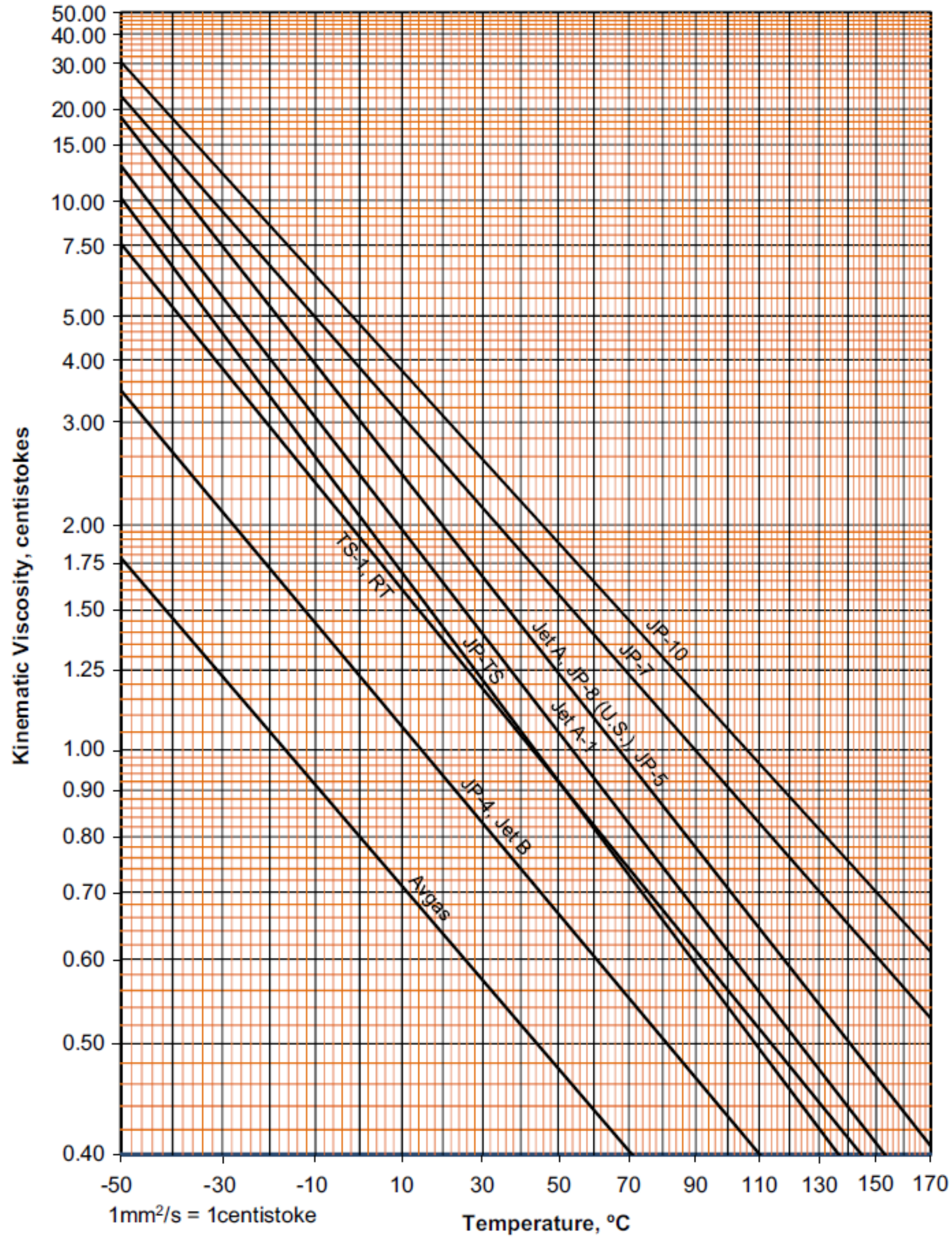


Figure 2-8. Kinematic Viscosities Versus Temperature for Typical Turbine Fuels, Avgas, and JP-10

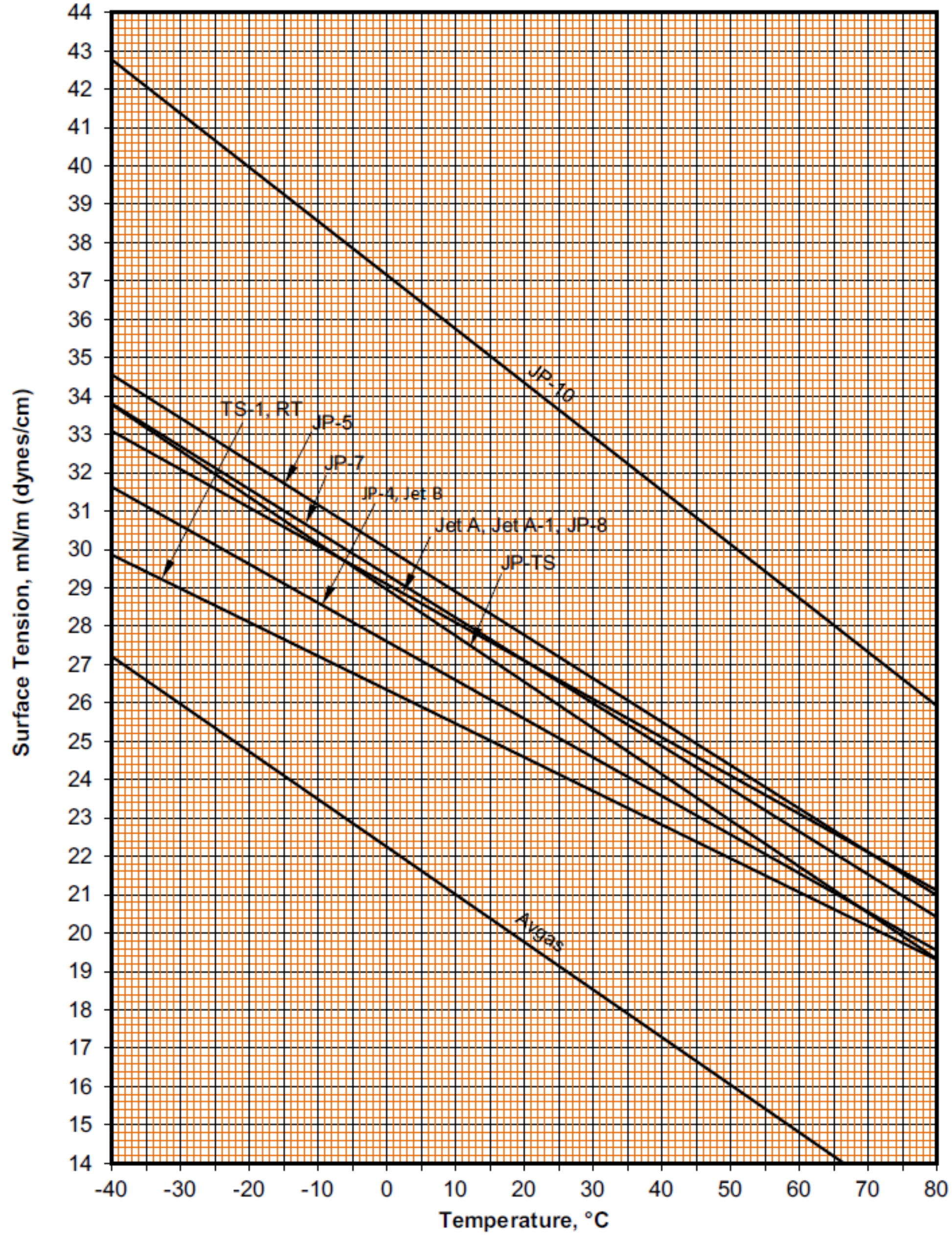


Figure 2-9. Surface Tension Versus Temperature for Typical Turbine Fuels, Avgas, and JP-10

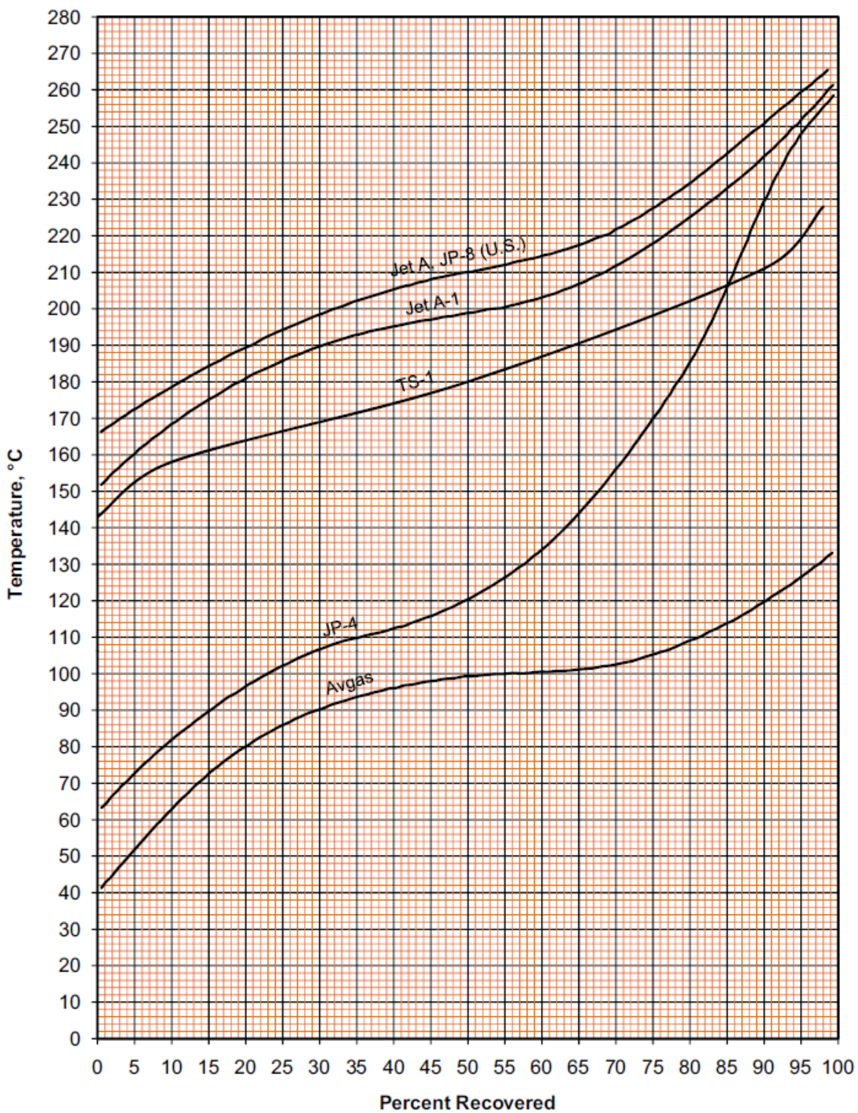


Figure 2-10. Distillation Curves for Typical Turbine Fuels and Avgas (ASTM D86 except for TS-1, GOST 2177)

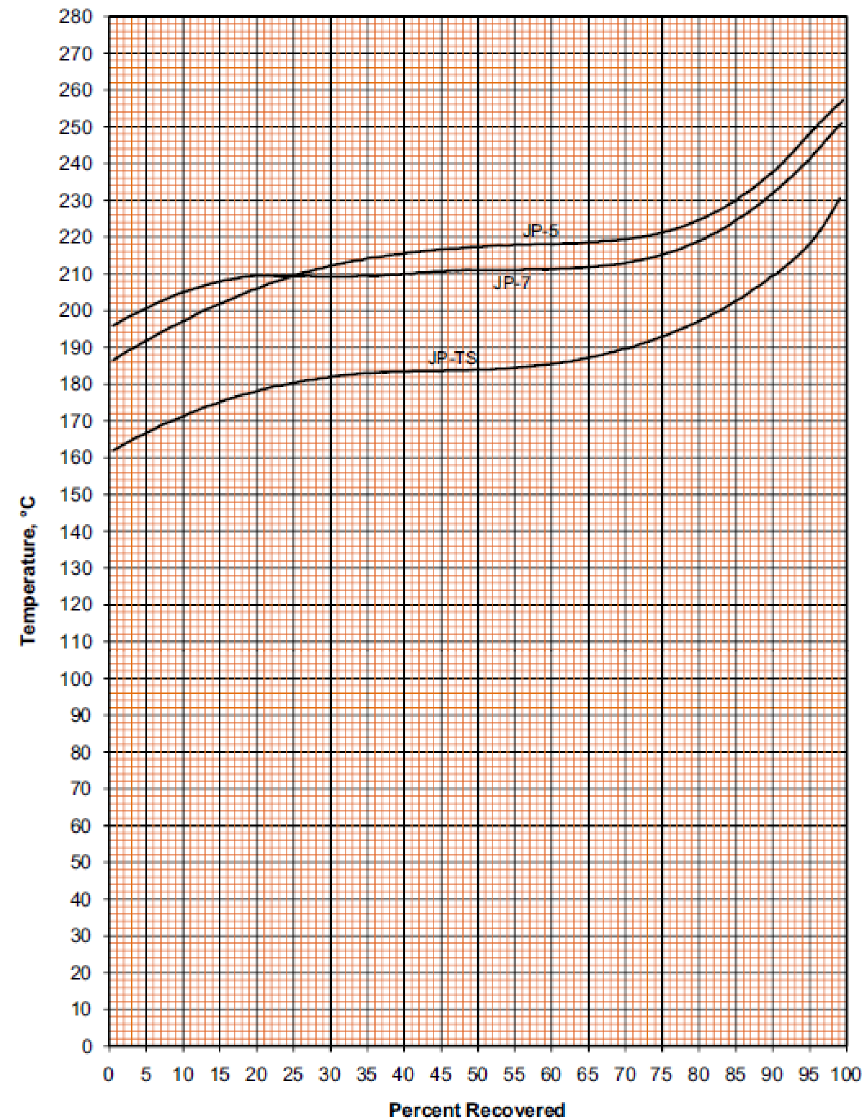


Figure 2-11. Distillation Curves for Typical Aviation Fuels (ASTM D86)

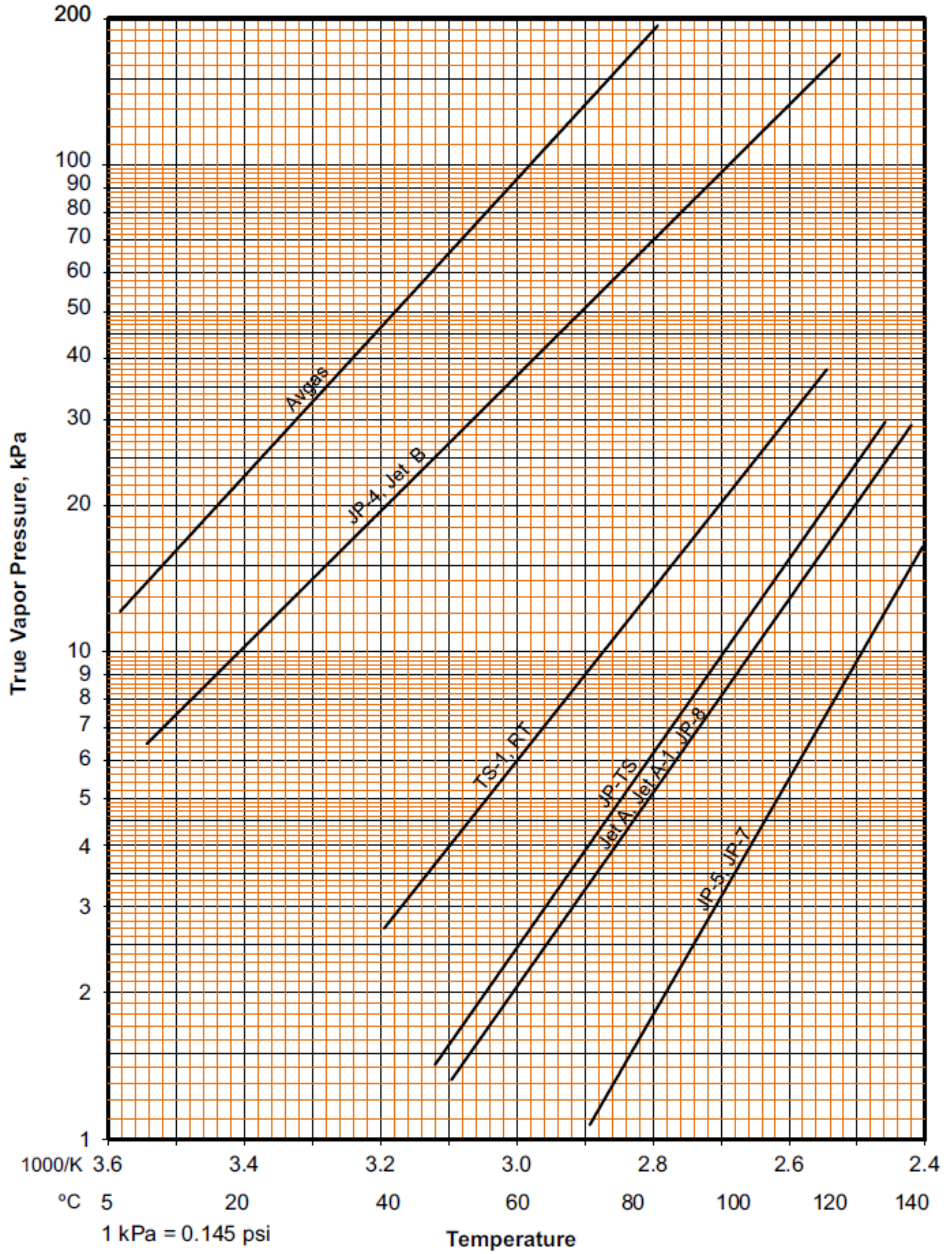


Figure 2-12. Vapor Pressure versus Temperature for Typical Aircraft Fuels and Avgas

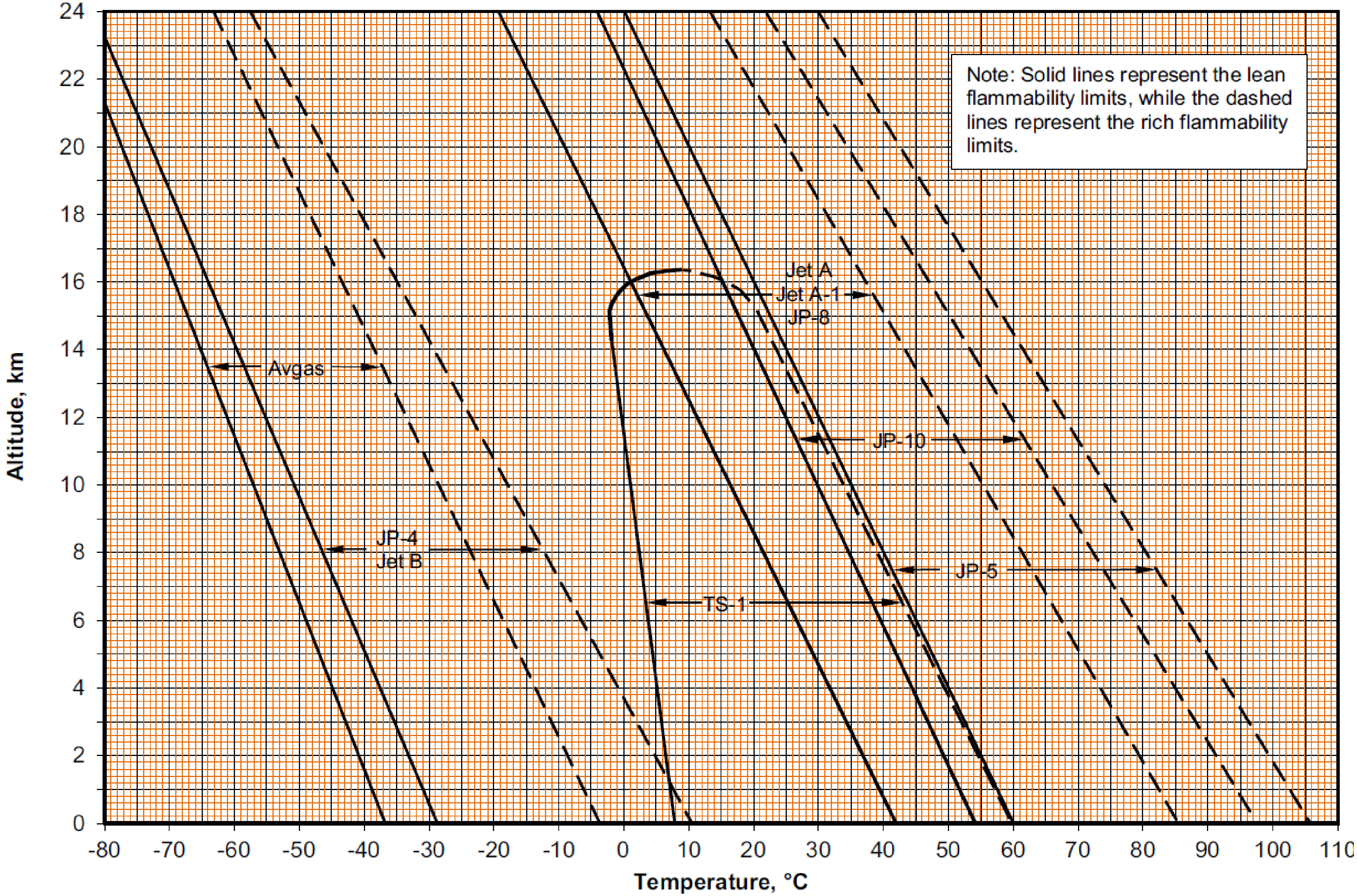
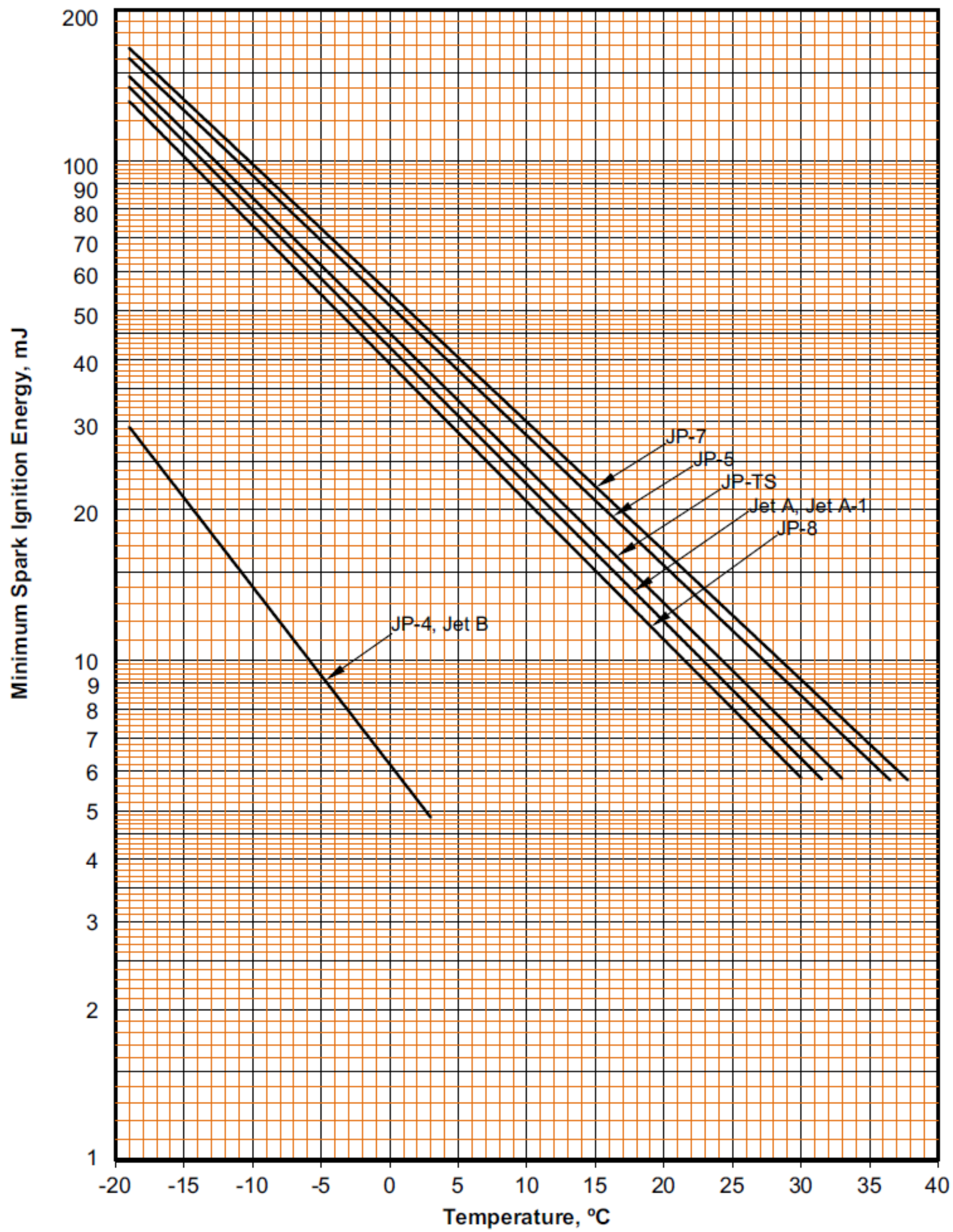


Figure 2-22. Flammability Limits Versus Altitude for Typical Turbine Fuels, JP-10, and Avgas



1.0 mJ = 9.478 $\times 10^{-7}$ Btu

Figure 2-25. *Minimum Spark Ignition Energy at 1 atm for Sprays of Typical Turbine Fuels*

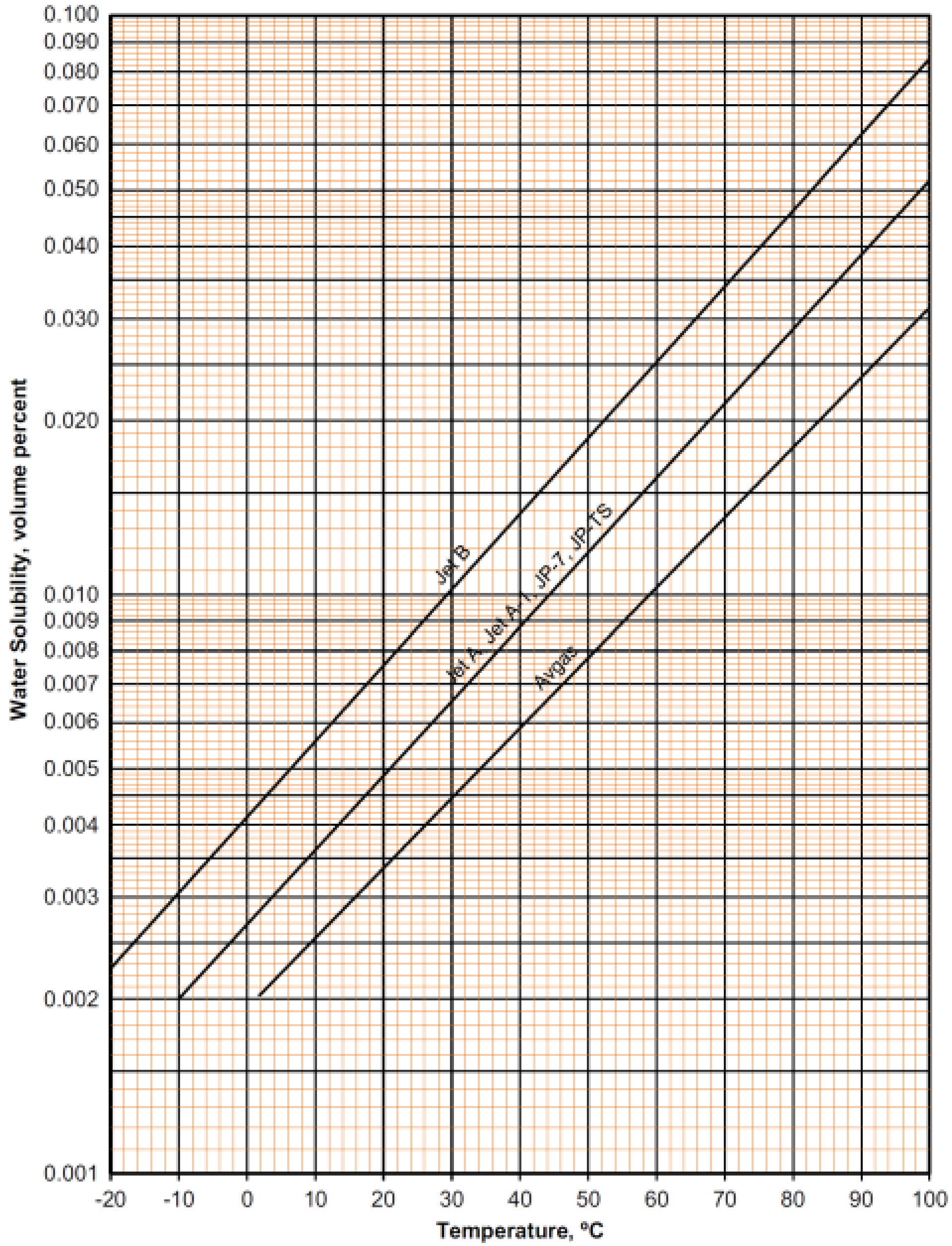


Figure 2-34. Solubility of Water in Typical Aircraft Fuels

Typical Flammability and Ignition Properties

Table 2-3 presents typical flammability and ignition properties of fuels. These values are examples as values vary significantly within the same fuel specification.

Table 2-3. Typical Flammability and Ignition Properties

Property	*Jet A/JP-8*	*JP-5*	*JP-7*	*JP-10*	*Avgas 100*	*JP-4/Jet B*
Flammability Concentration Limits[1] (vol %)						
Lower (Lean) Limit	0.6	0.6	0.6		1.2	1.3
Upper (Rich) Limit	4.7	4.6	4.6		7	8
Flammability Temperature Limits (°C)						
Lower (Lean) Limit[2] (1 atm)	53	64	60		-44	-23
Upper (Rich) Limit (1 atm)	77	102	100		-12	18
Min Electric Spark Ignition Energy (mJ)[1]	0.2 to 1	0.2 to 1	0.2 to 1		0.2 to 1	0.2 to 1
Approximate Burning Velocity[1] (m/s)	0.3 to 0.6	0.3 to 0.6	0.3 to 0.6		0.3 to 0.6	0.3 to 0.6
Autoignition Temperature (°C) (1 atm)	238	241	241	245	433	246

[1] Fuel vapors in air.

[2] Tag Closed Cup flash point data. Experimental flash points are generally higher than limit data.

Aviation Jet Fuel – Characteristics and Properties

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