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MILITARY HANDBOOK  
MOBILITY FUELS USER HANDBOOK



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MIL-HDBK-114

Mobility Fuels User Handbook For Use in Ground Equipment Systems.

1. This standardization handbook was developed by the Department of Defense in accordance with established procedure.
2. This publication was approved on 16 January 1984 for printing and inclusion in the military standardization handbook series.
3. This handbook provides basic information design criteria for the identification and selection of hydrocarbon fuels and alternative products, suitable for use in Army equipment systems. This handbook is not intended to be referenced in purchase specifications except for informational purposes, nor shall it supersede any specification requirements.
4. Every effort has been made to reflect the latest information on mobility fuel specification requirements, typical property characteristics, additive ingredients, field emergency fuels, engine technologies, and fuel property-performance relationships.
5. This handbook represents a new approach designed to assist field personnel and engine developers in the utilization practices of mobility fuels. Every effort will be made to update this document as research and development programs on mobility fuels generate the necessary technical data.
6. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: US Army Belvoir Research and Development Center, ATTN: STRBE-DS, Fort Belvoir, VA 22060, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

MIL-HDBK-114

FOREWARD

The purpose of this handbook is to provide a compilation of information relating to the types and potential applications of hydrocarbon fuels commonly used in ground mobility equipment. It includes a brief description of propulsion systems, details on the three fuel categories (gasoline, turbine fuel, and diesel), cleanliness and fuel handling/dispensing requirements and a section on field emergency fuels.

This handbook is intended to provide pertinent information to field personnel such as fuel requirements, interchangeability, product limitations, contamination, fuel-property correlations for use by engine developers, and safety considerations in product mixtures. It is designed to serve as a textbook and planning guide for users of mobility fuels.

Equipment manuals should be consulted for additional information regarding specific fuel requirements and fuel substitutions. In the event of any conflict between equipment manuals and this handbook, contact US Army Belvoir Research and Development Center, ATTN: STRBE-VF, Fort Belvoir, Virginia 22060.

## MIL-HDBK-114

## TABLE OF CONTENTS

		Page
I	MOBILITY FUELS: CATEGORIES AND PRODUCTION.....	1
	1.1 General.....	1
	1.2 Mobility Fuels Categories.....	1
	1.3 Refining/Treatment Process Used for Mobility Fuel.....	4
II	FUEL POLICY GUIDELINES.....	9
	2.1 General.....	9
	2.2 DOD Directives and Regulations.....	9
III	GROUND/AIRCRAFT ENGINE SYSTEMS UTILIZING MOBILITY FUELS.	11
	3.1 General.....	11
	3.2 Internal Combustion Engine.....	11
IV	MOBILITY FUELS - GASOLINE AND GASOHOL.....	15
	4.1 General.....	15
	4.2 Gasoline and Gasohol Specifications.....	15
	4.2.1 MIL-G-46015 - Gasoline, Automotive, Combat Referee Grade.....	15
	4.2.2 MIL-G-3056 - Gasoline, Automotive, Combat.....	16
	4.2.3 VV-G-1690 - Gasoline, Automotive, Leaded or Unleaded....	16
	4.2.4 MIL-G-53006 - Gasohol, Automotive, Leaded or Unleaded...	18
	4.3 Significance of the Physical and Chemical Properties Test Methods.....	19
V	MOBILITY FUELS - DIESEL.....	26
	5.1 General.....	26
	5.2 Diesel Fuel Specification.....	26
	5.2.1 MIL-F-46162 - Fuel, Diesel, Referee Grade.....	26
	5.2.2 VV-F-800 - Fuel Oil, Diesel.....	26
	5.2.3 MIL-F-16884 - Fuel, Naval Distillate.....	27
	5.2.4 VV-F-815 - Fuel Oil, Burner.....	28
	5.3 Significance of Test Methods.....	32
VI	MOBILITY FUELS - TURBINE.....	40
	6.1 General.....	40
	6.2 Turbine Fuel Specifications.....	40
	6.2.1 MIL-T-5624, Turbine Fuel, Aviation, Grades JP-4 and JP-5.....	40
	6.2.2 MIL-T-83133, Turbine Fuel, Aviation, Kerosene Type, Grade JP-8.....	40
	6.3 Significance of Physical and Chemical Properties Tests..	42
VII	MOBILITY FUEL QUALITY REQUIREMENTS/NEEDS.....	50
	7.1 General.....	50
	7.2 Origin and Types of Fuel Contaminants.....	50
	7.3 Practices and Procedures to Avoid Fuel Contamination....	51
	7.4 Understanding Low Temperature Diesel-Fueled Equipment Operability Problems.....	52
	7.5 Diesel Fuel at Low Temperature.....	58
	7.6 Low Temperature Operability Criteria.....	58

## MIL-HDBK-114

		Page
	7.7	Determining the Cause of Fuel Flow Problems..... 59
	7.8	Solutions for Fuel-Related Operability Problems..... 60
	7.9	Pipeline Operations..... 62
	7.10	Procurement Practices..... 63
VIII		FIELD EMERGENCY FUELS..... 65
	8.1	General..... 65
	8.2	FEF for Gasoline - Consuming Engines..... 65
	8.3	FEF for Diesel - Consuming Engines..... 66
	8.4	FEF for Multifuel Engines..... 67
	8.5	FEF for Ground Turbine Engines..... 67
	8.6	FEF for Aircraft Engines..... 68
IX		FUEL PROPERTY - PERFORMANCE CORRELATIONS AND RELATIONSHIPS ..... 71
	9.1	General..... 71
	9.2	Gasolines..... 71
	9.3	Diesel Fuel Properties Interrelationships..... 71
	9.4	Fuel Properties Map..... 72
	9.5	Diesel Fuel Specifications..... 72
	9.6	Air Turbine Fuels..... 72
	9.7	Determination of Fuel Properties with Minimal Testing... 73
	9.8	Correlative Methods for Fuels Properties..... 73
X		FUEL ADDITIVES COMMONLY USED BY REFINERS..... 80
	10.1	General..... 80
	10.2	Gasoline Additives..... 80
	10.3	Diesel Additives..... 80
	10.4	Turbine Fuels Additives..... 80
XI		GASEOUS MOBILITY FUELS..... 84
	11.1	General..... 84
	11.2	Advantages/Disadvantages of the use of Natural Gas as Fuel..... 84
	11.3	Safety..... 85
XII		REFERENCES..... 87
XIII		ACRONYMS AND ABBREVIATIONS..... 89
XIV		GLOSSARY OF TERMS..... 90

## FIGURES

Figure 1	Engine-Fuel Interface: Spark Ignition.....	23
Figure 2	Engine-Fuel Interface: Compression Ignition.....	34
Figure 3	Engine-Fuel Interface: Gas Turbine.....	45
Figure 4	Factors Contributing to Low Temperature Operability.....	54
Figure 5	Net Heating Value API Gravity Correlation.....	76
Figure 6	Diesel Fuel Property Map.....	76
Figure 7	ASTM 2-D Diesel Fuel Specifications.....	77
Figure 8	Smoke Point of Jet Fuels.....	77
Figure 9	Luminometer Number of Jet Fuels.....	78
Figure 10	Heat of Combustion of Jet Fuels.....	78
Figure 11	Hydrogen Content of Jet Fuels.....	79

## MIL-HDBK-114

## TABLES

	Page	
Table I	Additive Requirements for Military and Federal Specifications.....	17
Table II	Fuel Requirements for Army Mobility Engines: Spark Ignition.....	18
Table III	Test Methods Required in Gasolines and Gasohol Specifications.....	21
Table IV	Additives in Diesel and Burner Fuels.....	29
Table V	Fuel Requirements for Army Mobility Engines: Compression Ignition and Gas Turbines.....	30-31
Table VI	Test Methods Required in Diesel Fuel Specification and Burner Fuel.....	32-33
Table VII	Fuel Requirements for Army Mobility Engines: Turbines..	41
Table VIII	Test Method Required in Turbine Fuel.....	43
Table IX	Fuel Requirements for Army Mobility Engines for Diesel Engine, Gasoline Engine and Turbines.....	69-70
Table X	Functional Properties of Diesel Fuels.....	71
Table XI	Gasoline Fuels Additives.....	81
Table XII	Diesel Fuels Additives.....	82
Table XIII	Turbine Fuels Additives.....	83

## APPENDICES

Appendix A	Simplified Refinery Processing.....	121
Appendix B	Typical Value and Specification Requirements for Gasoline Fuel.....	122
Appendix C	Typical Values and Specification Requirements for Diesel and Burner Fuel.....	127
Appendix D	Typical Values and Specification Requirements for Turbine Fuel.....	134
Appendix E	Safety Hazards of Blending Diesel Fuel and Gasoline.....	138

## MIL-HDBK-114

## CHAPTER I

MOBILITY FUELS: CATEGORIES AND PRODUCTION1.1 General.

1.1.1 Many petroleum products are utilized by the military services and the quality requirements of these products change as new developments within the equipment systems impose limitations in fuels. A description of the type of fuels used within the military, their military specification and commercial designation as appropriate will be given in this chapter as well as a brief description of the refining processes available for producing fuels.

1.2 Mobility fuels categories.1.2.1 Automotive gasoline - VV-G-1690.

1.2.1.1 The chemical compounds that make up gasoline are called hydrocarbons which are chemical combinations of hydrogen and carbon atoms, the basic elements that make up all petroleum products. These elements can combine in many different ways, and each combination produces a substance with different characteristics. Because gasoline is composed of a great number of hydrocarbons, the character of a particular gasoline is determined by the combined characteristics of the many hydrocarbons that are present. This fuel is the source of energy for the spark-ignition internal combustion engine.

1.2.1.2 One of the major differences between hydrocarbons is their rate of evaporation. At a given temperature, some of the hydrocarbons in gasoline evaporate (or vaporize) very quickly, while others evaporate more slowly. The hydrocarbons that evaporate the fastest are called the most volatile. Refinery technologists commonly refer to the most volatile hydrocarbons in a gasoline as the "front end". The middle range of volatility is called the "mid-fill", and the least volatile part of the fuel is the "back end".

1.2.1.3 The volatility characteristics of the different hydrocarbons affect the gasoline's performance in an engine in several ways. The front end controls to a large extent, the startability of a vehicle on a cold morning, and whether or not it will stall after starting. It also defines whether or not stalling will occur because of vapor lock on a hot day. The mid-fill governs how fast an engine will warm up from a cold start and can have a significant effect on fuel economy. The back-end is mainly responsible for good mileage in long-distance driving, but can contribute to deposits in the engine.

1.2.1.4 The properties of commercial gasolines are influenced by the refinery processes employed, and the nature of the crude oil feedstock. Formulated gasolines will typically have a boiling range of about 30°-225° C (86-437° F). Gasolines are blended to satisfy diverse automobile requirements. Antiknock quality, distillation characteristics, vapor pressure, hydrocarbon composition, oxidation stability, and deposition tendencies are controlled to provide satisfactory vehicle performance. Additives may be used to provide or enhance specific performance features, and are described in chapter X.

## MIL-HDBK-114

1.2.1.5 Gasolines produced to the requirements of this specification comply with the industry standard, ASTM D 439.

1.2.2 Gasohol - MIL-G-53006.

1.2.2.1 This is a blend of 10 volume percent ethyl alcohol in automotive gasoline. Gasohol can be blended in leaded or unleaded automotive gasoline.

1.2.2.2 The base gasoline that is used is required to conform to VV-G-1690. It should not contain any oxygenated blending components (alcohols or ethers) other than the trace amounts normally used as anti-icing additives.

1.2.2.3 The ethyl alcohol which is added must have a minimum purity of 98.5 percent by volume and must be completely denatured. The total volume of denaturant, which is approved for fuel alcohol, may be included in the volume of ethyl alcohol provided it does not exceed the 5 percent volume specified. The ethyl alcohol that is used is required to be derived from renewable sources which excludes alcohol made from petroleum, natural gas, and coal.

1.2.3 Combat gasoline - MIL-G-3056.

1.2.3.1 This gasoline is somewhat similar to VV-G-1690, (1.2.1) but has a mandatory requirement for oxidation inhibitors and metal deactivators to insure long-term storage stability. It is produced in two types and only used in OCONUS locations. The two types are as follows:

a. Type I. General all-purpose gasoline intended for use in combat vehicles and equipment at all temperatures above 18° C (64° F).

b. Type II. A special low temperature all-purpose gasoline intended for use in combat vehicles and equipment in areas where the mean ambient temperature is consistently below 0° C (32° F).

1.2.4 Diesel fuel - VV-F-800.

1.2.4.1 Diesel fuel is the fuel used in compression-ignition engines. Diesel fuels, in general, are derived from petroleum refinery streams which are commonly referred to as middle distillates. Middle distillates represent those fractions which have a higher boiling range than gasoline and are obtained from fractional distillation of the crude oil or from streams from other refining processes described in 1.3. Finished diesel fuels represent blends of middle distillates and kerosenes.

1.2.4.2 The properties of diesel fuels depend on the refinery practices employed and the nature of the crude oils from which they are derived. They may differ therefore within the region which they are manufactured. Such fuels generally possess a boiling range between 163° and 371° C (325° and 700° F). Their makeup can represent various combinations of volatility, ignition quality, viscosity, gravity, hydrocarbon composition, and other characteristics. Additives may be used to impart special properties to the finished diesel fuel. The types and grades are as follows:

## MIL-HDBK-114

a. DF-A (arctic). This grade covers the lowest boiling range (more volatile) diesel fuels from the kerosene to light distillates. These fuels also have the lowest cloud and pour point characteristics. Fuels within this classification are suitable for use in medium and high-speed diesel engines in cases when abnormally low fuel temperatures are encountered (i.e., Arctic environments). This grade can also be used in pot type burner space heaters, in areas where mean ambient temperatures lower than minus 32° C (-26° F) occur, and where it is impractical to obtain or store both diesel and burner fuels. It should not be used for low-speed stationary engines.

b. DF-1 (winter). This grade includes the class of distillates of slightly higher boiling range than DF-A fuels. These fuels are for use during winter operations, where arctic weather is not encountered. This grade is intended for use in high speed automotive service in areas in which ambient temperatures as low as minus 32° C (-26° F) occur. It may be used for medium-speed stationary engine applications, where fuel heating facilities are not available.

c. DF-2. This grade includes the class of distillates of higher and wider boiling range than the DF-1 fuels. These are also normally lower in API gravity and higher in cloud and pour point than DF-1 fuels. These fuels are applicable for use in services involving relatively high loads uniform speeds operating in climates where cold starting and cold fuel handling are not severe problems. This grade is intended for use in all automotive high-speed diesel engines and in medium-speed applications in areas in which the ambient temperatures are above -18° C (0° F). The cloud point limitation for DF-2 changes according to location and month of the year the fuel will be used. Appendix A of Federal Specification VV-F-800 provides a tabulation of 10th percentile minimum temperatures for the United States during the months of September through March. This provides a guide for determining the cloud point requirement of DF-2 at the time and place of use.

d. DF-2 OCONUS. This is essentially the same as grade DF-2 CONUS; however, the requirements differ slightly to correspond with NATO F-54 diesel fuel.

### 1.2.5 Fuel, Naval Distillate - MIL-F-16884.

1.2.5.1 This specification covers a 100 percent distillate fuel oil suitable for use in compression ignition engines in submarines and ship-board operations at all temperatures above -6° C (20° F). These fuels are similar to VV-F-800 Diesel Fuel (see 1.2.4) except they have a somewhat higher upper boiling range, higher flash point, higher cloud and pour point characteristics, and will permit a higher sulfur content (i.e., 1.0 percent maximum where VV-F-800 allows 0.7 percent maximum).

### 1.2.6 Referee grade fuels.

1.2.6.1 Referee grade fuel represents the minimal or marginal quality level which can be procured under the "parent" fuel specification while meeting all of its requirements. It is designed to be equivalent to the quality of fuels being supplied in OCONUS or that production anticipated to be available in times of national emergency. It is to be used for research, development and proof testing to assure that the fuel-consuming equipment will perform adequately with all types of fuel procured under the VV-F-800 or MIL-G-3056 specifications. There are two types of referee fuels as follows:

## MIL-HDBK-114

a. Gasoline, automotive, combat, referee grade - MIL-G-46015. It is used for research development and proof testing to assure that equipment will perform adequately with all gasolines procured under MIL-G-3056.

b. Fuel, diesel referee grade - MIL-F-46162. It is used for research, development and proof testing to assure that all diesel-consuming equipment will perform adequately with all diesel fuels procured under VV-F-800.

1.2.7 Turbine fuels. These are fuels which are used in powering turbine engines. The most important turbine for military applications is the gas-turbine engine, since it is widely used in aircraft and other ground mobility equipment (M-1 Tank). The fuels used in military turbine engines are as follows:

a. MIL-T-5624 - JP-4. This is the standard military fuel for all army turbine-powered aircraft. The Reid vapor pressure of 2 to 3 psi is sufficiently low to insure that the fuel meets all requirements for subsonic flight, where aerodynamic heating of fuel tanks is not a factor. The freezing point limitation is low at  $-60^{\circ}\text{C}$  ( $-76^{\circ}\text{F}$ ), and the high hydrogen-carbon ratio results in excellent combustion characteristics with minimum smoke, minimum carbon deposition, and low flame luminosity. Note that JP-4 is not presently used by commercial airlines because of the potential hazards resulting from its low flash point and high volatility.

b. MIL-T-5624 - JP-5. This is a kerosene-type fuel blended for a flash point of  $60^{\circ}\text{C}$  ( $140^{\circ}\text{F}$ ). It was developed for use on aircraft carriers to minimize the hazards associated with lower flash point fuels. In order to meet the requirement of high flash point, it is necessary to exclude low-boiling range materials, and to maintain a freezing point of  $-40^{\circ}\text{C}$  ( $-40^{\circ}\text{F}$ ). Availability of product is therefore approximately less than 5 percent of the crude barrel. The present usage of JP-5 is for all aircraft operating aboard carriers.

c. MIL-T-83133 - JP-8. This is a specification for a military fuel to replace JP-4 (1.2.7a) as a means of reducing fire hazard. It has properties similar to the industry standard ASTM D 1655 Jet A-1, commercial aircraft turbine engine fuel.

### 1.3 Refining/treatment process used for mobility fuel.

#### 1.3.1 General.

1.3.1.1 The following information will provide details describing the types of processes used for refining mobility fuels. Different companies, depending on crude source and refinery configurations, will use different combinations of the processes to refine the finished fuels. A schematic showing the types of processes found in simple refinery processing is attached as Appendix A.

1.3.1.2 The types of crude oil available and the anticipated product slate defines the processes needed in a refinery. Crude distillation separates the crude oil into fractions of differing boiling points (i.e., distillation range) to make feedstock for the downstream processes. However, most refiners must clean-up the crude oil with crude desalting before subjecting it to crude distillation.

## MIL-HDBK-114

1.3.2 Crude desalting.

1.3.2.1 These processes water-wash crude oil to remove such impurities as dirt, silt and water-soluble minerals. The mixing of water and oil is so intimate that settling alone may not be sufficient to separate the two phases. Separation can be hastened by adding surface active chemicals, or by applying a strong electric field, or by a combination of both. Desalting pays for itself by reducing corrosion and catalyst poisoning in down-stream units. In fact, some refiners now use two or three stages of desalting to get additional crude oil cleanup.

1.3.3 Crude distillation.

1.3.3.1 The various fractions of crude oil which will go to specific downstream processes are determined primarily by the crude distillation unit. If a single stage is used, the operation will be near atmospheric pressure. The heaviest distillate will then have an upper temperature limit set by the point where cracking will start to occur.

1.3.3.2 The liquid from the bottom of the fractionating column (reduced crude) can be isolated into additional fractions by adding a second stage of distillation operated under vacuum. The sub-atmospheric pressure allows additional vaporization without cracking.

1.3.4 Thermal cracking.

1.3.4.1 Most forms of thermal cracking to make fuels have been replaced with catalytic cracking or hydrocracking. Two types of thermal cracking however remain in active use today: (a) coking and (b) visbreaking.

a. Coking: These processes represent severe forms of thermal cracking. Their feedstocks are residuals which economically resist cracking by other means. For many years, the coke was a byproduct of the processes, since the primary purpose of coking was to get more lighter stocks from a barrel of crude. Today, coke can be a valuable product. When its sulfur and metals content are low enough, the coke is suitable for the manufacture of electrodes and aerospace components. Coke with intermediate sulfur content makes a reasonably good fuel for generating electricity.

b. Visbreaking: This is a mild form of thermal cracking. It is used to reduce the viscosity of some residual fractions so that less cutter stocks are needed to meet burner fuel oil specifications for viscosity. In marketing areas where the demand for middle distillates exceeds that for motor fuels, the mild cracking which occurs with visbreaking will avoid excess motor fuel production.

1.3.5 Catalytic cracking.

1.3.5.1 This process has almost completely replaced thermal cracking as a means of making more motor fuel blending stocks from the heavier portions of crude oil. Innovations from time to time continue to hold fluid catalytic cracking processes in the position of being the major way to convert more of a barrel of crude oil into lighter mobility fuels.

## MIL-HDBK-114

1.3.5.2 This process uses a catalyst to accelerate the cracking of the heavy portions and allowing for shorter residence times, and greater conversion to lighter fuels.

1.3.6 Hydrocracking processes.

1.3.6.1 This process results in both cracking and hydrogenation. They can be viewed as a special extension of the hydrotreating processes. The products from hydrocracking are essentially saturated materials with high concentration of isoparaffins and naphthenes.

1.3.6.2 Hydrocracking processes can be operated to produce varying ratios of motor fuels and middle distillates. Even greater flexibility is possible during design stages when the process can be tailored to convert heavy residue into lighter oils or to change naphthas into liquified petroleum gases.

1.3.6.3 The processes offer the opportunity to desulfurize high-sulfur imported crude oil while upgrading the heavier portions of the crude to lighter fuel oils. At the same time, their flexibility can be used to increase gradually the relative yield of motor fuel if future markets dictate.

1.3.7 Hydrotreating.

1.3.7.1 This process can handle a variety of feeds. In all cases, the feed is combined with hydrogen and passed over a catalyst at elevated temperature and pressure. The extent of treatment depends on the nature of the feedstock, the severity of the reacting conditions and the type of catalyst.

1.3.7.2 Hydrotreating can be classified into two types depending on its purpose. In one case, the hydrotreated stream becomes a feedstock for subsequent processing. Then hydrotreating is justified by the improvement which comes to the downstream process. In the other case, the hydrotreated material is a blending stock for finished product. Justification then is on the basis of a marketing advantage which comes from having a more stable product or from having less sulfur and nitrogen compounds in the product.

1.3.7.3 Consideration has been given to the advantages of hydrotreating the entire crude oil charge to a refinery before the crude oil is separated into its fractions. The disadvantage is that some of the heavy fractions from the hydrotreated crude oil will still need additional treating later. Yet the sooner hydrotreating appears in the refining scheme, the more benefits the downstream processes will enjoy.

1.3.7.4 Hydrotreating offers a variety of advantages to finished refined products. Hydrotreated stocks are more stable. Hydrotreated fuels have better burning quality. The process is spurred into widespread use to replace earlier treating methods because the hydrogen needed for hydrotreating is more readily available as a byproduct from catalytic reforming. And in some cases, hydrotreating is popular enough to demand its own hydrogen manufacturing facilities.

## MIL-HDBK-114

1.3.8 Reforming.

1.3.8.1 The need to increase the antiknock quality of naphtha to get blending stocks for motor fuels is the greatest single reason for installing catalytic reforming. Although a number of reactions take place during reforming, the predominant one is the dehydrogenation of naphthenes to form aromatics. Some of these aromatics are isolated to become petrochemical feedstocks, but most become motor fuel blending stocks of high antiknock quality.

1.3.8.2 Most feedstocks for reforming are hydrotreated first to remove arsenic, sulfur and nitrogen compounds. Otherwise, these compounds would poison the reforming catalyst.

1.3.9 Isomerization.

1.3.9.1 Somewhat like catalytic reforming, isomerization processes also rearrange the molecular form of a feedstock while holding down losses from cracking or condensation reactions. In fact, some critics suggest the best place to accomplish isomerization of motor fuel fractions is in the catalytic reformer by selecting catalyst and operating conditions to accomplish both reactions.

1.3.9.2 The most popular form of isomerization for motor fuels is pentane and hexane isomerization. Impetus for this step comes from a need to upgrade the antiknock quality of the lighter portions of a fuel blend. For example, pentane having a clear Research octane rating of about 62 can be converted to isopentane having a clear Research octane rating of 92.

1.3.9.3 When a refinery makes mostly fuel oils (i.e., typical of European-type refinery), the resulting motor fuel blending stocks are largely straight run materials. Then isomerization can give antiknock quality improvement to the lighter portions of the motor fuel blend while catalytic reforming gives improvement to the heavier portions.

1.3.9.4 Refineries geared to maximize motor fuel yields may soon add isomerization units. The quickening trend to restrict the use of lead antiknock additives also hasten the need for processes to give antiknock quality improvement of both light and heavy motor fuel fractions.

1.3.10 Alkylation.

1.3.10.1 These processes combine isobutane with an olefin to produce a liquid with superior stability and antiknock quality suitable for blending aviation gasoline or motor fuel. When butylene is the olefin feedstock, the major component in the alkylate product is 2,2,4 - trimethyl pentane, commonly called iso-octane - the material designated as the 100 octane number reference for antiknock ratings of all other hydrocarbons.

1.3.11 Solvent Refining.

MIL-HDBK-114

1.3.11.1 Solvent Refining can separate petroleum fractions or remove impurities on the basis of their relative solubility in a solvent without regard for volatility. This process is used mostly to prepare lube oils and waxes or to purify feedstocks for subsequent processes, although some solvent refining is used as a final cleanup step for finished product blending stocks.

1.3.11.2 Solvents also are used to remove certain types of hydrocarbons such as asphaltenes or hydrocarbons containing sulfur, nitrogen or metals. These undesirable hydrocarbons are removed to improve the operation of subsequent processes.

1.3.12 Other treating.

1.3.12.1 Cleanup processes which do not fall into the earlier categories of hydrotreating or solvent refining are included here. These processes are characterized by their use of selective adsorption on solids to isolate specific fraction or to remove impurities.

## MIL-HDBK-114

## CHAPTER II

FUEL POLICY GUIDELINES

2.1 General. The proper utilization of mobility fuels is dependant upon the adherence to prescribed existing fuel policy directives. These directives provide specific instructions as to the primary fuel to be used in the operating of a particular weapons system and weapons support equipment and materiel. This chapter provides a listing of all existing fuel policy instructions and requirements intended for user as well as developers of ground equipment. For questions on quality surveillance of fuels, contact the US Army General Material and Petroleum Activity, ATTN: STSGP-F, New Cumberland Army Depot, New Cumberland, PA 17070.

2.2 DOD directives and regulations.

2.2.1 Department of Defense Directive 4140.43, dated 5 Dec 1975, subject: Department of Defense Liquid Hydrocarbon Fuel Policy for Equipment Design, Operation and Logistics Support.

2.2.1.1 This directive prescribes policy for (1) the utilization of liquid fuels within the RDTE cycle of materiel development to insure a standardization and greater flexibility in fuel utilization and (2) a reduction in the number of fuels existing within the logistics system.

2.2.2 Department of Army Regulation AR70-56, dated 6 April 1976, subject: Research and Development, Liquid Hydrocarbon Fuel Policy for Equipment Design, Operation and Logistics Support.

2.2.2.1 This regulation implements the Department of Defense Directive 4140.43 mentioned above. As in the above, specific classes of mobility fuels (i.e., unleaded gasolines, middle distillate fuels, etc.) are prescribed for six types of fuel consuming equipment. These are as follows:

- a. Turbine powered aircraft.
- b. Spark-ignition engine powered aircraft.
- c. Ground vehicles and equipment powered by spark-ignition engines.
- d. Mobile and stationary ground equipment powered by compression-ignition and turbine engines.
- e. Conventional shipboard power plants.
- f. Stationary boiler, power plants, and industrial and residential heating equipment.

2.2.3 Department of Army Regulation AR 703-1, dated 15 September 1978, subject Coal and Petroleum Products Management, Coal and Petroleum Products Supply and Management Activities.

2.2.3.1 This regulation establishes basic Army policies, assigns responsibilities, and prescribes procedures for the management, planning, and coordination of all activities within the petroleum supply, support, and utilization systems. Under Chapter 2, Policy and Planning, Section I provides petroleum logistics doctrine and concepts for user and developer activities:

MIL-HDBK-114

2.2.3.2 Under paragraph 2-4, entitled Liquid Hydrocarbon Fuels to be Used in Army Fuel Consuming Materiel, definitions are provided for Primary, Alternate, and Emergency Fuels. Also, the five fuels specified for use in Army materiel are listed. These are as follows:

- a. Aviation Gasoline (AVGAS), MIL-G-5572, Grade 100/130.
- b. Gasoline, Automotive, Unleaded, VV-G-1690 (MOGAS, Unleaded).
- c. Gasoline, Automotive, Combat, MIL-C-3056 (Combat MOGAS, 83/91).
- d. Turbine Fuel, Aviation, MIL-T-5624, Grade JP-4.
- e. Fuel Oil Diesel, VV-F-800.

2.2.4 Department of Air Force Technical Manual T.O. 42B1-1-1, dated 15 May 1981, subject: Fuels for USAF Piston and Turbine Support Equipment and Administrative Vehicles.

2.2.4.1 This manual designates the grades of fuel to be used in all USAF piston and turbine engine-powered support equipment and administrative vehicles. In the event of conflict between the USAF technical orders and this handbook, the technical orders takes precedent over this handbook. Contact SA-ALC/SFTT, Kelly AFB, TX 78241.

2.2.5 Department of the Air Force Technical Manual T.O. 42B1-1-14, subject: Fuels, for USAF Aircraft.

2.2.5.1 This manual designates the grades of fuel to be used in all USAF aircraft. In the event of conflict between AF T.O. and this handbook, the manual takes precedence over this handbook. Point of contact as in 2.2.4.1.

## MIL-HDBK-114

## CHAPTER III

GROUND/AIRCRAFT ENGINE SYSTEMSUTILIZING MOBILITY FUELS

3.1 General. This section is an overview of the types and characteristics of engines used in the military. For the purposes of this handbook, an engine is a device to convert the chemical energy contained in a fuel into mechanical work. In general, an engine produces work by turning a rotating shaft, the drive shaft. This is not always the case since aircraft "jet" engines produce thrust rather than turn a shaft. However, all current ground equipment in the military produce shaft work by either turning a vehicle's wheels or turning an electric generator or similar rotary equipment. Engines can be divided into two classes depending upon where the combustion of the fuel takes place. If combustion takes place outside of the structure of the engine, then it is an "external combustion" engine. Examples are boilers and Stirling engines. Likewise, an "internal combustion" engine has the combustion of the fuel taking place within the engine. All of the military's mobility engines are currently of the internal combustion type. Engines can also be classified in terms of open or closed cycle, where closed cycle is defined as a cycle whereby the working fluid is continuously recycled within a sealed system.

3.2 Internal Combustion Engines. All internal combustion engines operate in the same general fashion, at least from the standpoint of the air that they use. The engine takes in air, compresses it to a higher pressure, and mixes fuel with it. The fuel and air mixture is ignited, which further raises both the temperature and pressure of the mixture. The high pressure, hot products of this combustion are allowed to expand while moving some mechanical device. This extracts work from the gas. Finally, the gas mixture, now at a lower pressure and temperature with its energy removed, is exhausted into the atmosphere and the cycle is repeated.

3.2.1 Turbine engines. Gas turbine engines are becoming more widely used in the military ground equipment because of their high power output for a given size and weight. These engines take in air and compress it using a series of fans (compressor blades). This compressed air is then routed to a combustion section where the fuel is sprayed in and combustion occurs. The mixing of the fuel and air and the subsequent combustion takes place in a special housing which is designed to contain and control the burning mixture. Once combustion is started, usually by a spark plug, it is self-sustaining. Power is produced by expanding the hot gases through another series of fans (turbine blades). This power turbine is connected to the output shaft (usually through a series of reduction gears) and also to the compressor section. Turbine combustion is a continuous process. The efficiency of combustion is dependent on the proper mixing of the fuel and air plus the stabilization of the flame front in the proper location within the combustion area. Turbine engines can be designed to operate on a wide variety of fuels. However, because of the necessity of carefully controlling the mixing of fuel and air in the combustion area, once

## MIL-HDBK-114

the engine has been designed only very specific fuels can be used. Almost all of the current military ground turbine engines are designed to be operated on distillate-type fuels such as diesel fuel or kerosene fuels like JP-5, JP-8, or the kerosene/naphtha fuel JP-4.

3.2.2 Reciprocating engines. The other class of internal combustion engines found within the military ground fleet is reciprocating engines. Unlike the turbine engines, these engines use the up-and-down motion of a piston in a cylinder to contain the combustible gases and extract work from the combustion event. Reciprocating engines can be further subdivided either by the way the combustion event is initiated (Otto or diesel) or by the number of piston strokes per combustion event (two-stroke cycle or four-stroke cycle). In all cases, the basic events of air intake, fuel addition, combustion, work extraction, and exhaust of spent products are followed.

3.2.2.1 Four-cycle engines. Within a four-cycle engine the piston makes four distinct strokes within the cylinder for each combustion event. Initially, the piston is at the top of the cylinder. A valve is opened admitting air and possibly fuel into the cylinder. The piston begins to move down, drawing the gas mixture into the cylinder. After the piston reaches the bottom of its travel, the intake valve is shut, trapping the gas charge in the cylinder. The piston then is moved upward, compressing the gas which raises its pressure and temperature. This is the second piston stroke. When the piston reaches the top of the cylinder again, the gas mixture is ignited and combustion takes place. Unlike the gas turbine engines, the combustion process is an intermittent event in reciprocating engines. Combustion greatly increases the temperature and pressure of the trapped volume of gas, and this increased energy is used to force the piston back down the cylinder in the third, expansion stroke. This piston movement during the expansion process produces power at the output shaft. Finally, when the piston is at the bottom of the cylinder after the power stroke, another valve is opened connecting the cylinder to the exhaust system. A fourth upward piston stroke forces the gas mixture out of the engine. At the end of this exhaust stroke, the piston is at the top of the cylinder, the exhaust valve is closed, the intake valve is reopened, completing one four-stroke cycle, and the process is repeated.

3.2.2.2 Two-cycle engines. In two-cycle engines, the combustion event is condensed into two strokes of the piston. This is done by designing the engine to combine the intake and exhaust strokes. In this type of engine, the piston is up and the fuel and air charge is compressed and ignited. The hot high pressure gas begins to force the piston down until just before the piston completes the power-producing stroke, the exhaust port is opened. The gas is thus exhausted with more energy remaining unextracted than in a four-cycle engine. Soon after the exhaust blowdown, the intake ports are opened and a fresh intake mixture is allowed to enter the chamber. Because of the residual pressure from the spent gases, there is usually some mechanism such as a blower to force the induction of the new air charge. The intake event continues as the piston reaches the bottom of its travel and begins to return toward the top of the cylinder. When the piston is part-way up the cylinder (on the second

## MIL-HDBK-114

stroke), the intake port is closed, and compression begins from that time. Because of this delay in closing the intake port due to the need to "blow out" all of the exhaust gas, the intake mixture is not compressed to the extent that would take place in a four-cycle engine. When the piston has returned to the top of the cylinder, the new gas charge is ignited, combustion takes place, completing one two-stroke cycle, and the process begins again. Because of the lack of complete expansion of the combusted mixture and the less extensive compression of the intake mixture, the two-cycle engine is less efficient at extracting work from each fuel and air charge. However, because there are twice as many power cycles for each rotation of the output shaft, these engines can produce more power for their size and weight than most four-cycle engines. For this reason, the military uses a large number of two-cycle diesel engines in the combat vehicle fleet.

3.2.3 Otto engines. The Otto or spark ignition (SI) engine is by far the most common vehicle powerplant in civilian use. This engine was developed by Nikolaus A. Otto in 1876 and was until recently virtually the only type of engine used in passenger cars. The distinguishing characteristic of this type of engine is that the air and fuel are added in carefully controlled proportions prior to the beginning of the compression stroke, and then the mixture is compressed within the cylinder. Once the air and fuel mixture has been compressed to the proper pressure, the gas is ignited by a spark plug to begin the combustion process. Because of the premixing of the air and fuel, the composition of the gas mixture at the time of ignition is uniform (homogeneous), and combustion occurs by a flame spreading throughout the combustion chamber from the spark plug. The amount of power produced by the engine is controlled by varying the volume of the air and fuel mixture that is admitted to the cylinder. This is done by a throttling valve which restricts the air (and fuel) flow to the engine. This throttle is usually located in the base of the carburetor. A homogeneous mixture of fuel and air will only burn when the ratio of air to fuel is within a narrow range of values. For hydrocarbon fuels there must be from 3.7 to 21 pounds of air per pound of fuel for the mixture to support combustion. The chemically ideal mixture is 14.7 pounds of air per pound of fuel (gasoline). As a result, great care must be exercised in the mixing process, particularly since exhaust emissions, efficiency, and power are dramatically affected by minor changes in the air/fuel ratio. This metering of fuel is done either by a carburetor or a fuel injection system. A carburetor measures the amount of air going into the engine, then adds the correct amount of fuel to maintain the proper air/fuel ratio. Current (1983) passenger-car carburetors try to maintain this air/fuel ratio to within 0.05 of 14.7. This fuel handling and ignition system imposes certain requirements on the fuel properties. The necessity of premixing the fuel and air to make a uniform gas charge requires that the fuel have sufficient volatility to adequately evaporate at ambient temperatures. Since the fuel mixture is compressed and therefore heated before the ignition system starts the combustion process, the fuel must have sufficient resistance to self-ignition so that it will not ignite by itself. This resistance to autoignition is measured by the octane number. Gasoline is currently the fuel of choice for most Otto engines, although other fuels such as methanol, propane, or natural gas can be used in properly designed engines.

## MIL-HDBK-114

3.2.4 Diesel engines. The other major type of reciprocating engine in common use is the diesel or compression ignition (CI) engine. This engine type, developed by Rudolph Diesel in 1892, is the more common engine in the military's tactical and combat fleet. The diesel engine may further be divided into direct injection (DI) and prechambered or indirect injection (IDI) engines. Although similar in design to the Otto engine they are structurally heavier than Otto engines to overcome higher peak cylinder pressures in the combustion chamber. The difference is in how the fuel is added to the air and how combustion is initiated. In a diesel engine only air is admitted during the intake stroke. This air charge is then compressed to a higher pressure than in a SI engine. This compression raises the temperature of the air. At the appropriate time, the fuel is sprayed into the high-pressure air in the cylinder. The fuel spray ignites as it mixes with the air and the normal combustion and expansion process takes place. Ignition of the fuel takes place only because the air has been raised to a sufficiently high temperature. Combustion takes place around the jet of fuel that is being sprayed in, and there are areas within the chamber where there is either insufficient fuel or too much fuel for combustion to occur. No matter how much or how little fuel is injected, there are areas where the air-to-fuel ratio is in the correct range and combustion does take place. The power produced by the engine is controlled by varying the amount of fuel injected. A fuel-air charge is used in every cycle, and there is no throttling of the air as in a SI engine. The combination of a higher compression ratio with the lack of energy lost due to air throttling means that diesel engines are more fuel efficient than equivalent Otto-cycle engines, particularly at low power outputs. However, less than optimal mixing of the fuel and air occurs. When combustion occurs in areas where there is insufficient air for the fuel present, carbon particles are formed. If these particles are not consumed later during combustion, they are emitted in the exhaust as black smoke. As a result, the amount of fuel injected per cycle has to be limited to minimize this smoke formation. The end result is that the diesel engine produces less power for its size than an Otto-cycle engine. Because the diesel engine draws in only air during the intake process, a two-cycle engine can be made more efficient in this configuration than in a SI configuration. In a two-cycle Otto engine, it is difficult to prevent raw fuel in the intake charge from being lost through the exhaust during the combined intake/exhaust stroke. In many diesel two-cycle engines, excess air is blown through the engine to help remove combustion products without fear of wasting fuel. Thus, there are presently far more two-cycle diesel engines than Otto versions so that the improvement in power output to engine size can be obtained. In particular, the military uses a large number of Detroit Diesel two-cycle engines for this reason. Fuels for diesel engines need to be easy to autoignite. This property of the fuel is measured by cetane number, where the higher the cetane number means that the fuel will ignite more quickly at high temperature. The fuel must also provide lubrication for and not form deposits within the precision machined fuel injection equipment.

## MIL-HDBK-114

## CHAPTER IV

MOBILITY FUELS - GASOLINE AND GASOHOL

4.1 General. Gasoline is a multicomponent blend of petroleum-derived hydrocarbons with appropriate additives. Several grades of gasoline are formulated with varying antiknock values. The boiling range (i.e., volatility) of gasoline is seasonally adjusted to compensate for anticipated ambient temperature and the intended area of use. Hydrocarbons are chemical combinations of hydrogen and carbon atoms which are the basic elements that make up all petroleum products. The additives are chemical compounds added to the gasoline to provide or enhance specific performance features. Gasohol on the other hand, is a blend of a gasoline with 10 percent ethyl alcohol. Typical properties of gasoline as well as the specifications requirements are provided in Appendix B.

4.2 Gasoline and gasohol specifications.4.2.1 MIL-G-46015 - Gasoline, automotive, combat referee grade.

4.2.1.1 Scope. Referee grade gasoline is a gasoline representing the minimal or marginal quality level which can be procured under the parent specification MIL-G-3056 while meeting all its requirements. It is designed to be equivalent to the quality of OCONUS gasoline production or that available for production in times of a national emergency. It is used for research, development and proof testing to assure that equipment will perform adequately with all gasolines procured under MIL-G-3056.

4.2.1.2 Intended use. Gasolines covered by this specification are intended for use in research, development and proof-testing or qualification of spark-ignition and ground-based turbine engines, components, vehicle heaters, etc. The use of referee fuel in conjunction with Development Testing (DT I through DT III) is necessary to uncover potential operational problems with respect to equipment performance, development of suitable RAM-D data, and to permit data correlation of all testing sites regardless of their geographical location. The gasolines are of the following grades:

a. Grade I - Engine endurance gasoline. This gasoline is intended for use in all engine and vehicle qualification, proof, engineering or pilot model testing in conjunction with appropriate reference engine oils to assure compatibility with military standard supply items.

b. Grade II - Cold start gasoline. This gasoline is intended for use in low temperature testing to permit evaluation of cold starting and warm-up operational characteristics for temperatures below 0° C (32° F).

4.2.1.3 Limitations. Referee fuels should not be used in engines or other equipment in the field as a substitute for MIL-G-3056 gasoline without approval of the engine manufacturer or of the US Army Belvoir Research and Development Center, ATTN: STRBE-VF, Fort Belvoir, VA 22060.

## MIL-HDBK-114

4.2.1.4 Constituent materials. The gasoline shall be of volatile hydrocarbon fuels plus additives. The additives shall be of the type listed under table I as required in the specification.

4.2.1.5 Alternate designation. None are provided.

4.2.2 MIL-G-3056 - Gasoline, automotive, combat.

4.2.2.1 Scope. This specification covers combat-grade gasolines suitable for use in all gasoline engines other than aircraft under all conditions of service.

4.2.2.2 Intended use. Gasolines covered by this specification are intended for use in automotive, stationary and marine gasoline engines, vehicle and personnel heaters, and cooking units. Gasolines are supplied in two types; the application of these are based on ambient temperatures as follows:

a. Type I. Type I gasoline is intended for general use at all temperatures above  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ).

b. Type II. Type II gasoline is intended for use in areas where the mean temperature is consistently below  $0^{\circ}\text{C}$  ( $32^{\circ}\text{F}$ ).

4.2.2.3 Limitations. This fuel shall not be used in those equipments (portable heaters, cooking units) where the manufacturer does not recommend the use of leaded fuels.

4.2.2.4 Constituent materials. The gasolines shall be of volatile hydrocarbon fuels plus additives. The additives required are shown in table I.

4.2.2.5 Alternate designation. See table II.

4.2.3 VV-G-1690 - Gasoline, automotive, leaded or unleaded.

4.2.3.1 Scope. This specification covers commercial leaded or unleaded gasoline for use in automotive spark-ignition engines under all climatic conditions. The leaded and unleaded automotive gasolines shall each be of three grades. The major differences among these grades are in the antiknock index levels.

4.2.3.2 Intended use. Gasolines furnished under this specification are intended for immediate use in spark-ignition internal-combustion engines utilized in automotive, marine and stationary equipment. The gasolines are not intended for static storage for extended periods. They should not be stored in stand-by equipment for more than 60 days without replenishment because of auto-oxidation which can result in deterioration of the overall quality of gasoline, unleaded gasoline must be used in vehicles equipped with catalytic convertors. The gasolines are of the following grades.

a. Limited grade leaded gasoline. Limited grade leaded gasoline meets the antiknock requirements of most 1971 and later model equipment that can use leaded gasoline, and pre-1971 equipment with low antiknock requirements or low compression ratios.

## MIL-HDBK-114

b. Regular grade leaded gasoline. Regular grade leaded gasoline meets the antiknock requirements of most 1970 and prior model equipment designed to operate on leaded gasoline, and most 1971 and later model equipment that can use leaded gasoline and has antiknock requirements which exceed those of limited grade leaded gasoline.

c. Premium grade leaded gasoline. Premium grade leaded gasoline is intended for equipment that can use leaded gasoline and has very high antiknock requirements which exceed those of regular grade leaded gasoline.

d. Limited grade unleaded gasoline. Limited grade unleaded gasoline is intended for equipment having emission control system requirements with low antiknock requirements or low compression ratios.

e. Regular grade unleaded gasoline. Regular grade unleaded gasoline meets the antiknock requirement of most 1971 and later equipment.

f. Premium grade unleaded gasoline. Premium grade unleaded gasoline is intended for equipment with high antiknock requirements which exceed those of regular grade unleaded gasoline.

4.2.3.3 Limitations. These gasolines are not intended for static storage for extended periods as they do not possess adequate storage stability characteristics.

TABLE I. Additive requirements for military and federal specifications.

Additives	MIL-G-46015	MIL-G-3056	VV-G-1690
Oxidation inhibitors	Yes	Yes	(1)
Metal deactivators	Yes	Yes	(1)
Corrosion inhibitors	(1)	(1)	(1)
Antiknock compounds	Yes	Yes	(2)
Other types (i.e. detergents, dispersants, solvent oils, etc)	(3)	(3)	(4)

- (1) May be added at the option of the refiner or if required by the procuring activity.
- (2) Additives only used in leaded gasoline.
- (3) None are permitted except dyes which are required to meet the color requirement.
- (4) They are permitted in procurement of gasoline provided prior examinations have verified the absence of their potential deleterious effects and adverse side effects.

4.2.3.4 Constituents material. The gasolines shall be volatile hydrocarbon fuels plus additives. The additives shall be of the type shown in table I as required in the specification.

4.2.3.5 Alternate designation. See table II.

## MIL-HDBK-114

TABLE II. Fuel requirements for Army mobility engines: spark ignition (AR 703-1).

ENGINE SYSTEM	PRIMARY FUEL, NATO CODE NO.	ALTERNATE FUEL, NATO CODE NO.	EMERGENCY FUEL, NATO CODE
SPARK-IGNITION: GROUND EQUIPMENT-	VV-G-1690 (MOGAS)	MIL-G-5572 (AVGAS), F-18	
CONUS OCONUS	MIL-G-3056 (MOGAS), F-46	F-49 (GASOLINE) F-50 (GASOLINE) ASTIM D439 (GASOLINE) MIL-G-53006 (GASOHOL)	

4.2.4 MIL-G-53006 - Gasohol, automotive, leaded or unleaded.

4.2.4.1 Scope. This specification covers commercial leaded or unleaded Gasohol for use in automotive spark-ignition engines under all climatic conditions within the continental United States (including Alaska and Hawaii).

4.2.4.2 Intended use. Gasohol furnished under this specification is intended for immediate use in all spark-ignition internal-combustion engines and all other equipment designed to operate on gasoline. Gasohol, as well as gasolines procured under VV-G-1960, (see 4.2.3) is not intended for static storage environments. It should not be stored for more than 60 days without replenishment because of possible auto-oxidation and water absorption which can result in deterioration of the overall quality of gasohol. The gasohol has the following grades:

a. Limited-grade Gasohol. Limited-grade gasohol is intended for use in 1971 (or later) commercial and administrative vehicles equipped with the lower compression ratio spark-ignition engines designed to operate on a reduced antiknock quality product. This grade may be used in many earlier model vehicles equipped with lower compression engines described above or which have been modified to accommodate this grade.

b. Regular-grade Gasohol. Regular-grade gasohol is intended for use in spark-ignition engines designed to operate with a product of this antiknock quality or when so required by equipment manufacturer's recommendations. This grade may be required in 1971 or later model vehicles that have antiknock requirements which exceed those of limited grade.

c. Premium-grade Gasohol. Premium-grade gasohol is intended for use in spark-ignition engines designed to operate with a product of this antiknock quality or when so required by equipment manufacturer's recommendations. This grade may be required in 1971 or later model vehicles that have antiknock requirements which exceed those of regular grade.

4.2.4.3 Limitations. Based upon recently completed research investigations, satisfactory utilization of gasohol will occur if the following conditions and reservations are adhered to:

## MIL-HDBK-114

a. Gasohol should never be introduced into any above or under ground tankage where water bottoms or sumps are known to exist. This accumulated water will cause extraction of ethyl alcohol and a resultant loss in product.

b. Where gasohol has been inadvertently contaminated with water resulting in two phases, separation of water with use of standard military designed filter-separators (as is normally done with gasoline, turbine fuel, etc.) is not recommended. The two phases will be represented by a top fuel phase and a bottom water phase. Both phases will contain some alcohol. Separation of the two phases can be accomplished by decanting and discarding the bottom phase. The fuel phase will be now deficient in alcohol but could still be an adequate fuel. Specific instructions can be provided from the US Army Belvoir Research and Development Center, ATTN: STRBE-VF, Fort Belvoir, VA 22060.

c. Where water contamination in gasohol is suspect, microbiological organisms may proliferate in those areas where relatively mild or warm ambient temperatures exist. To control this growth of micro-organisms, the addition of an approved biocide additive may be required. Specific instruction relative to the biocide addition can be provided from the above mentioned address.

d. Gasohol is not recommended for use in those multifuel engines (LD/LDT/LDS-495 series and LDS-427) currently powering the 2-1/2-ton and 5-ton military truck fleet. The addition of ethyl alcohol to gasoline produces an unusually low cetane number which effects startability and creates abnormal combustion problems.

4.2.4.4 Constituent material. The Gasohol shall be composed of 90 percent volume gasoline and 10 percent volume ethyl alcohol. A tolerance of 1 percent is established. The additives will be the same as for VV-G-1690. A description of the main constituents is as follows:

a. Gasoline. The gasolines shall be volatile hydrocarbon fuels conforming to VV-G-1690. They must contain no oxygenated blending components (alcohols or ethers) other than minor amounts used as anti-icing additives.

b. Ethyl alcohol. The ethyl alcohol used shall have a minimum purity of 98.5 percent by volume and shall be completely denatured. The total volume of denaturant, which is approved for fuel alcohol, may be included in the volume of ethyl alcohol provided it does not exceed the 5 percent volume specified. The ethyl alcohol to be used shall be derived from renewable sources and shall exclude alcohol made from petroleum, natural gas, and coal.

4.2.4.5 Alternate designation. Same as VV-G-1690 (see table II).

#### 4.3 Significance of the physical and chemical properties test methods.

4.3.1 General. This section will provide a brief explanation of the significance on the test methods used to determine the quality and performance characteristics of the fuel. The test methods used on the specifications are provided in table III, and figure 1 will provide the engine-fuel property interface for spark-ignition engine systems.

4.3.2 Distillation, ASTM D 86.

## MIL-HDBK-114

4.3.2.1 Significance. Gasoline for motor vehicles is a complex mixture. It is composed almost entirely of relatively volatile hydrocarbons that have widely divergent vapor pressure and boiling points. The volatility of motor gasoline must be balanced to provide all the desired performance features that depend on the vaporization behavior of the product; i.e., easy starting, quick warm-up, freedom from carburetor icing, rapid acceleration, freedom from vapor lock, good manifold distribution, and minimum crankcase dilution. These performance requirements are the aggregate of a wide variety of conditions imposed by the design features of many different kind of consuming units, and by the extremes in atmospheric conditions. The balanced volatility of motor gasolines that results from judicious selection of its components achieves practical compromises in these performance features considering the extremely wide demands put on the product.

4.3.3. Vapor liquid (V/L) ratio, ASTM D 2533.

4.3.3.1 Significance. The tendency of a gasoline to vaporize in common automobile fuel systems is indicated by the vapor-liquid ratio of that gasoline at conditions approximating those in critical parts of the fuel systems.

4.3.4. Reid vapor pressure, ASTM D 323.

4.3.4.1 Significance. The Reid vapor pressure of motor gasoline is a widely used criterion of freedom from vapor lock in automotive equipment. When used in conjunction with the initial portion of the distillation curve, the vapor locks relationships become more precise. In addition, these data are closely related to the composition of the gasoline in terms of the lightest hydrocarbons.

4.3.5. Existent gum/unwashed gum, ASTM D 381.

4.3.5.1 Significance. The true significance of this method for determining gum in motor gasoline is not firmly established. It has been proved that high existent gum can cause induction-system deposits and sticking of intake valves, and in most instances it can be assumed that low gum will ensure absence of induction-system difficulties. The user should, however, realize that the test is not of itself correlative to induction-system deposits. The primary purpose of the test, as applied to motor gasoline, is the measurement of the oxidation products formed in the sample prior to or during the comparatively mild conditions of the test procedure. Since many motor gasolines are purposely blended with nonvolatile oils or additives, the heptane extraction step is necessary to remove these from the evaporation residue so that the deleterious material, gum, may be determined. The existent and unwashed gum are defined as follows:

- a. Existent gum - the evaporation residue of aircraft fuel or the heptane-insoluble portion of the evaporation residue of motor gasoline.
- b. Unwashed gum - the evaporation residue of motor gasoline consisting of existent gum and nonvolatile additive components.

4.3.6. Lead.

## MIL-HDBK-114

4.3.6.1 Significance. The method is used to determine the amount of tetraethyllead in motor gasolines and similar volatile distillates, and to control blending for uniformity of mix and compliance with specification standards for tetraethyllead content. The methods give equivalent results within their stated limits of precision.

TABLE III. Test methods required in gasolines and gasohol specifications. 1/

TEST	ASTM METHOD NUMBER			
	MIL-G-3056	MIL-G-46015	VV-G-1690	MIL-G-53006
Distillation	D 86	D 86	D 86	D 86
Vapor-liquid (V/L ratio)	D 2533 <u>2/</u>	D 2533 <u>2/</u>	D 2533 <u>2/</u>	D 2533 <u>3/</u>
Reid vapor pressure <u>4/</u>	D 323	D 323	D 323	D 323 <u>5/</u>
Unwashed gum <u>6/</u>	D 381	D 381	NR	NR
Existent/unwashed gum	NR	NR	D 381	D 381
Lead	D 526	D 526	NR	NR
Leaded gasoline	NR	NR	D 2547	D 2547
Unleaded gasoline	NR	NR	D 3237	D 3237
Sulfur <u>7/</u>	D 1266	D 1266	D 1266	D 1266
Corrosiveness	D 130	D 130	D 130	D 130
Oxidation stability	D 525	D 525	D 525	D 525
Water and sediment	D 2709	D 2709	D 2709	NR
Composition	NR	D 1319	D 1319 <u>8/</u>	NR
Color	<u>9/</u>	<u>9/</u>	NR	NR
Phosphorus	NR	NR	D 3231	D 3231
Gravity	NR	D 287	NR	NR
Benzene content	NR	NR	D 3606	NR
Octane rating, Research method	D 2699	D 2699	D 2699	D 2699
Octane rating, Motor method	D 2700	D 2700	D 2700	D 2700
Particulate contamination	NR	NR	NR	D 2276
Water	NR	NR	NR	D 1744 <u>10/</u>
Water tolerance	NR	NR	NR	<u>11/</u>
Acidity	NR	NR	NR	D <u>1613</u>
Alcohols	NR	NR	NR	<u>12/</u>
Manganese content	NR	NR	NR	<u>13/</u>

1/ Alternative test methods are indicated in the specification.

2/ As an alternative, the temperature at a vapor-liquid ratio of 20:1 may be calculated in accordance with paragraph A2.3 of ASTM D 439. However, use ASTM D 2533 as the reference V/L method when calculated values are questionable.

3/ ASTM D 2533 must be modified to use mercury in the leveling bulb in place of glycerin.

4/ ASTM D 2551 for Vapor Pressure of Petroleum Products (Micro-method) may be used as an alternative method for determining vapor pressure.

5/ ASTM D 323 must be modified as described in the ASTM Information Document on gasohol in the 1981 ASTM Std Part No. 23.

MIL-HDBK-114

- 6/ Unwashed gum is defined in paragraph 4.2 of ASTM D 381. Follow the procedure for unwashed gum in D 381.
- 7/ ASTM D 2622. Sulfur in Petroleum Products (X-Ray Spectrographic Method) may be used as an alternative method for determining sulfur content.
- 8/ Hydrocarbon types (aromatics).
- 9/ Use method 103 of FED-STD-791 for determination of color.
- 10/ ASTM D 1744 is to be used in the determination of water in gasohol; ASTM E 203 is to be used in the determination of water in the ethanol.
- 11/ See appendix in the specification test methods 2 and 4.
- 12/ See appendix in specification.
- 13/ Manganese will be determined by the method given in the EPA MSAPC Advisory Circular A/C No. 26-B, D 4 or other equivalent method.

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# ENGINE FUEL INTERFACE: SPARK IGNITION

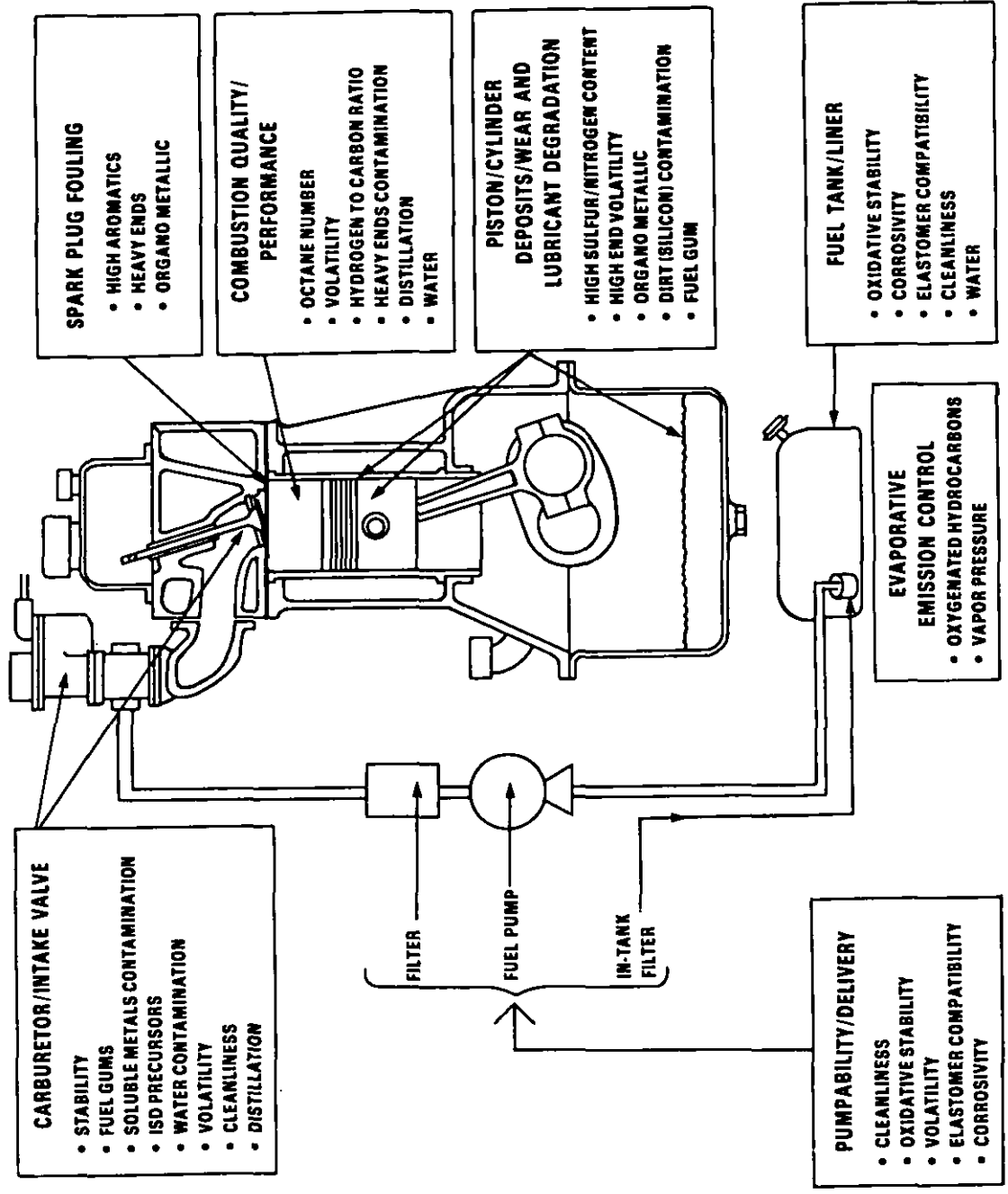


FIGURE 1.

## MIL-HDBK-114

4.3.7 Sulfur. ASTM D 1266, D 2622.

4.3.7.1 Significance. Total sulfur content is significant because it governs the amount of sulfur oxides formed during combustion. Water from combustion of the hydrocarbon fuels collects on the cylinder walls, whenever the engine operates at low jacket temperature (below 60° C). Under such operating conditions, part of the sulfur oxides combine with the water to form dilute solutions of sulfurous and sulfuric acids. These acids attack the cylinder walls and piston rings, aid rust formation, and thus cause increased wear of the metal surfaces. However, the evaluation of corrosive combustion products cannot be based on the sulfur oxides alone because there is some evidence that other acids (halogen and nitrogen) formed during combustion are also factors in increasing wear.

4.3.8 Phosphorus, ASTM D 2831.

4.3.8.1 Significance. This method provides a means to control the concentration of phosphorus additives in the finished product. Phosphorus acts as a poison in catalytic converters.

4.3.9 Corrosiveness, ASTM D 130.

4.3.9.1 Significance: Crude petroleum contains sulfur compounds, most of which are removed during refining. However, of the sulfur compounds remaining in the petroleum product, some can have a corroding action on various metals and this corrosivity is not necessarily related directly to the total sulfur content. The effect can vary according to the chemical types of sulfur compounds present. The copper strip corrosive test is designed to assess the relative degree of corrosivity of a petroleum product.

4.3.10 Oxidation stability, ASTM D 525.

4.3.9.10 Significance: The induction period may be used as an indication of the tendency of motor gasoline to form gum in storage. It should be recognized, however, that its correlation with the formation of gum in storage may vary markedly under different storage conditions and with different gasolines.

4.3.11 Water and sediment, ASTM D 2709.

4.3.11.1 Significance. Appreciable amounts of water and sediment in a fuel tend to cause fouling of facilities for handling it, and to give trouble in combustion mechanisms. Sediment may accumulate in storage tanks and on filter screens or combustion parts, resulting in obstruction to free passage of fuel from the tank to the combustor. Water is the basic cause of the corrosion of tanks and equipment. This test covers the determination of free water and sediment as a pass-fail indication of product quality.

4.3.12 Composition, ASTM D 1319.

## MIL-HDBK-114

4.3.12.1 Significance. Separation by the fluorescent-indicator adsorption procedure is a convenient and rapid way to ascertain the percentages of saturates, nonaromatic olefins, and aromatics in gasolines, jet fuels, and other liquid petroleum products or fractions thereof that boil below 315.6° C (600° F). (Bifunctional molecules that contain both an olefinic double bond and an aromatic ring, such as styrene and dihydronaphthalene, are counted as aromatics by this method.) However, method D 936 is more accurate for aromatic content of straight-run fractions free from olefins and nonhydrocarbons.

4.3.13 Color, FED-STD-791, method 103.

4.3.13.1 Significance. One of the most frequent uses of color is for identification of dyed products, such as gasolines, certain diesel fuels, and hydraulic brake fluids. Color can be observed without the aid of instruments. Since it is widely used as an indication of the uniformity of quality of a given product or brand, it must be carefully controlled by the refiner. Actually it is not always a reliable guide. For that reason, color specifications should not be more stringent than required for the specific use of a product.

4.3.14 Gravity, ASTM D 287.

4.3.14.1 Significance. Accurate determination of the gravity of petroleum and its products is necessary for the conversion of measured volumes to volumes at the standard temperature of 15.5° C (60° F). Gravity is a factor governing the quality of crude oils. However, the gravity of a petroleum product is an uncertain indication of its quality. Correlated with other properties, gravity can be used to give approximate hydrocarbon composition and heat of combustion.

4.3.15 Benzene, ASTM D 3606.

4.3.15.1 Significance: Benzene is classed as a toxic material. A knowledge of the concentration of this compound may be an aid in evaluating the possible health hazard to persons handling and using the gasoline. This method is not intended to evaluate such hazards.

4.3.16 Octane rating; research method, ASTM D 2699.

4.3.16.1 Significance. The research method octane number correlates with full-scale spark-ignited engine antiknock performance at low speed. In conjunction with the motor method, it provides a means of defining the antiknock quality of a motor gasoline for use in vehicles on the road.

4.3.17 Octane rating; motor method, ASTM D 2700.

4.3.17.1 Significance: The motor method octane number correlates with full-scale spark-ignited engine antiknock performance at high speed. In conjunction with the research method, it provides a means of defining the antiknock quality of a motor gasoline for use in vehicles on the road.

## MIL-HDBK-114

## CHAPTER V

MOBILITY FUELS - DIESEL

5.1 General. Diesel fuel is the fuel most utilized by the military, especially in ground equipment. This fuel is composed of middle distillate fractions which have a higher boiling range than gasoline. The following is a description of the different specifications, with their intended use and limitations. Typical properties as well as specification requirements of Diesel and Burner fuel are provided in Appendix C.

5.2 Diesel Fuel Specification.5.2.1 MIL-F-46162 - Fuel, Diesel, Referee grade.

5.2.1.1 Scope. Referee grade diesel fuel. This fuel represents the minimal or marginal quality level which can be procured under the parent specification VV-F-800 while meeting all of its requirements. It is designed to be equivalent to the quality of OCONUS distillate production or that production available in times of national emergency.

5.2.1.2 Intended use. This diesel fuel is intended for use in research, development and proof-testing of all compression-ignition engines, diesel-powered auxiliary units, gas turbine engine driven ground vehicles and mobile electric power generators, and other fuel handling supply items. The use of referee fuel in conjunction with Development Testing (DT I through III) is considered necessary to uncover potential operational problems with respect to performance and to enable data correlation of all testing sites regardless of geographical location.

5.2.1.3 Limitations. Referee fuels should not be used in engines or other equipment in the field as a substitute for VV-F-800 diesel fuel without approval of the engine manufacturer or from the US Army Belvoir Research and Development Center, ATTN: STRBE-VF, Fort Belvoir, VA 22060. This diesel fuel is intended for use in all engine and equipment qualification, proof, engineering or pilot model testing where ambient temperatures at or above minus 18° C (-0.4° F) are anticipated. At temperatures below -18° C, (-0.4° F), JP-8 fuel conforming to MIL-T-83133 should be used.

5.2.1.4 Constituent materials. The diesel fuels shall be refined petroleum distillates. Those fuels meeting the requirements shall be blended using straight-run, catalytically, or thermally processed blending fractions with additives as indicated in the specification and shown in table IV. Addition of an antioxidant or stabilizer and a corrosion inhibitor is mandatory. Addition of cetane improver(s) or a pour-point depressant or flow improver is permissible, if necessary, to meet requirements of this specification. The particular additives and the amounts used shall be limited to those specified.

5.2.1.5 Alternate designations. See table V.

5.2.2 VV-F-800 - Fuel oil, diesel.

## MIL-HDBK-114

5.2.2.1 Scope. This specification covers diesel fuel oils suitable for use in compression-ignition engines and gas turbine engines other than aircraft under all climatic conditions.

5.2.2.2 Intended use. The fuel should be of the following grades:

(a) Military symbol DF-A. Arctic-grade diesel fuel oil is intended for use in high-speed automotive-type diesel engines, gas turbine engines other than aircraft, and pot-type burner space-heaters, in areas where ambient temperatures lower than  $-32^{\circ}\text{C}$  ( $-26^{\circ}\text{F}$ ) generally occur, and where it is impractical to maintain dual storage capabilities. This grade of diesel fuel should not be used for low-speed stationary engine applications.

(b) Military symbol DF-1. Winter-grade diesel fuel oil is intended for use in high-speed automotive diesel engines and gas turbine engines other than aircraft, in areas in which ambient temperatures as low as  $-32^{\circ}\text{C}$  ( $-26^{\circ}\text{F}$ ) may occur (see Appendix A). This grade of diesel fuel may be used for medium-speed stationary engine applications, where fuel heating facilities are not available.

(c) Military symbol DF-2. Regular-grade diesel fuel oil is intended for use in all automotive high-speed/medium-speed engine applications and gas turbine engines other than aircraft, in temperate climates according to guidelines in Appendix A of VV-F-800. All ground forces within NATO use diesel fuel which conforms to NATO F-54 Diesel Fuel. This fuel is supplied under the grade DF-2 in OCONUS.

5.2.2.3 Limitations. This fuel should be used in accordance with the minimum temperatures determined for different geographical areas in CONUS and OCONUS and showed in table III of VV-F-800.

5.2.2.4 Constituent material. The diesel fuels supplied under VV-F-800 shall be refined petroleum distillates. Additive agents, such as antioxidants, pour point depressants, flow improvers, etc., will be permitted for products purchased by individual installations in the continental US (CONUS) providing prior approval has been given. However, for military bulk deliveries outside the continental US (OCONUS), or long term storage (greater than six months) applications (i.e., Army depot facilities, stand-by power generators), only those additives indicated in the specification will be permitted (see table IV).

5.2.2.5 Alternate designation. See table V.

5.2.3 MIL-F-16884, Fuel, Naval Distillate.

5.2.3.1 Scope. This specification covers one grade of 100 percent distillate fuel oil (NATO symbol F-76).

5.2.3.2 Intended use. This grade of Naval distillate fuel is intended for use in diesel engines in submarines and for such other uses as may be specified at temperatures above  $-1.1^{\circ}\text{C}$  ( $30^{\circ}\text{F}$ ). Below this temperature, MIL-T-5624 (JP-5) should be used.

## MIL-HDBK-114

5.2.3.3 Constituent material. The fuel supplied under MIL-F-16884 shall be distillate fuel and may contain only those additives indicated in the specification (see table IV).

5.2.3.4 Alternate designation. See table V.

5.2.4 VV-F-815, Fuel oil, burner.

5.2.4.1 Scope. This specification covers fuel oil for stationary oil-burning heat and power generation equipment. This specification is currently replaced by ASTM D 396.

5.2.4.2 Intended use. Burner fuel oils covered by VV-F-815 fall into two broad classes, distillates and residuals. The oils are intended for use in various types of fuel-burning equipment under various climatic and operating conditions, for heat in furnaces for heating buildings, or for other purposes. The grades covered by VV-F-815 are intended for specific applications as indicated below:

(a) Grade No. 1. A light distillate oil intended for use in burners of the vaporizing type in which the oil is converted to a vapor by contact with a heated surface or by radiation.

(b) Grade No. 2. A heavier distillate than grade No. 1. It is intended for use in atomizing-type burners which spray the oil into a combustion chamber where the tiny droplets burn while in suspension. This grade of oil is used in most domestic burners and in many medium-capacity commercial-industrial burners where its ease of handling and ready availability sometimes justify its higher cost over the residual grades.

(c) Grade No. 4 (light). Usually a light residual, but is sometimes a heavy distillate. It is intended for use in burners equipped with devices that atomize oils of higher viscosity than domestic burners can handle. Its permissible viscosity range allows it to be pumped and atomized at relatively low storage temperatures.

(d) Grade No. 4. Usually a light residual but sometimes a heavy distillate. It is intended for use in burners equipped with devices that atomize oils of higher viscosity than domestic burners can handle. Its permissible viscosity range allows it to be pumped and atomized at relatively low storage temperatures. Thus, except in extremely cold weather, it requires no preheating for handling.

(e) Grade No. 5 (light). A residual fuel of intermediate viscosity for burners capable of handling fuel more viscous than grade No. 4 without preheating. Preheating may be necessary in some types of equipment for burning and in colder climates for handling.

(f) Grade No. 5 (heavy). A residual fuel more viscous than grade No. 5 (light). It is intended for similar service. Preheating may be necessary in some types of equipment for burning and in colder climates for handling.

(g) Grade No. 6. A high-viscosity oil, sometimes referred to as "Bunker C", and used mostly in commercial and industrial heating. It requires preheating in the storage tank to permit pumping and additional preheating at the burner to permit atomizing. The extra equipment and maintenance required to handle this fuel usually preclude its use in small installations.

## MIL-HDBK-114

5.2.4.3 Limitations. This fuel is not intended for automotive engines, only for oil-burning heat-generating equipment.

5.2.4.4 Constituent materials. Burner fuel oil shall consist of hydrocarbon fuel derived from crude oil and may contain waste lubricants or other recycled ingredients. Blending of various compatible grades of the material to produce an intermediate grade is permitted; however, such blending shall be accomplished by mechanical mixing or agitation in a tank, or by in-line blending prior to loading the product into transport equipment. The product formed by such blending shall comply with all the requirements of the grade produced.

5.2.4.5 Alternate designation. None

TABLE IV. Additives in diesel and burner fuels.\*

Additives	MIL-F-46162	VV-F-800	MIL-F-16884	VV-F-815 <sup>1/</sup>
Antioxidant/ stabilizers	<u>2/</u>	Yes	Yes	NS
Corrosion inhibitors	<u>3/</u>	<u>3/</u>	NR	NS
Cetane improver	<u>4/</u>	Yes	Yes	NS
Pour point depressant	<u>4/</u>	NR	NR	NS
Fuel system icing Inhibitor	NR	<u>5/</u>	NR	NS
Metal deactivator	NR	NR	Yes	NS

\* See the corresponding specification for the approved treatment levels and approved additive compounds. NR = not required; NS = not specified.

- 1/ VV-F-815 does not specify any additive package, as long as it meets the physical and chemical properties. It has been replaced by ASTM D396.
- 2/ The addition of antioxidants or stabilizers other than those listed in the specification is permitted, provided that prior approval is obtained from Belvoir Research and Development Center, ATTN: STRBE-VF, Ft Belvoir, VA 22060.
- 3/ The corrosion inhibitor shall conform to MIL-I-25017.
- 4/ Addition is permissible, if necessary to meet the requirements.
- 5/ The fuel system icing inhibitor shall conform to MIL-I-27686.

MIL-HDBK-114

TABLE V. Fuel requirements for Army mobility engines: compression ignition and gas turbines.

ENGINE SYSTEM	PRIMARY FUEL, NATO CODE NO.	ALTERNATE FUEL, NATO CODE NO.	EMERGENCY FUEL, NATO CODE NO.
COMPRESSION-IGNITION, GROUND EQUIPMENT: TWO-CYCLE AND FOUR-CYCLE, NA <sup>1</sup> / <sub>1</sub> & TURBOCHARGED ENGINES	VV-F-800 (DF-2), F-54 <u>2</u> / F-34	MIL-T-5624 (JP-5), F-44 ASTM D 975 (1-D & 2-D DIESEL)	MIL-T-83133 (JP-8), MIL-F-16884 F-76 F-75 (NAVY DISTILLATE) MIL-T-5624 (JP-4), F-40 ASTM D 2880 (TURBINE FUEL, 1-GT and 2-GT) ASTM D 3669 (KEROSENE) ASTM D 1655 (AVIATION FUEL) ASTM D 396 (NO-1 & NO-2) ASTM D 975 (4-D DIESEL)
FOUR-CYCLE, MAN SYSTEM (MULTIFUEL)	VV-F-800 (DF-2), F-54 <u>2</u> / F-40, F-44	MIL-T-5624 (JP-4, JP-5), MIL-T-83133 (JP-8), F-34	VV-G-1690, LIMITED GRADE (MOGAS) ASTM D 439, ANTIKNOCK INDEXES 87 & 89 (GASOLINE)
GAS TURBINE: GROUND EQUIPMENT	VV-F-800 (DF-2), F-54 F-40, F-44	MIL-F-16884 F-76 F-75 (NAVY DISTILLATE) MIL-G-3056 (MOGAS), F-46 F-50 (GASOLINE) ASTM D 3699 (KEROSENE) ASTM D 1655 (AVIATION FUEL) ASTM D 2880 (TURBINE FUEL) ASTM D 975 (DIESEL)	MIL-G-3056 (MOGAS), F-46 MIL-G-5572 (AVGAS), F-18

MIL-HDBK-114

TABLE V. Fuel requirements for Army mobility engines: compression ignition and gas turbines. (Cont)

ENGINE SYSTEM	PRIMARY FUEL, NATO CODE NO.	ALTERNATE FUEL, NATO CODE NO.	EMERGENCY FUEL, NATO CODE NO.
GAS TURBINE: GROUND EQUIPMENT (continued)		MIL-F-16884 F-76 F-75 (NAVY DISTILLATE) ASTM D 975 (DIESEL) ASTM D 3699 (KEROSENE) ASTM D 1655 (AVIATION FUEL) ASTM D 2880 (TURBINE FUEL) ASTM D 396 (FUEL OIL, NOS. 1&2)	VV-G-1690, (MOGAS) MIL-G-53006 (GASOHOL) F-49 (GASOLINE) F-50 (GASOLINE)

1/ Normally-Aspirated

2/ F-54 is intended for OCONUS use. Within CONUS, Grades DF-A, DF-1, &amp; DF-2(OONUS) apply.

## MIL-HDBK-114

5.3 Significance of test methods.

5.3.1 General. This section will provide a brief explanation of the significance of the test methods used to determine the quality and performance characteristics of the fuel. The test methods used on the specifications are provided on table VI, and figure 2 provides the engine-fuel property interface in the diesel engine.

5.3.2 Gravity, ASTM D 287.5.3.2.1 Significance.

(a) Volume Determinations. Gravity Standards of high precision are necessary for the conversion of measured volumes at the standard temperature of 15.6° C (59° F). This converted volume is the basis for most commercial transactions.

(b) Other Uses. Gravity is one of the principal factors governing the price structure for crude oils. However, the gravity of a petroleum product is a very uncertain indication of its quality, although a few states grade some products according to gravity. Used with other properties it can be correlated roughly with hydrocarbon composition heat of combustion, and cetane index. The gravity test is quickly and easily made and is useful for control of refinery operations.

5.3.3 Density, ASTM D 1298.

5.3.3.1 Significance. Accurate determination of the density, relative density (specific gravity), or API gravity of petroleum and its products is necessary for the conversion of measured volumes at the standard temperature of 15° C or 59° F. Density, relative density (specific gravity), or API gravity is a factor governing the quality of crude petroleum; crude petroleum prices are frequently posted against values in degrees API. However, this property of petroleum is an uncertain indication of its quality unless correlated with other properties.

TABLE VI. Test methods required in diesel fuel specification and burner fuel.

Test	ASTM TEST METHODS <sup>1/</sup>			
	MIL-F-46162	VV-F-800	MIL-F-16884	VV-F-815
Gravity, °API	D 287		D 287	D 287
Density		D 1298		D 1298
Flash point	D 93	D 93	D 93	D 93
Cloud point	D 2500	D 2500	D 2500	
Pour point	D 97	D 97	D 97	D 97
Kinematic viscosity	D 445	D 445	D 445	D 445 <sup>2/</sup>
Viscosity saybolt	NR	NR	NR	D 2161
Distillation	D 86	D 86	D 86	D 86
Carbon residue	D 524	D 524	D 524	D 524

## MIL-HDBK-114

TABLE VI. Test methods required in diesel fuel specification and burner fuel. (Cont)

Test	ASTM TEST METHODS <sup>1/</sup>			
	MIL-F-46162	VV-F-800	MIL-F-16884	VV-F-815
Sulfur	D 1552	D 1552	D 1552	D 1552
Copper strip corrosion	D 130	D 130	D 130	D 130
Ash	D 482	D 482	D 482	NR
Sulfated ash	NR	NR	NR	D 874
Accelerated stability	D 2274	D 2274	D 2274	NR
Neutralization No.	D 974	D 974	D 974	NR
Neutrality	NR	NR	FTM 791, Method 5101	NR
Aromatics	D 1319	NR	NR	NR
Heat of combustion	D 240	NR	NR	NR
Gross heat of combustion	NR	NR	NR	D 240
Particulate contamination	D 2276	D 2276	NR	NR
Sediment	NR	NR	NR	D 473 <sup>3/</sup>
Water	NR	NR	NR	D 95 <sup>4/</sup>
Cetane Number	D 613 <sup>5/</sup>	D 613 <sup>5/</sup>	D 613 <sup>5/</sup>	NR
Fuel system icing inhibitor	NR	FTM 791, Method 5327	NR	NR
Demulsification	NR	NR	D 1401	NR
Aniline point	NR	NR	D 611	NR
Appearance	NR	NR	6/	NR
Color	NR	NR	D 1500	NR

- 1/ For alternate test methods see the corresponding specification. VV-F-815 has been replaced by ASTM D 396. NR = Not Required
- 2/ Viscosity determinations using ASTM D 445 may not, on occasions, fall within the established repeatability limits due to the presence of volatile components. In these instances, the viscosity values should be listed in sequence.
- 3/ ASTM D 473 is modified with the requirement that a new refractory thimble be used for each determination.
- 4/ ASTM D 95 is modified with the requirement that the sample volume taken for analysis be reported.
- 5/ D 613 is the preferred method for determining cetane quality. However, where cetane improvers have not been used (as determined by the Appendix in the specification), D 976 may be used as an alternate.
- 6/ Visual inspection - a slight haze is acceptable providing a maximum water and sediment of 0.01% is obtained using procedure ASTM D 2709.

MIL-DEK-114

# ENGINE FUEL INTERFACE: COMPRESSION IGNITION

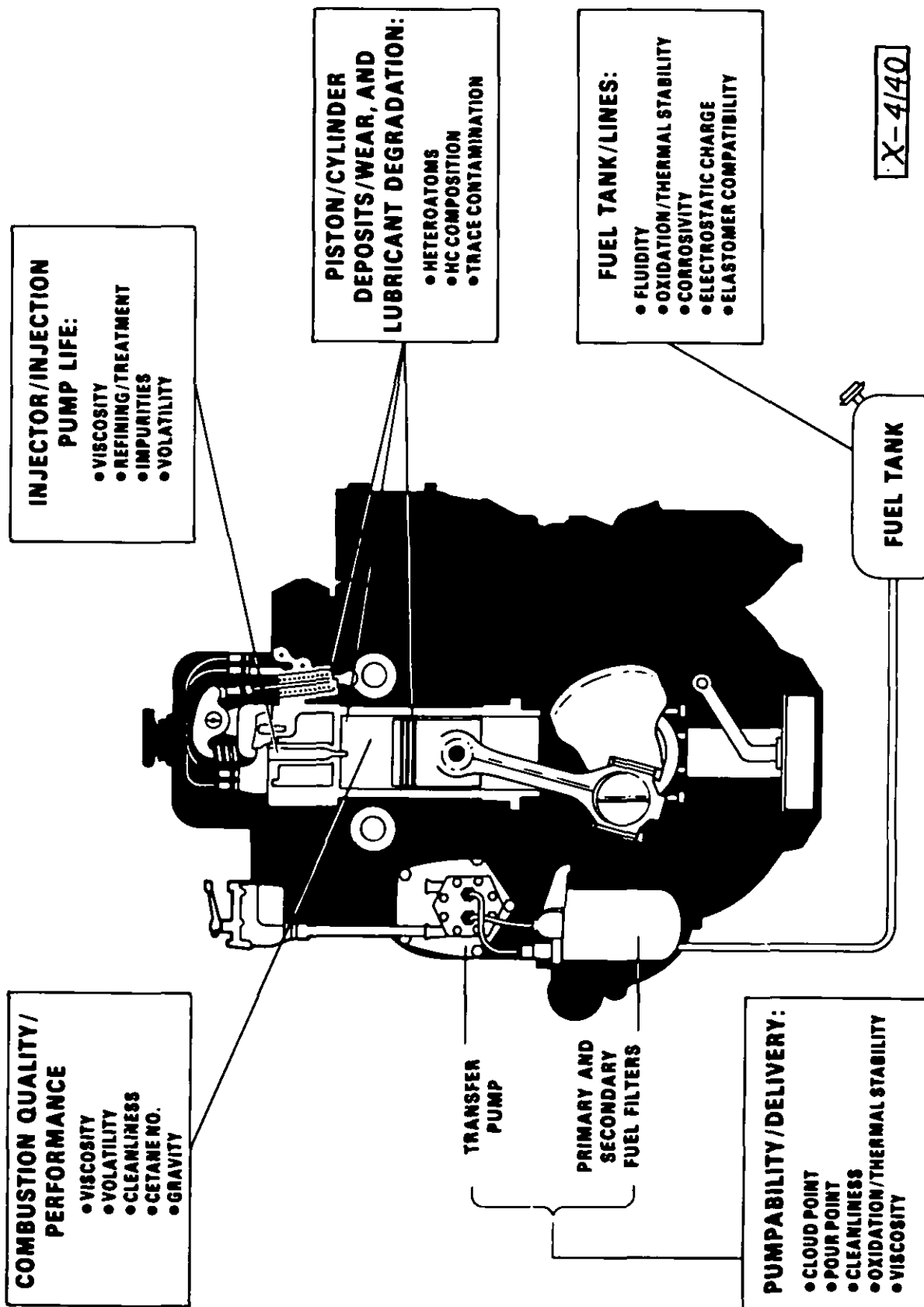


FIGURE 2.

## MIL-HDBK-114

5.3.4 Flash point, ASTM D 93.5.3.4.1 Significance.

(a) Diesel fuels. The flash point of a diesel fuel as obtained with the Pensky-Martens Closed Cup is not directly related to engine performance. It is, however, of importance in establishing safety precautions and legal requirements for the handling and storage of fuel. Flash point is normally set to conform to insurance and fire regulations.

(b) Fuel oils. Relatively high flash points are desirable for safe handling and use of burner fuel oils. The minimum permissible flash point is usually regulated by federal, state, or municipal laws and is based on accepted practice in handling and use. For household installations, the usual minimum flash point is 37.8° C (100° F) by the Pensky-Martens Closed Cup Tester.

5.3.5 Cloud point, ASTM D 2500.

5.3.5.1 Significance. This method will determine the lowest temperature at which the first formation of wax crystals are observed. This temperature will indicate whether or not the fuel could be used under the operational requirements of the equipment.

5.3.6 Pour point, ASTM D 97.

5.3.6.1 Significance. This method will provide the lowest temperature at which an oil will pour or flow when chilled without disturbance under specified conditions. It is an indication of the minimum temperature at which the fuel could be pumped and used.

5.3.7 Kinematic viscosity, ASTM D 445.5.3.7.1 Significance.

(a) Diesel fuels. For some diesel engines it is advantageous to specify minimum viscosity to assure adequate lubrication of the fuel pump and to avoid power loss due to possible leakage or slippage in the injection pump and injector. On the other hand, maximum viscosity is limited by considerations involved in the design and size of the engine, and by the characteristics of the injection system. Since viscosity changes with temperature and the rate of change varies considerably for diesel fuels from various sources and methods of manufacture, it is sometimes desirable to predict the viscosity at a temperature other than that at which the standard test is made. This may be done by using the viscosity-temperature charts of D 341.

(b) Fuel or heating oils. For the lighter grades of heating oil, such as Nos. 1 and 2, viscosity is less significant than for the heavier grades. However, limits are generally set to help maintain uniform fuel flow in appliances with gravity flow, or to provide satisfactory atomization in small nozzles of household heating burners. Some burners are dependent on the fuel for lubrication. Therefore a minimum viscosity is specified. For the heavier

## MIL-HDBK-114

grades of industrial and bunker fuel oils, viscosity is of major importance. Preheating is generally required to provide good atomization in a given type of burner. However, this is not the only factor to be considered. It is equally important that the maximum viscosity under the existing conditions of temperature and pressure be such that the oil can be pumped satisfactorily from the storage tank to the preheater. For such diverse requirements it is desirable to know the viscosity of a fuel at temperatures other than those at which standard viscosity tests are usually made. The viscosity-temperature charts of D 341 answer this need. They are particularly useful for determining the proper temperature for preheating heavy oil to control its viscosity as it enters the atomizing mechanism.

5.3.8 Saybolt viscosity, ASTM D 2161, D 88.

5.3.8.1 Significance. Same as Kinematic Viscosity, (see 5.3.7.1).

5.3.9 Distillation, ASTM D 86.

5.3.9.1 Significance. Distillation (volatility) characteristics of petroleum products are indicative of performance in their intended applications. Petroleum product specifications generally include distillation limits to assure products of suitable volatility performance. The empirical results obtained by use of this distillation method have been found to correlate with automotive equipment performance factors and with other characteristics of petroleum products related to volatility.

5.3.10 Carbon residue, ASTM D 524.

5.3.10.1 Significance. The carbon residue value of burner fuel serves as a rough approximation of the tendency of the fuel to form deposits in vaporizing pot-type and sleeve-type burners. Similarly, provided amyl nitrate is absent (or if it is present, provided the test is performed on the base fuel without additive) the carbon residue of diesel fuel correlates approximately with combustion chamber deposits.

5.3.11 Sulfur, ASTM D 1552, D 2628, D 219.

5.3.11.1 Significance. Total sulfur content varies considerably in petroleum crudes and many products made from them. Control of sulfur content is particularly important for products that are to be burned in engines, heating appliances, or lamps. The sulfur oxides formed during combustion may cause corrosion by combining to form corrosive acids, or may be in the form of objectionable fumes.

5.3.12 Copper strip corrosion, ASTM D 130.

5.3.12.1 Significance. The copper strip test is used on a wide variety of petroleum products because it is a sensitive test for free sulfur and corrosive sulfur compounds.

## MIL-HDBK-114

(a) Aviation, Motor, Tractor, and Diesel Fuels. A requirement that an aviation, motor, tractor, or diesel fuel must pass the copper strip test is adequate assurance that the product will not corrode the copper or copper-containing parts of fuel systems.

(b) Fuel or Heating Oils. For the lighter grades of fuel oil a copper strip test is desirable, at 50° C (122° F) or 100° C (212° F), whichever temperature is appropriate for the product. Corrosivity to copper is generally not a significant factor for heavy fuel oils.

### 5.3.13 Ash, ASTM D 482.

5.3.13.1 Significance. The dry ash content of the lighter distillate fuels is usually nil, and even the heavier fuels rarely contain more than a fraction of one per cent. Ash forming constituents are important factors in either diesel or burner fuels only when present in an amount and form such that the fuel is abrasive or undue deposits are formed on the surfaces with which the products of combustion come in contact.

### 5.3.14 Sulfated ash, ASTM, D 874.

5.3.14.1 Significance. The sulfated ash may be used to indicate the concentration of known metal-containing additives in new oils. When phosphorus is absent, barium, calcium, magnesium, sodium and potassium are converted to their sulfates and tin and zinc to their oxides. Sulfur and chlorine do not interfere, but when phosphorus is present with metals, it remains partially or wholly in the sulfated ash as metal phosphates.

### 5.3.15 Accelerated stability, ASTM D 2274.

5.3.15.1 Significance. The test measures the stability of a fuel under accelerated oxidizing conditions. The fuel sample is aged and cooled down, and the total amount of insoluble matter is determined.

### 5.3.16 Neutralization number, ASTM D 974.

5.3.16.1 Significance. New and used petroleum products may contain basic or acidic constituents that are present as additives or as degradation products formed during service, such as oxidation products. The relative amount of these materials can be determined by titrating with acids or bases. The neutralization number, whether expressed as "acid number" or "base number", is a measure of the amount of acidic or basic substances, respectively, in the fuel oil -- always under the conditions of the test. This method may be used to indicate relative changes that occur in a fuel oil during use under oxidizing conditions.

### 5.3.17 Neutrality, FTMS 791, Method 5101.

5.3.17.1 Significance. New and used petroleum products may contain acidic constituents that are present as additives or degradation products formed during service. This method provides a qualitative indication of the acidity of the fuel.

## MIL-HDBK-114

5.3.18 Aromatics, ASTM D 1319.

5.3.18.1 Significance. Separation by the fluorescent-indicator adsorption procedure is a convenient and rapid way to ascertain the percentages of saturates, non-aromatic olefins, and aromatics in gasolines, jet fuels, other liquid petroleum products or fractions thereof that boil below 316° C (599° F). The amount of aromatics in the fuel will indicate potential elastomeric compatibility problems.

5.3.19 Heat of combustion, ASTM D 240.

5.3.19.1 Significance. The heat of combustion is a measure of the energy available from a fuel. A knowledge of this value is essential when considering the thermal efficiency of equipment for producing either power or heat. Heat of combustion can be expressed as gravimetric (Btu/lb, kJ/kg) or volumetric (Btu/gal, kJ/m<sup>3</sup>), which is dependent on density. Fuels with the same gravimetric heat of combustion will have different volumetric heat of combustion when their densities are different. The fuel with the higher volumetric heat of combustion will provide an increase in range using the same amount of fuel.

5.3.20 Particulate contamination, ASTM D 2276 Appendix A2.

5.3.20.1 Significance. This method will provide an indication of the particulate content of the fuel, the tendencies of the fuel to cause filter plugging, overall cleanliness of the fuel and whether good housekeeping procedures are in effect.

5.3.21 Sediment, ASTM D 473.

5.3.21.1 Significance. Fuel Oils. Appreciable amounts of water and sediment in a fuel oil tend to cause fouling of facilities for handling it, and to give trouble in burner mechanisms. Sediment may accumulate in storage tanks and on filter screens or burner parts, resulting in obstruction to free passage of oil from the tank to the burner. For heavy residual oils it is usual to determine the water by distillation (ASTM D 95) and the sediment by extraction (ASTM D 473).

5.3.22 Water, ASTM D 95.

5.3.22.1 Significance. Fuel Oils. Appreciable amounts of water and sediment in a fuel oil tend to cause fouling of facilities for handling it, and to give trouble in burner mechanisms. Sediment may accumulate in storage tanks and on filter screens or burner parts, resulting in obstruction to free passage of oil from the tank to the burner. Water is the basic cause of the corrosion of tanks and equipment. For heavy residual oils it is usual to determine the water by distillation and the sediment by extraction. For diesel fuels, water contributes to corrosion problems occurring to storage/holding tanks and vehicle fuel tanks. It also contributes to microbiological growth problems.

5.3.23 Cetane number, ASTM D 613.

## MIL-HDBK-114

5.3.23.1 Significance. The cetane method provides a means of determining the compression-ignition characteristics of diesel fuels. The method utilizes a single-cylinder engine and requires critical adjustment of the fuel-air ratio and compression ratio to produce a standard ignition delay (the interval between the beginning of fuel injection and the beginning of combustion). This method should not be confused with Cetane Index ASTM D 976.

5.3.24 Fuel system icing inhibitor, FTMS 791, Methods 5327, 5330, 5340.

5.3.24.1 Significance. This method is used to determine if the icing inhibitor is in the specified concentration.

5.3.25 Demulsification ASTM D 1401.

5.3.25.1 Significance. This method provides an indication of tendencies of the fuel to resist formation of a stable water/oil emulsion. This property is most important for vessels which use water-ballasted fuel tank.

5.3.26 Aniline point, ASTM D 611.

5.3.26.1 Significance. The aniline point of a given type of oil generally increases with increased molecular weight and decreases as the percentage of either naphthenic or aromatic constituents increases. A product of high aniline point will be low in aromatics and naphthenes, and therefore high in paraffins. On this basis it is possible to calculate the approximate heat of combustion.

5.3.27 Color, ASTM D 1500.

5.3.27.1 Significance. Color can be observed without the aid of instruments, but does require a colorimeter. Since it is widely used as an indication of the uniformity of quality of a given product or brand, it must be carefully controlled by the refiner. Actually it is not always a reliable guide. For that reason, color specifications should not be more stringent than required for the specific use of a product. In diesel fuels, the color can indicate fuel degradation or contamination with residual oil.

## MIL-HDBK-114

## CHAPTER VI

MOBILITY FUELS - TURBINE

6.1 General. There are several turbine fuels in use by the military services. This is due to the different operational needs of the services or to specific applications requiring special fuels. The primary fuel for the US Air Force and Army is the wide-cut JP-4 fuel that meets operational requirements and reflects a broad availability. The US Navy, particularly for carrier safety, relies on JP-5, a high flash point fuel. JP-8, a kerosene based fuel very similar to the commercial Jet A-1 (ASTM D 1653), is under consideration by the NATO ministers and the USAF as a replacement for JP-4. This chapter is intended to provide a short description of these fuels. Typical properties as well as specification requirements of jet fuel are provided in Appendix D.

6.2 Turbine fuel specifications.6.2.1 MIL-T-5624, Turbine fuel, aviation, grades JP-4 and JP-5.

6.2.1.1 Scope. This specification covers two grades of aviation turbine fuel.

<u>Grade</u>	<u>NATO Code No.</u>	<u>Description</u>
JP-4	F-40	Wide cut, gasoline type
JP-5	F-44	High flashpoint, kerosene type

6.2.1.2 Intended use. The fuels covered by this specification are intended for use in aircraft turbine, ramjet, and rocket engines.

6.2.1.3 Constituent material. The fuel shall consist completely of hydrocarbon compounds, except as otherwise indicated in the specification.

6.2.1.4 Alternate designation. See table VII.

6.2.2 MIL-T-83133, Turbine fuel, aviation, kerosene type, grade JP-8.

6.2.2.1 Scope. This specification covers one grade of aviation turbine fuel.

<u>Grade</u>	<u>NATO Code No.</u>	<u>Description</u>
JP-8	F-34	Kerosene type similar to ASTM Jet A-1 fuel

6.2.2.2 Intended use. The fuel covered by this specification is intended for use in aircraft turbine engines.

6.2.2.3 Constituent material. Except as otherwise indicated in the specification, the fuel shall consist completely of hydrocarbon compounds.

6.2.2.4 Alternate designation. See table VII.

MIL-HDBK-114

TABLE VII. Fuel requirements for Army mobility engines: turbines.

ENGINE SYSTEM	PRIMARY FUEL, NATO CODE NO.	ALTERNATE FUEL, NATO CODE NO.	EMERGENCY FUEL, NATO CODE NO.
AVIATION EQUIPMENT	MIL-G-5572 (AVGAS), F-18	MIL-G-5572 (AVGAS), F-22 ASTM D 910 (AVIATION GASOLINE)	
GAS TURBINE: GROUND EQUIPMENT	VV-F-800(DF-2), F-54	MIL-T-5624 (JP-4, JP-5), F-40, F-44 MIL-T-83133 (JP-8), F-34 MIL-F-16884 F-76	MIL-G-3056 (MOGAS), F-46 MIL-G-5572 (AVGAS), F-18 VV-G-1690 (MOGAS) MIL-G-53006 (GASOHOL) F-49 (GASOLINE) F-50 (GASOLINE)
AVIATION EQUIPMENT	MIL-T-5624 (JP-4), F-40	F-75 (NAVY DISTILLATE) ASTM D 975 (DIESEL) ASTM D 3699 (KEROSENE) ASTM D 1655 (AVIATION FUEL) ASTM, D 2880 (TURBINE FUEL 1-GT and 2-GT) ASTM D 396 (FUEL OIL, NOS. 1&2)	

## MIL-HDBK-114

### 6.3 Significance of physical and chemical properties tests.

6.3.1 General. This section will provide a brief explanation of the significance of the test methods used to determine the quality and performance characteristics of aviation turbine fuels. Table VIII provides the test methods required in the specifications, and figure 3 provides the engine-fuel property interface in the turbine engine.

#### 6.3.2 Color ASTM D 156.

6.3.2.1 Significance. This test is required to be reported as a quality assurance test.

#### 6.3.3 Total acid number, ASTM D 3242.

6.3.3.1 Significance. To control the acidic compounds such as phenols and naphthenic acids.

#### 6.3.4 Aromatics and olefins, ASTM D 1319.

6.3.4.1 Significance. Separation by the fluorescent-indicator adsorption procedure is a convenient and rapid way to ascertain the percentages of saturates, nonaromatic olefins, and aromatics in gasolines, jet fuels, and other liquid petroleum products or fractions thereof that boil below 316° C (599° F). (Bifunctional molecules that contain both an olefinic double bond and an aromatic ring, such as styrene and dihydronaphthalene, are counted as aromatics by this method.)

#### 6.3.5 Mercaptan sulfur, ASTM D 3227.

6.3.5.1 Significance. To determine quantitatively whether the Mercaptan sulfur content is below the permissible limit.

## MIL-HDBK-114

TABLE VIII. Test method required in turbine fuel.

Requirements	ASTM TEST METHODS <sup>1/</sup>	
	MIL-T-5624 JP-4 & JP-5	MIL-T-83133 JP-8
Color	D 156	D 156
Total acid number	D 3242	D 324 2
Aromatics	D 1319	D 1319
Olefins	D 1319	D 1319
Mercaptan sulfur <sup>2/</sup>	D 3227	D 3227
Sulfur	D 1266	D 1266
Distillation temperature <sup>3/</sup>	D 86	D 86
Explosiveness	<u>4/</u>	NR
Flash point	D 93	D 56
Density	D 1298	D 1298
Gravity	NR	NR
Vapor pressure	D 323	NR
Freezing point	D 2386	D 2386
Viscosity	D 445	D 445
Heating value, Aniline-gravity product, or net heat of combustion	D 1405 D 240 <sup>5/</sup>	NR D 240 <sup>5/</sup>
Hydrogen content	D 1018 <sup>6/</sup> & <sup>7/</sup>	D 1018 <sup>7/</sup>
Smoke point	D 1322	D 1322
Copper strip corrosion	D 130	D 130
Thermal stability: Change in pressure drop preheater deposit code	D 3241 <sup>8/</sup> D 3241 <sup>8/</sup>	D 3241 <sup>8/</sup> D 3241 <sup>8/</sup>
Existent gum	D 381	D 381
Particulate matter	D 2276 <sup>9/</sup>	D 2276 <sup>10/</sup>
Filtration time	<u>9/</u>	NR
Water reaction Interface rating	D 1094	D 1094
Water separation index, modified	D 2550	D 2550
Fuel system icing inhibitor	<u>11/</u>	<u>11/</u>
Fuel electrical conductivity allowable range	D 2624	D 2624

## MIL-HDBK-114

- 1/ For other allowed ASTM methods, refer to the specification.
- 2/ The mercaptan sulfur determination may be waived at the option of the inspector if the fuel is "doctor sweet" when tested in accordance with the doctor test of ASTM D 484.
- 3/ A condenser temperature of 0° C to 4° C (32° F to 39° F) shall be used for the distillation of all the grades except JP-4. For JP-4, group 3 test conditions shall be used. Distillation shall not be corrected to 760 mm pressure.
- 4/ Test shall be performed in accordance with Method 1151 FED-STD-791.
- 5/ When the fuel distillation test is performed using ASTM D 2887, the average distillation temperature for use in ASTM D 3388 shall be calculated as follows:

$$V = \frac{10\% + 50\% + 95\%}{3}$$

- 6/ ASTM D 3343 is only allowed for use with JP-4 fuel.
- 7/ When the distillation test is performed using ASTM D 2887, the average distillation temperature for use in D 3343 shall be calculated as follows:

$$V = \frac{10\% + 50\% + 95\%}{3}$$

- 8/ ASTM D 3244 test conditions:

- a. Heater tube temperature at maximum point: 260° C (500° F)
  - b. Fuel system pressure: 3.45 MPa (500 psig)
  - c. Fuel flow rate: 3.0 ml/minute
  - d. Test duration: 150 minutes.
- See procedure in the specification.

- 9/ A minimum sample size of one gallon shall be filtered. Filtration time will be determined in accordance with the procedure described in the specification. This procedure may be used as an alternate to ASTM D 2276.
- 10/ A minimum sample size of one gallon shall be filtered.
- 11/ Test shall be performed with Method 5327 or Method 5340 of FED-STD-791.

MIL-STD-114

X-4141

# ENGINE FUEL INTERFACE: GAS TURBINE

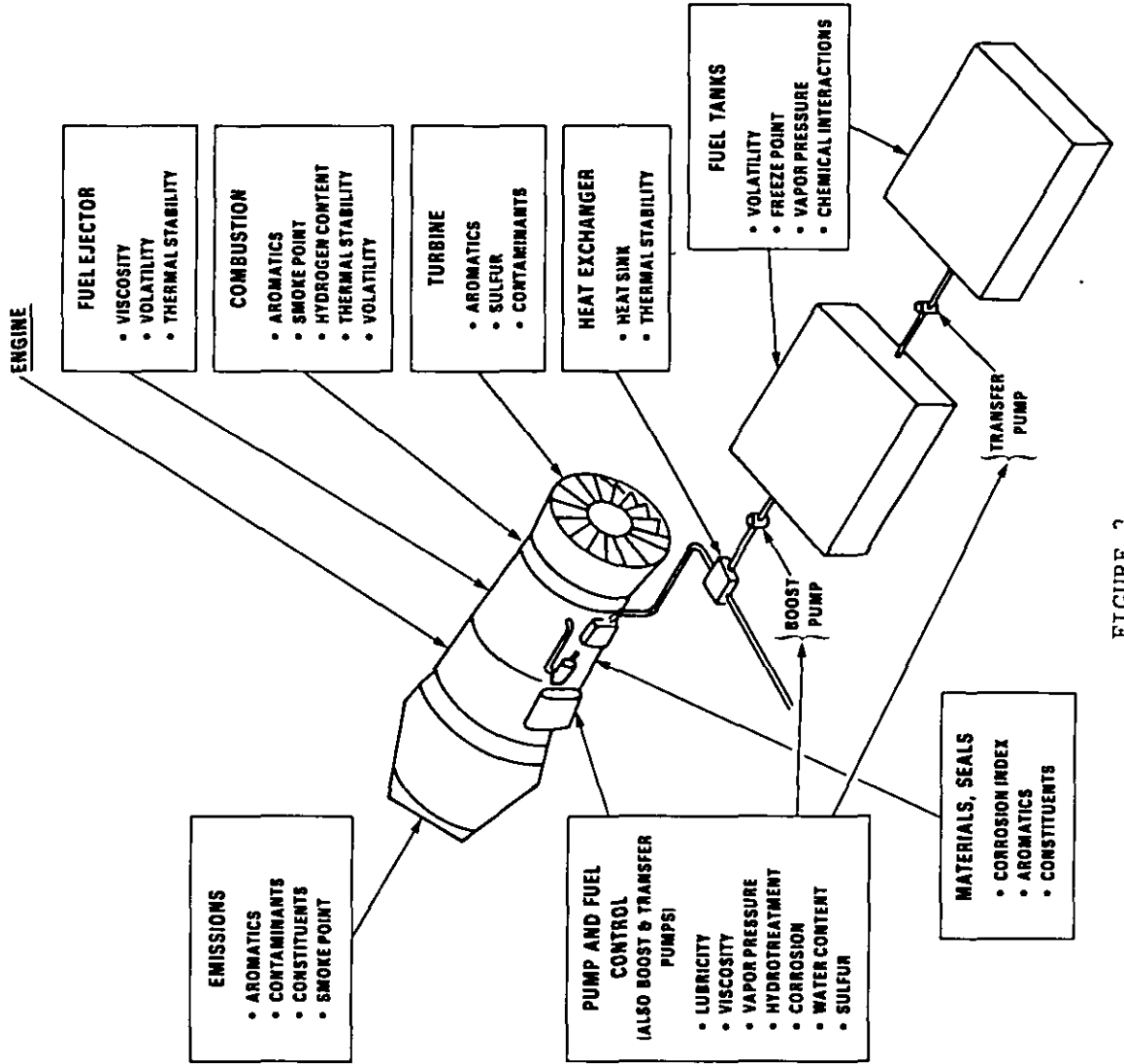


FIGURE 2.

## MIL-HDBK-114

6.3.6 Sulfur, ASTM D 1266, D 2622.

6.3.6.1 Significance. Total sulfur content varies considerably in petroleum crudes and many products made from them. Control of sulfur content is particularly important for products that are to be burned in engines, heating appliances, or lamps. The sulfur oxides formed during combustion may cause corrosion by combining to form corrosive acids, or may be in the form of objectionable fumes.

6.3.7 Distillation, ASTM D 86, ASTM D 2887.

6.3.7.1 Significance. Distillation (volatility) characteristics of petroleum products are indicative of performance in their intended applications. Petroleum product specifications generally include distillation limits to assure products of suitable volatility performance.

6.3.8 Explosiveness. Method 1151, FED-STD-791.

6.3.8.1 Significance. This method provides a means to establish safety considerations on the handling of the fuel.

6.3.9 Flash point, ASTM D 93, D 56, D 3243.

6.3.9.1 Significance. Flash point measures the response of the sample to heat and flame under controlled laboratory conditions. It is only one of a number of properties which must be considered in assessing the overall flammability hazard of a material. It is used in shipping and safety regulations to define "flammable" and "combustible" materials. One should consult the particular regulation involved for precise definitions of these classes. Flash point can indicate the possible presence of highly volatile and flammable materials in a relatively nonvolatile or nonflammable material. For example, an abnormally low flash point on a sample of kerosene may indicate gasoline contamination.

6.3.10 Density, ASTM D 1298.

6.3.10.1 Significance. Accurate determination of the density, relative density (specific gravity), or API gravity of petroleum and its products is necessary for the conversion of measured volumes to volumes at the standard temperatures of 15° C or 59° F. Density, relative density (specific gravity), or API gravity is a factor governing the quality of crude petroleum; crude petroleum prices are frequently posted against values in degrees API. However, this property of petroleum is an uncertain indication of its quality unless correlated with other properties.

6.3.11 Gravity, ASTM D 287.

6.3.11.1 Significance. Accurate determination of the gravity of petroleum and its products is necessary for the conversion of measured volumes to volumes at the standard temperature of 15° C (59° F). Gravity is a factor governing the

## MIL-HDBK-114

quality of crude oils. However, the gravity of a petroleum product is an uncertain indication of its quality. Correlated with other properties, gravity can be used to give approximate hydrocarbon composition and heat of combustion.

### 6.3.12 Vapor pressure, ASTM D 323, D 2551.

6.3.12.1 Significance. Vapor pressure is one measure of the volatility characteristics of a fuel. Fuels are used in many types of engines with large variations in operating conditions and over a wide range of operating temperatures. These variations impose limitations on the fuel volatility if it is to give satisfactory performance. Fuels having high vapor pressures may vaporize too readily in the fuel-handling systems, resulting in decreased flow to the engine and possible stoppage by vapor lock. Conversely, fuels of low vapor pressure may not vaporize readily enough, resulting in hard starting, and poor warm-up and acceleration.

### 6.3.13 Freezing point, ASTM D 2386.

6.3.13.1 Significance. Freezing point is an important characteristic of turbine fuels. It must be very low to prevent solidification of any of the component hydrocarbons and consequent interference with flow of the fuel through filter screens to the engine at the low temperatures prevailing at high altitudes.

### 6.3.14 Viscosity, ASTM D 445.

6.3.14.1 Significance. Fuel viscosity exerts a strong influence on the shape of fuel spray. High viscosities can cause poor atomization, large droplets, and high-spray jet penetration. With high viscosities, the jet tends to be a solid stream instead of a spray of small droplets. As a result, the fuel is not distributed in, or mixed with, the air required for burning. This results in poor combustion, accompanied by loss of power and economy.

### 6.3.15 Aniline point, ASTM D 611.

6.3.15.1 Significance. The aniline point (or mixed aniline point) is useful as an aid in the characterization of pure hydrocarbons and in the analysis of hydrocarbon mixtures. Aromatic hydrocarbons exhibit the lowest, and paraffins, the highest values. Cycloparaffins and olefins exhibit values that lie between those for paraffins and aromatics. In homologous series the aniline points increase with increasing molecular weight. Although it occasionally is used in combination with other physical properties in correlative methods for hydrocarbon analysis, the aniline point is most often used to provide an estimate of the aromatic hydrocarbon content of mixtures. The net heat of combustion is calculated using the equation in part 4.5.3 of the specification.

### 6.3.16 Aniline-gravity product, ASTM D 1405.

6.3.16.1 Significance. This method is intended for use as a guide in cases where an experimental determination of heat of combustion is not available and

## MIL-HDBK-114

cannot be made conveniently and where an estimate is considered satisfactory. The aniline point in degrees Fahrenheit is multiplied by gravity in degrees API to obtain the aniline-gravity product.

6.3.17 Net heat of combustion, ASTM D 240, D 2382, D 3338.

6.3.17.1 Significance. The heat of combustion is a measure of the energy available from fuel. A knowledge of this value is essential when considering the thermal efficiency of equipment for producing either power or heat.

6.3.18 Hydrogen content, ASTM D 1018, D 3343, D 3701.

6.3.18.1 Significance. The content of hydrogen in combined form in the hydrocarbons of petroleum fractions is often desirable information, particularly in the manufacture of such products as solvents and various types of fuels. Hydrogen content is useful for ascertaining the general nature or type of hydrocarbons present in light petroleum fractions. Percent hydrogen, with other pertinent data, is also useful for calculation of the naphthene content of mixtures of paraffinic and naphthenic hydrocarbons, because there is less combined hydrogen in a naphthene than in paraffin of the same number of carbon atoms. Hydrogen content may also be used as an indication of purity or identity of pure hydrocarbons. It is necessary information for calculation of net Btu values of fuels from the corresponding gross values.

6.3.19 Smoke point, ASTM D 1322.

6.3.19.1 Significance. The combustion performance of wide-cut fuels correlates well with smoke point when a fuel volatility factor is included because carbon formation tends to increase with boiling point and with lower hydrogen content. The smoke-point test alone is not universally accepted as a reliable criterion for combustion performance.

6.3.20 Copper strip corrosion, ASTM D 130.

6.3.20.1 Significance. Crude petroleum contains sulfur compounds, most of which are removed during refining. However, of the sulfur compounds remaining in the petroleum product, some can have a corroding action on various metals and this corrosivity is not necessarily related directly to the total sulfur content. The effect can vary according to the chemical types of sulfur compounds present. The copper strip corrosive test is designed to assess the relative degree of corrosivity of a petroleum product.

6.3.21 Thermal stability, ASTM D 3241.

6.3.21.1 Significance. The test results are indicative of fuel performance during gas turbine operation and can be used to assess the level of deposits that form when liquid fuel contacts a heated surface that is at a specified temperature.

6.3.22 Existent gum, ASTM D 381.

## MIL-HDBK-114

6.3.22.1 Significance. The true significance of this method for determining gum in motor gasoline is not firmly established. It has been proved that high gum can cause induction-system deposits and sticking of intake valves, and in most instances it can be assumed that low gum will ensure absence of induction-system difficulties. The user should, however, realize that the test is not of itself correlative to induction-system deposits. The primary purpose of the test when applied to aviation turbine fuel is the measurement of the oxidation products formed in the sample prior to or during the comparatively mild conditions of the test procedure. Large quantities of gum are indicative of contamination of fuel by higher boiling oils or particulate matter and generally reflect poor handling practices in distribution down-stream of the refinery.

6.3.23 Particulate matter, ASTM D 2276.

6.3.23.1 Significance. This test provides field quality control of dirt content.

6.3.24 Water reaction, ASTM D 1094.

6.3.24.1 Significance. A high water tolerance indicates the presence of alcohol or other components, which absorb appreciable amounts of water before becoming immiscible with the hydrocarbons. When the fuel contains such compounds the aqueous layer may be smaller at the end of the test. When the fuel consists entirely of hydrocarbon components there is no measurable change in volume of the water layer.

6.3.25 Water separation index, ASTM D 2550.

6.3.25.1 Significance. The test provides a measure of the presence of surfactant agents in the fuel. It is intended to detect carryover of traces of refinery treating residues in fuel as produced, particularly sulfonates and naphthenates. Method D 3602 describes a portable test that can also detect surfactant agents acquired by the fuel during distribution and handling in the field. Some of these surfactants could affect the ability of filter coalescers to separate free water from aviation turbine fuels.

6.3.26 Fuel system icing inhibitor, FED-STD-791, Method 5327, 5330, or 5340.

6.3.26.1 Significance. This method is a quality assurance test to determine if the proper concentration of icing inhibitor has been added.

6.3.27 Fuel electrical conductivity, ASTM D 2624, D 3114.

6.3.27.1 Significance. The ability of a fuel to dissipate charge that has been generated during pumping operations is controlled by its electrical conductivity, which depends upon its content of ion species. If the conductivity is sufficiently high, charges dissipate fast enough to prevent their accumulation and dangerously high potentials in a receiving tank are avoided.

## MIL-HDBK-114

## CHAPTER VII

MOBILITY FUEL QUALITY REQUIREMENTS/NEEDS

7.1 General. Contaminants from a wide variety of sources can enter the fuel at any point in the supply chain from the refinery down to the using vehicle. Quality surveillance of products must begin upon receipt and continue until the fuel is consumed. If contaminated fuel is found in a vehicle, samples should be taken at previous points in the supply chain (e.g., refueling truck, storage tank, etc.) until the source of the contamination is located and corrective action is taken. This chapter will provide information on the origin and types of fuel contaminants, practices to avoid fuel contamination, pipeline problems, and cold weather problems.

7.2 Origin and types of fuel contaminants. Fuel contaminants generally fall into three categories - water, sediment, and other fuels (commingling).

7.2.1 Water. Water contamination can arise from condensation, leakage or seepage of ground water into underground storage tanks, or from rain leaking into storage and vehicle tanks. Condensation can occur when the air space above the fuel cools down, causing the water vapor to condense and fall into the fuel. Another type of condensation occurs when fuel containing dissolved water cools down, causing the fuel to become cloudy or hazy when the water can no longer remain in solution. In the process just described, dissolved water is converted to free water. Dissolved water cannot be removed by mechanical means, and its maximum concentration varies with the type of fuel and the temperature. Free water can also cause operational problems when it freezes and blocks fuel lines during cold weather.

7.2.2 Sediment. Sediment may be in the form of dust, powder, flakes, granules, fibrous material, agglomerates (i.e., insoluble products of fuel deterioration), sludge, or slime. If the fuel container has a water bottom, some or all of the sediment may be present at the fuel-water interface rather than at the bottom of the container. In many cases, the sediment is a mixture of inorganic and organic materials.

7.2.2.1 Inorganic sediment. Inorganic sediment usually arises from two sources - corrosion products from inside the fuel system or dust, dirt, and sand from outside the fuel system. Corrosion products formed in pipelines and bulk storage tanks can be entrained in the fuel and delivered into vehicle tanks unless the fuel is filtered during each transfer. Corrosion may also occur inside the vehicle fuel tank itself.

7.2.2.2 Organic sediment. Organic sediment in fuels generally arises from gradual chemical and thermal deterioration of the fuel, or from the growth of microbiological organisms. The chemical/thermal deterioration products take the form of brown to black insolubles, gums, or sludges which can rapidly clog filters. Microbiological organisms include fungus, yeasts, bacteria, and protozoa. These organisms can grow in strings, mats, or globules and usually appear black, green, or brown. Growth takes place at the fuel-water interface,

## MIL-HDBK-114

where the organisms get trace minerals and water to sustain growth, and use the fuel as their source of energy. As the organisms grow and multiply, they produce acids and other metabolic products which promote corrosion of the metal tank surfaces. In addition, the mats or globules of organisms can quickly clog filters, cutting off the fuel supply.

7.2.3 Contamination with other fuels (commingling). Contamination of this type usually results from accidental mixing of different types of fuel during transportation and storage, or from refueling Military equipment with the wrong type of fuel. The effects of commingling vary with the amount and type of fuels, and the following examples will illustrate this.

- a. Contamination of AVGAS with aviation turbine fuel such as JP-4 will degrade the octane rating of the AVGAS and could cause catastrophic engine failure because of excessive detonation.
- b. Contamination of aviation turbine fuel with leaded gasoline is less serious, but it can cause lead deposits to form on the turbine blades and will reduce engine life.
- c. Contamination of diesel fuel with gasoline or JP-4 will lower the flash point of the diesel fuel and cause a safety hazard (see Appendix E).
- d. Contamination of motor gasoline with diesel fuel will reduce the antiknock index and could also cause increased engine deposits.

7.3 Practices and procedures to avoid fuel contamination. General instructions and minimum procedures to be utilized by the military services in quality surveillance of Government-owned petroleum products are published in MIL-HDBK-200, Quality Surveillance Handbook for Fuels, Lubricants, and Related Products. The most applicable fuel contamination avoidance procedures for Army equipment are summarized below.

7.3.1 Use of filter/separators. The use of filter/separators is mandatory for aviation fuels, and is recommended for all other mobility fuels as well. Delivery of diesel fuel to the consuming vehicles through filter/separators will reduce water and sediment contamination to a minimum and prevent corrosion, wear, and deposits in the fuel pumps and injectors. Furthermore, the lifetime of the vehicle-mounted filters will be increased, and fewer instances of clogged vehicle filters will occur.

7.3.2 Water bottoms. All fuel tanks, from the vehicle back to the bulk storage tank, should not accumulate water bottoms. The fuel tanks should be drained frequently to prevent accumulation of water. This practice will deprive microorganisms of water essential to their growth, reduce corrosion in the fuel system, and prevent ice blockage of fuel lines during cold weather.

7.3.3 Fuel tank inspections. Fuel operating tanks (fixed tanks dispensing fuel directly to using vehicles) and bulk storage tanks shall be inspected in accordance with MIL-STD-457, Frequency for Inspection and Cleaning of Petroleum Fuel Operating and Storage Tanks. Aviation fuel tanks are inspected on a periodic basis, while ground and marine fuel tanks are inspected whenever fuel samples approach or exceed the deterioration limits, or when they show evidence

## MIL-HDBK-114

of excessive rusting and sludging, microbial growth, or liner deterioration. Each activity is required to maintain a card file on storage and operating tanks citing all inspections and cleanings.

7.3.4 Keeping vehicle tanks filled. The empty space at the top of the fuel tank "breathes" through the vent during daily temperature and pressure changes. As a result, moisture-laden air is drawn into the tank where the moisture can condense on the metal surfaces to cause corrosion and support microbiological growth. Keeping the vehicle tanks full will reduce the volume of the air space and minimize condensation of water.

7.3.5 Additives. Fuel system icing inhibitor (FSII) meeting the requirements of MIL-I-27686 can be added to diesel fuels at concentrations up to 0.15 percent by volume to cope with small amounts of water contamination (i.e., entrained water) or to keep separated water from freezing. FSII is required in concentrations of 0.10 to 0.15 for JP-4 and JP-8, and 0.15 to 0.20 for JP-5. Biocide additives are used to prevent the growth of microorganisms. Other additives which are designed to retard the oxidation, deterioration, and sludge-forming processes in fuel are antioxidants, metal deactivators, corrosion inhibitors, and dispersants. It must be emphasized that additives are not substitutes for good housekeeping and proper maintenance of fuel tanks. Additives are only preventive measures and cannot restore fuel that has already deteriorated past the use limits. Most applications of additives are to vehicles destined for depot storage or to prepositioned equipment stored in a fully-fueled condition for extended periods.

7.4 Understanding low temperature diesel-fueled equipment operability problems. When vehicles experience problems in cold weather environments, attention is immediately focused on the fuel which invariably is directly or indirectly held accountable. These problems can range from a starting inability to a stalling as engine load is applied or operating under reduced power.

7.4.1 In reality, however, the ability of vehicles/equipment to satisfactorily operate at low temperatures is dependent upon three inter-related variables; (1) the fuel, (2) the equipment/vehicle, and (3) user/field practices. Inoperability (i.e., not being able to operate satisfactorily) will occur as a summation of critical factors which individually or collectively contribute to this problem. The attached figure 4 attempts to explain this problem and draw attention to the inter-relationships and synergism of the various contributory factors that result in fuel line plugging, line freezeup, wax formation, plugged filters, stallings, etc.

7.4.2 Each of the "Contributing Factors" are briefly explained in the following paragraphs to enable a better understanding of this problem with the expectation that this knowledge will assist to insure the satisfactory operation of military equipment.

7.4.3 Under "Fuel" the following factors are contributors to the inoperability problem:

## MIL-HDBK-114

a. Fuel composition. The crude source and the manner in which diesel fuels are refined/blended controls their low temperature properties. Fractions containing quantities of normal and branched paraffinic hydrocarbons will have poorer low temperature properties (i.e., tendency for waxy/paraffinic hydrocarbons to precipitate and become insoluble) than those fractions containing quantities of cycloparaffinic hydrocarbons and aromatic complexes. Refinery de-waxing processes remove these waxy hydrocarbons from distillate feedstocks or, in some instances, kerosene is blended into the diesel pool fractions to dilute the wax content. The latter method is generally done prior to cold weather at terminals as a means of "winterizing" diesel fuels.

b. Fuel properties. The viscosity and volatility of blended fuels can be such that proper atomization of fuel droplets during the injection process will not occur. These physical properties can be somewhat independent of the wax or cloud points of a diesel fuel. Starting aids such as air intake heaters or ether ingestion are used at times.

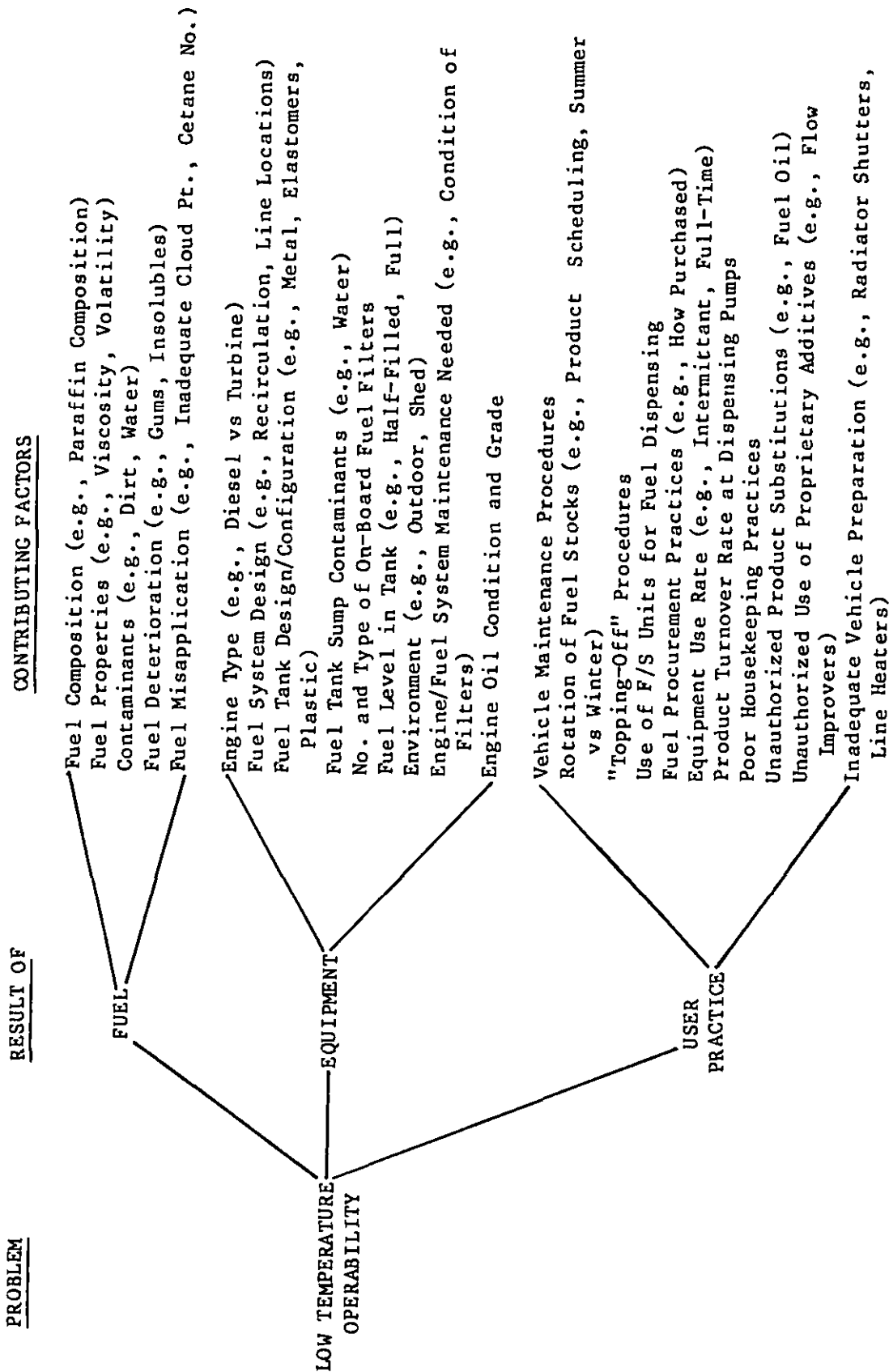


FIGURE 4. Factors contributing to low temperature operability.

## MIL-HDBK-114

c. Contaminants. The presence of water and dirt will not only contribute to filter plugging and injector nozzle sticking, but also will accelerate the formation of wax particles. This can cause a cloud point (i.e., the first occurrence of separated wax) to occur appreciably above that temperature where it normally would occur. Large quantities of free water can result in an apparent cloud point of 0° C to -1° C (32° to 31° F) for a fuel having a much lower cloud point.

d. Fuel deterioration. The insoluble gums and residues that are generated as a result of oxidation can significantly increase the cloud point.

e. Fuel misapplication. A diesel fuel intended for use in the spring, summer, and fall months should not be introduced into an environment where low winter ambient temperatures are anticipated. Winter grade fuels should be used.

7.4.4 Under "Equipment", the following factors are contributors to the inoperability problem:

a. Engine. All diesel engines marketed within the US employ fuel recirculation as an integral part of their injector delivery systems. This permits a mechanism whereby heated fuel is returned to the fuel tank which causes the temperature of the fuel to be increased significantly above the ambient. Gas turbine engines however do not have fuel recirculation. As such, no heating of the fuel within the vehicle tank occurs in those vehicles powered by gas turbine engines. Generally, as the fuel becomes heated via recirculation, operation at lower ambient temperature can be attained.

b. Fuel system design. Certain engine systems have greater fuel recirculation rates than others. For example, in a recent cooperative industry test on diesel fuel low temperature operability, three heavy duty diesel trucks were evaluated and it was found that the percent of fuel being recycled to the fuel tank via the injector return line varied from 45 to 72 percent. Also, the manner in which fuel lines are constructed and located will affect the tendencies for wax formation to occur during cold weather (i.e., sharp bends, exposed surfaces, etc., tend to enhance fuel line stoppage problems).

c. Fuel tank design. The construction and design of fuel cells will contribute to low temperature operability. Metal tanks will permit more rapid heat transfer to occur whereas those constructed from plastic will transmit little heat. Separate versus adjoining fuel tanks will also contribute to waxing problems because of their isolation. Elastomer liners will also reduce any convectional radiant heat transfer. Reticulated open-cell support foam in bladder tanks tend to increase low temperature fluidity problems because of the minute barriers they create.

d. Fuel tank contaminants. The presence of water bottoms and tank debris will contribute to premature waxing or fuel line freezing as was explained in the above section under "Contaminants". The fuel system icing Inhibitor reduces water crystal formation problems.

e. On-board fuel filters. Depending on the number and construction of filters (i.e., sock, pleated paper, versus surface absorbent), some systems may be more tolerant of waxy hydrocarbons and ice crystals than others. Also, the location of the filter relative to the engine will affect how quickly filter warm-up occurs.

## MIL-HDBK-114

f. Fuel level. The contribution of the fuel recirculation in heating the fuel (which cools the injectors on CI engines) will be greater as the fuel tank volume decreases.

g. Environment. Vehicles/equipment stored in enclosed, unheated facilities will not be subjected to wind chill factors. Wind chill cannot cool fuel below the ambient temperatures, but it can increase the rate of heat loss from fuel filters and fuel tanks.

h. Engine fuel system maintenance. A partially-plugged filter will have little or no tolerance to waxy hydrocarbons as compared to a new filter. Also, properly adjusted fuel injectors will be capable of functioning at low temperatures. Attention must also be directed to insuring proper maintenance of battery, injector systems, etc., for cold starting. Low friction lubricants also aid in reducing cold starting problems.

i. Engine oil condition. The quality of the engine lubricant and its viscosity grade will impact the starting ability of engine systems. As engine oils accumulate service, the levels of carbonaceous soot/insolubles will increase which, in turn, increases the overall viscosity of the oil.

7.4.5 Under "User Practice" the following factors are contributors to the inoperability problem:

a. Vehicle maintenance procedures. The ability of any piece of equipment to start under low ambient temperatures will depend to a great deal on the "readiness of its power plant system." Proper attention must be paid to vehicle maintenance before and not after the fact.

b. Rotation of fuel stocks. The scheduling of diesel fuel inventories must be controlled to insure that summer grade diesel is consumed during warm and autumn seasons and not during cold weather. If fuel is to be provisioned for future use, attention must be paid to the intended storage interval, the area for its intended use, and what will be the lowest anticipated ambient temperature during its storage/use period. That lowest temperature is what the cloud point should be specified against prior to its procurement.

c. Topping-off procedures. Where vehicles are continually topped-off after short periods of use, attention should be paid to rotating that fuel prior to the winter season (i.e., winter fuel should be used to replace summer fuel to assure cold weather operability).

d. Use of filter/separators (F/S). Whenever possible, fuel being introduced into vehicle/equipment fuel tanks should be filtered through a F/S (mandatory when refueling aircraft. This offers a tremendous advantage since it not only removes entrained/free water (except for gasohol), but also eliminates particulate contamination which significantly contributes to low temperature inoperability problems.

e. Fuel procurement practices. Personnel involved in procurement or specifying fuel requirements should insure that product being delivered conforms to the monthly 10th Percentile Minimum Value limitations. These values, as given in VV-F-800, predict a 10 percent probability that the ambient temperature might be lower during that month.

f. Equipment use rate. Vehicles in constant use will always be using "current deliver" or fresh fuel. These vehicles would not be prone to experience the extent of problems that will occur within those vehicles which are used less or (worst case) randomly used.

## MIL-HDBK-114

g. Product turnover rate. Dispensing pumps that see a high volume usage will generally be turning over the received fuel within its designated period of use (i.e., the cloud point will be following the monthly changes). This assumes however, that the supplier/terminal distributor is furnishing bulk deliveries in accordance with VV-F-800. Those dispensing outlets having a slow turnover rate will have the potential for providing product to vehicles/equipment that may not be satisfactory because of the slow use rate (e.g., fuel intended for December being dispensed into vehicles during late January or February).

h. Poor housekeeping. Attention must be paid to maintaining good housekeeping procedures in fuel terminals, fuel transport equipment, petroleum distribution equipment, and retail dispensing centers. Tank bottoms must be continually checked, product scheduling rates must be monitored and followed, lines and fueling points must be kept clean, F/S should be used whenever possible, etc. If product storage, holding, and transfer tanks are kept relatively clean, the absence of water and contaminants will significantly improve the potential for low temperature operability.

i. Unauthorized product substitutions. Fuel oil numbers 1 and 2 should not be substituted for diesel fuel in cold weather. The low temperature operability criteria for fuel oil is more reflected with fuel's pour point (i.e., the temperature at which the fuel will start to flow). However, the low temperature operability criteria for diesel fuel is its cloud point or pump limiting viscosity which is, generally, well above the pour point. Also, fuel oils tend to contain more particulate contamination and more importantly, there is no requirement for cetane quality.

j. Unauthorized use of additives. The only additive authorized for use by field personnel in diesel fuel is Fuel System Icing Inhibitor (FSII) which is described by MIL-I-27686. This is generally added at the ratio of 1 pint per 40 gallons of fuel. It is, however, only intended to function as an antifreeze for separated water within the fuel tank and fuel system of vehicles. It does not alter the cloud point. Flow improver additives or pour point depressants are becoming widely used in CONUS to improve the low temperature characteristics of fuel oils. These flow improvers are organic polymeric compounds, which when added to distillate fuels, depress (i.e., lower) its pour point. It is postulated that these polymeric compounds co-crystallize on the wax crystals during their initial stage of formation, and prevent the growth of larger crystals which eventually form the structure of gelling of fuel. However, these additives do not alter the cloud point. Although their addition to fuels can effect a lowering of pour point values, the cloud point will remain unchanged. It should also be noted that flow improver additives, when applied to fuel oils, are highly selective. That is, they do not perform the same in each blend of fuels. They, therefore, are not universally effective as a solution for the user, and are not authorized.

k. Inadequate vehicle preparation. The most effective means to reduce cold weather fuel problems is through advance equipment preparation or winterization. Vehicles and equipment can be designed or modified for low-temperature operability by incorporating preventative measures such as fuel line heaters, water traps with drain-off valves, filter heaters, insulating exposed fuel lines, increasing filter capacities, use of radiator enclosures/shutters, etc. The preventative measures must be done before the onset of cold weather and not after the first reporting of starting or operating problems.

## MIL-HDBK-114

## 7.5 Diesel fuel at low temperature.

7.5.1 Diesel and distillate fuels all contain paraffin waxes in varying amounts. Most refineries today are not able to remove the minor amounts of wax present, at least not without significantly reducing product yields. It is these paraffin waxes, given the right low temperature weather conditions, that drop out of solution and clog fuel systems. While paraffin waxes can be troublesome, they do in fact, provide some benefits to the fuel blend. Cetane numbers of the waxes are high, so they improve ignition quality. Their volumetric heat content is also relatively high and this contributes to better fuel mileage. In addition, they are quite stable and enhance storage life of the fuel.

7.5.2 The wax content of Grade DF-2 diesel fuels can typically be about 6 to 8 percent and at normal temperatures this wax is easily held in solution. At low temperatures, the fuel can no longer dissolve all this wax and some portion will crystallize out. As temperature drops further, more wax crystallizes, the crystals grow larger, and finally, linking together, form a cellular wax matrix with liquid fuel caught between the cells. When the wax crystals first precipitate, they appear as a dispersed cloud, and the temperature at which this occurs is therefore known as the cloud point.

7.5.3 Both cloud and pour points will vary widely depending upon the crude feedstocks, refinery processes, blending procedures, and distribution systems. However, the critical factor having major importance to user/operator personnel during cold weather periods is the Cloud Point. While the fraction of the fuel in the solid phase may only be a small percent of the total (i.e., less than 1 volume percent) the wax crystals can form a matrix which will rapidly impair fluidity of the fuel in a very short period.

## 7.6 Low temperature operability criteria.

7.6.1 Satisfactory operability of vehicles and equipment will be possible if the cloud point of diesel fuel in a vehicle is at or below the prevailing ambient temperature. Selection of the proper fuel for cold weather use requires knowledge of temperatures anticipated. Current diesel fuel specifications use the "Tenth Percentile Minimum" value which, in effect, states "... this is the lowest temperature that will occur 90 percent of the time or there is only a 10 percent expectation that the minimum temperature will be lower than the Tenth Percentile Minimum." The Tenth Percentile Minimum approach has been adopted by industry, SAE, and ASTM as a means for predicting anticipated low temperatures. The basis for development of this percentile methodology was an extensive climatic study involving hourly atmospheric temperature data from 340 first-order weather bureau stations taken over at least a 20-year period of record. These data were processed and evaluated by assessing temperature distribution on a percentile basis. It is fully recognized that this may not account for all unexpected changes in the prevailing ambient temperatures as may occur; however, unusually low temperatures are always considered to be extremes and their potential use (i.e., Third Percentile Minimum, etc.) would obviously curtail fuel availability and increase procurement costs significantly if adopted universally.

## MIL-HDBK-114

## 7.7 Determining the cause of fuel flow problems.

7.7.1 A problem can usually best be met or managed when its cause is known and understood. The diesel engine cold flow problem - the partial or complete blockage of fuel flow to the injectors - is caused by either ice or wax crystals or both, forming in cold fuel. Most often these crystals (which are not really very large) plug the fine pores of the fuel filter element. While fuel filters are most vulnerable, fuel lines can also plug. When lines do plug, it is usually at fitting points or at elbows where flow is restricted.

7.7.2 If a diesel engine exhibits poor startup or reduced power, it should first be determined whether the cause is a plugged filter and, if so, whether the plugging is due to wax or ice. This is best done by replacing the fuel filter and observing operation of the vehicle. If the engine runs normally, even for a short period of time, it can be assumed that the filter is plugging. Next, place the plugged filter in a container, such as a shallow pan, and allow it to warm to room temperature. If water does not appear on the filter or at the bottom of the container, the problem is due to wax, not ice. If the filter does not appear to be plugged, look for wax or ice accumulations at points of constriction elsewhere in the fuel system, such as tank pick-up screens, sharp bends in the fuel line, or fittings. The overall problem that confronts operators of diesel-powered equipment at low temperatures involve three primary factors; the fuel, the equipment, and specific user/operator practices. An explanation of their inter-relationships is provided in 7.4.

7.7.3 If icing is the problem, the solution is clear - get water out of the fuel system and keep it out. For the most part, this is a matter of good housekeeping. Vehicle tanks should be drained on some fixed routine to forestall buildup of water. To minimize water accumulating through condensation, vehicle tanks should ordinarily be filled before being parked overnight or weekends. Vehicle fuel filters having water draw-offs should be drained or checked on a daily basis. Removal of water from fuel tanks and preventing its re-entry should be the primary control method in meeting the ice problems. The approved fuel deicer, MIL-I-27686 (ethylene glycol monomethyl ether), may be used as a secondary control. This deicer should not be relied upon to remove relatively large amounts of water from a vehicle tank. (The solubility relationship of fuel-water-glycol ether at various temperatures is not simple. Under certain conditions, it is very possible for the deicer to increase rather than decrease the water phase.) When relatively small amounts of water are involved, (less than the amount of deicer added) deicers may dissolve amounts of water in the fuel phase. This helps since some small amounts of water are removed but, more important, dissolved water does not freeze.

7.7.4 Fleets or plants that have fuel storage tanks should see that water bottoms are kept at absolute minimum practicable levels. Tank bottoms should be gauged or probed on a set routine using a suitable water indicating paste to determine if water is present. Any excessive amount of water should be promptly pumped out to prevent carryover into vehicle tanks. Storage tank systems should be examined for possible avenues for intrusion of water from the outside. For example, caps on fill lines, particularly those located at or below grade,

## MIL-HDBK-114

should be carefully inspected. Worn or missing gaskets must be replaced. Where a fill cap is located below grade (or situated where it can be covered by snow accumulations) consideration should be given to extending the fill pipe to a point above grade. Cracked or loose pipes and fittings should be replaced or tightened. While doing this, the vehicle tanks should not be ignored. Fill caps should be inspected to insure that they give good sealing action.

7.7.5 Fuel stored underground in the winter generally remains at a higher temperature than it will in above ground tankage/equipment. Studies have shown that fuels stored underground generally remain at between 4°C and 10° C (39° F and 50° F), regardless of the prevailing ambient temperatures (Arctic areas excepted). When storage is above ground, even a shed or enclosure around the storage tankage will have some value in reducing heat loss at night. Good fuel system housekeeping cannot be over emphasized as it is more important in winter than in summer. It is impossible to keep water out of fuel because of storage and equipment tank breathing. This problem is more severe in winter than in summer because moisture can freeze in tanks and lines, and block fuel flow.

#### 7.8 Solutions for fuel-related operability problems.

7.8.1 Fuel selection. User and supply personnel may know from past experience how low winter temperatures may drop in their location. This experience should be used in consonance with the Tenth Percentile Minimum in selecting or specifying the cloud point value. If fuel is procured over a period of time and the product "turnover time" is slow, caution must be exercised to insure that diesel fuel designed for use in October is not to be used in January for those areas where significant decreases in temperatures exist. If these "product turnover times" are lengthy, the fuel should be procured using the lowest temperature value anticipated during that period of intended use. These guide minimum values for specifying cloud point limitations are given in VV-F-800, Fuel Oil, Diesel and also in the ASTM D 975 Standard for Diesel Fuel. If large quantities of diesel fuel are procured and provisioned for future use, care must be exercised to insure that its cloud point value will be at least equivalent to or lower than the prevailing ambient temperature at the time of use. If the cloud point is above or anticipated to be above the prevailing ambient temperature, provisions should then be made to blend with a kerosene or other solvent so as to dilute the wax content.

7.8.2 Blending fuels. Normally, diesel or distillate fuel suppliers will blend kerosene at terminal facilities to provide a "winterized" version of DF-2. If available, the following fuels/solvents can be used as blending ingredients to lower the cloud point value:

- a. Aviation turbine fuel meeting MIL-T-5624, Grade JP-5.
- b. Aviation turbine fuel meeting MIL-T-83133, Grade JP-8.
- c. High flash point calibration fluid meeting MIL-F-27351.
- d. Dry cleaning solvent meeting P-D-680, Types I or II.
- e. Kerosene meeting ASTM D 3669 (Note: This superseded VV-K-211 and VV-K-220).
- f. Commercial aviation turbine fuel meeting ASTM D 1655, JET A or JET A-1.

## MIL-HDBK-114

7.8.2.1 It should be noted that all of the above fuels and solvents have flash points above 38° C (100° F). Generally, the change in cloud point resulting from a blending of two fuels will be dependent upon the cloud point of the two respective products (i.e., 30 volume percent of a kerosene having a cloud point of -40° C (-40° F) will lower the cloud point of a -7° C (19° F) diesel fuel to -13° C (8.6° F). The addition of any fuel or solvent to a vehicle experiencing problems will not provide immediate relief as mixing of the two fuels must occur for the lowering of the respective cloud point.

7.8.2.2 Blending of diesel/distillate fuel with automotive gasoline or JP-4 fuel will not be performed under any circumstances. This mixing of a relatively volatile fuel with diesel or distillate fuel creates an extremely hazardous mixture that can be ignited either by some external ignition source or by generation of electrostatic charge phenomena. As little as 10 volume percent of either gasoline or JP-4 to a diesel/distillate fuel will create a concentration of vapors at ambient temperatures to fall within the explosive limits envelope (i.e., for JP-4 fuel, these limits are 1.3 volume percent to 8.1 volume percent) thereby rendering the blend extremely unsafe.

7.8.2.3 The procedures for blending kerosene and other approved solvents in the field are being developed and will be forthcoming from Belvoir R&D Center. In addition to the blending procedures, a method will also be provided for initially determining the cloud point of the fuel using readily available equipment.

7.8.2.4 Additives. There has been considerable advertisement and marketing of additives within industry that are reported to improve the low temperature operability of diesel and distillate fuels. These additives, referred to as "flow improvers or pour point depressants" are becoming widely used in CONUS to improve the low temperature characteristics of heating/burner fuel oils. These additives are essentially organic polymeric compounds which, when added to distillate fuels, depress (i.e., lower) its pour point. It is postulated that these polymeric compounds co-crystallize on the wax crystals during their initial stage of formation, and prevent the growth of larger crystals which eventually form the structure for gelling of fuel. However, these additives do not alter the cloud point characteristic. Although their addition to fuels results in a significant lowering of pour point values in some instances, the cloud point will remain unchanged; hence, low temperature operability cannot be guaranteed as vehicles and equipment are "limited" by the cloud point. It should also be noted that flow improver additives when applied to heating and burner fuel oils are highly selective. That is, they do not perform the same in each blend of fuels. They therefore are not universally effective as a solution for the user. Because of their lack in changing the cloud point as well as their responsiveness to base fuels in lowering the pour point, these additives are not to be used in diesel fuels.

7.8.3 Equipment preparation and aids. In striving towards more reliable cold weather operation the user should look at his equipment from the standpoint of preparation or modifying it by adding cold weather aids. The extent of any modifications or equipment additions will be influenced largely by the climatic

## MIL-HDBK-114

conditions encountered and the duty cycle of the equipment. In some sections of the country, it may be necessary to use relatively elaborate arrays of equipment as vehicles are operated on an eight-hour duty cycle. The most effective means to reduce cold weather fuel problems is through advanced equipment preparation and winterization. Vehicles and equipment can be designed or modified for low-temperature operability by incorporating the following fuel system features:

- a. Fuel filter and screens should be located near the engine to receive maximum heat.
- b. Larger surface areas on filters and screens should be used to allow for maximum accumulation of wax before blocking occurs.
- c. Primary filters should have a minimum restriction to flow.
- d. Maximum transfer of heat from hot return fuel (i.e., fuel recirculation rate) to the area of the tank suction line is needed.
- e. Tight engine enclosure to conserve engine heat during warm-up is most beneficial.
- f. Adequately sized water traps with drain-off valves are recommended.
- g. Exposed fuel lines should be insulated or fuel heaters installed to reduce fuel line waxing. Various types are available and encompass electrical exhaust gas, and coolant systems.

**7.9 Pipeline operations.** Petroleum pipelines represent the most efficient means of transporting fuel from a supply point to using unit. However, the use of pipelines can contribute to fuel contamination from scale or rust and from the commingling of products. Many commercial pipelines are fabricated of steel and can form rust particles and scale after periodic scraping. Much of the rust and scale can get in the fuel requiring the use of filter separators. Military tactical pipelines are usually constructed of aluminum and do not represent a major source of solid contamination.

**7.9.1 Pipeline problems.** The major problem with these pipelines is the possibility of the commingling of products, i.e., in a multi-product pipeline one fuel becoming inadvertently mixed with another. Commingling is usually caused by improper batching, improper operation or improper switching. Ideally, each type of fuel (product) should have its own dedicated pipeline. Usually this is not practical, so that, most military pipelines are multi-products - carrying up to four or five different fuels with no separation between the products. At the point where one quantity or lot of a product (called a batch) contacts another there will always be a zone of mixed portions called an interface which must be kept to a minimum. The problems in operating a multiproduct pipeline are as follows:

- (1) Scheduling the various batches of products in proper sequence (batching);
- (2) Preventing accidental mixing of the batches during pumping;
- (3) Accurately following the progress of the batches and the interface so that they can be taken off the pipeline at the proper time and place; and
- (4) Disposition of the interfaces.

**7.9.1.1 Batching** is usually arranged so that related products are next to one another usually in ascending or descending order of gravity. The purpose of

## MIL-HDBK-114

this is to lessen the impact of accidental mixing and to generate interfaces that can be disposed of properly. Thus, MOGAS may be followed by JP-4 which in turn may be followed by kerosene and then diesel fuel. Batches can be kept from accidental mixing in the pipelines by maintaining a non-turbulent type flow known as laminar flow. Laminar flow can only be attained by taking into consideration the pipe diameter, the internal smoothness of the pipe, the gravity and viscosity of the product(s) being pumped, and the fluid velocity. In general, increasing velocity can lead to a turbulent flow consideration, consequently velocity is usually considered the controlling factor.

7.9.1.2 Batch change and interface location must be determined with a high degree of precision to allow accurate off-loading (switching) of the separate batches. Usually, the operator knows the approximate time when the interface will arrive at the switching point based on the velocity within the pipeline and the insertion time of the batches. Accurate determination of interfaces can be made by continual reading of specific gravity changes. Samples can be drawn off of a tee located just upstream of the switching point and the gravity measured using a hydrometer. When available, the new electronic Pipeline Interface Detector will give a continuous readout of gravity changes. Interfaces are disposed of by blending off with fuel batches that have properties that are similar to those of the interfaces. Care must be taken to insure that an interface containing a fuel with a low flash point (e.g., gasoline) is not blended into a high flash point fuel batch (e.g., diesel fuel). Particular care is given to JP-4 to ensure that no interfaces containing "dirty" type fuels (e.g., diesel fuel) is allowed to be blended into it. Only kerosene-JP-4 interfaces are used for blending into JP-4. MOGAS has the advantage that almost any type of interface can be blended with it. Obviously, failure to apply the proper procedure in a pipeline operation could result in a large quantity of mixed products which will be difficult to dispose of.

#### 7.10 Procurement practices.

7.10.1 Diesel fuel consumed in Army vehicles and equipment is procured under VV-F-800 (Fuel oil, diesel). This specification identifies four grades; Grades DF-A, DF-1, DF-2 (CONUS), and DF-2 (OCONUS). Grade DF-A is intended primarily for arctic use whereas Grades DF-1 and DF-2 (CONUS) are intended for use in CONUS. Those fuels supplied against the requirements of DF-1 are intended for use by light-duty diesel-powered vehicles and contain significantly higher quantities of kerosene blending fractions. Grade DF-2 (CONUS) is intended more for heavy-duty diesel-powered vehicles and contain significantly higher quantities of the "lighter" kerosene fractions. Users generally prefer the heavier (i.e., lower API gravity) DF-2 (CONUS) which provides a greater energy content and hence more fuel economy. Because of this difference in composition, DF-1 fuels will have inherently better low temperature properties than DF-2 (CONUS) fuels. However, there has existed and will continue to exist a general shortage of kerosene blending fractions which precludes wholesale adoption of DF-1 fuel by Army post-camp-station uses during the winter season. To minimize this tight supply situation and provide for satisfactory operability of ground equipment, suppliers of diesel fuel have incorporated a policy of "winterizing" DF-2 (CONUS) fuels at their bulk terminals by adding kerosene to meet cloud point criteria for the particular geographical area.

## MIL-HDBK-114

7.10.2 Fuel supplied against Grade DF-2 (OCONUS) presents a different issue. This fuel is intended for use in the European theater of operations. Because of international standardization agreements described under STANAGs 1135, 2754, and 2845, the specification requirements of DF-2 (OCONUS) are required to be in conformance with the requirements of NATO F-54, the diesel fuel used within the NATO Armed Forces and supplied through the Central European Pipeline System. This fuel has fixed cloud and pour point values as it is used year-round. The cloud point is specified at  $-13^{\circ}$  C max whereas the pour point is specified at  $-18^{\circ}$  C max. Because of this interchangeability requirement and standardization policies, any other diesel fuel (i.e., Grade DF-1 and DF-2 (CONUS)) cannot be made available for use by US Forces in Europe.

## MIL-HDBK-114

## CHAPTER VIII

FIELD EMERGENCY FUELS

8.1 General. Army Regulation No. 703-1 on "Coal and Petroleum Products Supply and Management Activities" describes the liquid hydrocarbon fuels to be used in Army fuel-consuming materiel and defines them as:

- (1) Primary fuel: A fuel that permits full design performance.
- (2) Alternate fuel: A fuel that provides performance equal to the primary fuel but may be a restricted item of supply in tactical areas or has environmental limitations. No degradation of performance or service life occurs as a result of the use of an alternate fuel within the prescribed operational range.
- (3) Emergency fuel: A fuel used when the primary or alternate fuel is not available. The use of an emergency fuel may result in increased maintenance and reduced engine life. Severe performance derating is permissible when an emergency fuel is used, but it must not destroy the materiel within the operating period prescribed by the engine designer.

AR 703-1 proceeds to list the primary, alternate, and emergency fuels that are permissible for each type of engine. In addition, other combustible liquids could be used neat or blended with primary fuels. Examples of these are alcohols, hydrocarbon cleaning fluids, fog oil, etc. Sacrifices in vehicle performance while using Field Emergency Fuels (FEF) are to be expected; however, these fuels would be used only when emergencies exist. In this chapter, those fuels which could be used as substitutes or extenders will be presented according to the particular types of engines.

8.2 FEF for gasoline-consuming engines.

8.2.1 The spark-ignition (SI) engine requires a fuel that can be easily vaporized and mixed with air in the carburetor before it is introduced into the combustion chamber. There, air-fuel mixture is ignited by a spark, and the resulting combustion products expand to force the piston out, thus creating power. The combustion products are exhausted during the return stroke of the piston.

8.2.2 Substitute fuels. The primary fuel for spark-ignited, ground equipment engines as designated by AR 703-1 and shown in table IX is MIL-G-3056 (MOGAS), NATO F-46 for OCONUS and VV-G-1690 (MOGAS) for CONUS. Alternate fuels are all gasolines listed as VV-G-1690, ASTM D 439, F-49, F-50, AVGAS MIL-G-5572 (F-22) and MIL-G-53006 (GASOHOL). These fuels are in reality the only substitute fuels available in field environment for spark ignition engine systems. Many combustible liquids could be thought of as adequate field emergency fuels for spark-ignited engines; however, due to the carburetion system in these engines these materials will not permit operation. Examples are ethanol and methanol, which are excellent gasoline extenders, and operate quite well in engines with carburetion systems designed for their specific use. However, they are not suitable for use as a direct fuel replacement. There are no quick retrofit systems for changing a gasoline-burning engine to a methanol- or ethanol-burning one.

## MIL-HDBK-114

8.2.3 Extenders/blend for gasoline engines. Different types of engines require specific fuels for normal operation, and attempts to operate one type of engine on fuel intended for another engine could result in complete failure. However, some dilution of the primary fuel with another fuel may enable operation with reduced level of performance. Continued studies in this area are being made for the purpose of making available more fuels under emergency situations. It should be noted that blending of gasolines with DF-2, Jet A, or Kerosene-type fuels creates more hazardous fuel mixtures than do the individual fuels themselves. Due to the vapor pressures of the respective fuels at ambient temperatures, gasoline produces a vapor-air mixture in the vapor area of a container that is fuel rich and above the flammability limits; diesel fuels and kerosenes produce mixtures that are fuel lean and below flammability limits; but a broad range of concentration mixtures of the two will produce flammable vapor-air mixtures at normal ambient temperatures.

8.3 FEF for diesel-consuming engines.

8.3.1 Compression-ignition (CI) engines, more commonly referred to as diesel engines, are high-compression, self-ignition engines in which the fuel is ignited by the heat of compression, and no spark plug is used. The cycle consists of charging the combustion chamber with air, compressing the air, injecting the fuel which ignites spontaneously, expanding the burned gases, and exhausting products of combustion. The compression ignition engines can be designed to operate on a four or a two-stroke cycle. The four-stroke cycle has better volumetric efficiency, good combustion characteristics, and positive exhaust gas scavenging, while the two-stroke cycle has the advantage of compactness in relation to power output. Both types of compression-ignition engines are found in the U.S. Army's vehicle fleet. A variation of the four-stroke cycle engine with a modified sphere cast entirely in the piston is common in the military vehicle fleet. The system developed by Maschinenfabrik Augsburg-Nurnberg, AG (MAN) permits this engine to use a wide range of fuels; therefore, it is designated a multifuel engine. Field emergency fuel for the multifuel engines will be discussed in a later section.

8.3.2 Substitute fuels. The primary fuel for compression-ignition ground equipment, two-cycle and four-cycle, normally aspirated and turbocharged engines is designated by AR-703-1 and shown in table IX as VV-F-800 and F-54 (OCONUS use). Alternate and Emergency Fuels are also designated in AR-703-1 as shown in the table. To date, the only approved substitute fuels are those indicated in AR-703-1. Work is being done in which other fuels and fluids available in the army inventory are being considered as fuels.

8.3.3 Extenders/blend for diesel engines. Several hydrocarbon-based products are in the Military supply system that could be blended with available diesel fuel to produce field emergency fuels. A list of such products follows: JP-8; ASTM D396, Nos. 1, 2 and 4 Fuel Oils; P-D-680 Type II, dry cleaning solvent; commercial kerosene; MIL-F-12070, fog oil; and MIL-H-5606, hydraulic fluid. JP-5 is an alternate fuel to DF-2 for use in compression-ignition engines. Blends such as JP-4 in diesel fuel may produce vapor-air mixtures which are

## MIL-HDBK-114

likely to be within flammable limits at ambient temperatures, making the blend more hazardous than the individual fuels. For the above mentioned fluids, except those included in the AR-703-1, work is being done to ascertain their usefulness as extenders for diesel engines.

#### 8.4 FEF for multifuel engines.

8.4.1 The four-cycled MAN combustion system family of multifuel engines, designated the LD-465, LDT-465, and LDS-465 can be operated on a wide range of fuels.

8.4.2 Substitute fuels. As mentioned before, fuels that could be used directly in this engine include petroleum products ranging from gasolines to NATO F-75 Navy distillate. Gasoline, a fuel listed as an alternate fuel for this engine in AR-703-1, may not be adequate if it is a premium grade having a high octane number. Certain combustible materials existing in the military system that may be thought of as possible substitutes or emergency fuels in the multifuel engine may not be adequate due to the limitation of 15 cetane number for fuels in this engine. Materials such as AVGAS, premium gasoline, methanol and ethanol generally have cetane numbers too low for starting and running in multifuel engines.

8.4.3 Extenders/blends fuels. Those fluids mentioned in 8.3.3 for diesel-consuming engines (not multifuel) could also be used with the multifuel engines. This engine has the greatest availability of fuel due to its multifuel capability.

#### 8.5 FEF for ground turbine engines.

8.5.1 A wide range of gas-turbine engines are in use, from large industrial gas turbines for electrical generation to smaller ones for aircraft and ground vehicles. Selection of the fuel for use in these engines requires consideration of the availability of the fuel, design of the gas turbine, and fuel-handling systems and maintenance/operating requirements. In addition to numerous helicopters, the U.S. Army combat fleet includes the M-1 tank powered by a gas turbine engine. The AGT-1500 engine in the M-1 battle tank was designed to use DF-2 as the primary fuel since this fuel is the primary fuel for essentially all tactical/combat ground vehicles, as well as turbine/CI-powered electrical generators.

8.5.2 Substitute fuels. The range of combustible liquids that could be used as substitute fuels for the ground gas turbine has not been determined; however, it appears that most of the materials listed for the multifuel, compression ignition engine would also be suitable for this engine with a few exceptions. This engine may be limited to operation with fuels of certain viscosity and boiling range. Therefore, it may not operate with materials such as the heavier burner fuels or hydraulic fluids. Methanol, ethanol, and other oxygenated products, on the other hand, may be adequate field emergency fuels. This area needs further investigation.

## MIL-HDBK-114

8.5.3 Extenders/blends for gas turbine engines. Although the M-1 tank engine was designed for burning DF-2, it is a tolerant engine with respect to fuel. The list of alternative fuels in AR 703-1, shown in table IX, is extensive and includes all aircraft turbine fuels in military and ASTM specifications. Numbers 1 and 2 burner fuels are included, but not No. 4. Based on these observations, it would appear that all fuels and combustible materials listed as fuel extenders for diesel engines (8.3.3) would also apply to ground turbine engines, with the exception of No. 4 burner fuels and hydraulic oils. Further investigations are needed to determine the fuel viscosity and boiling range limitations for the ground gas turbine engine, although the manufacturer of the engine has indicated that a maximum of 12 cSt is the limiting fuel viscosity for start-up of this engine.

8.6 FEF for aircraft engines.

8.6.1 Field emergency fuels for aircraft engines, both spark-ignited and gas turbine, should be limited to those fuels listed as alternate in AR 703-1. For spark-ignition engines these are:

MIL-G-5572 (AVGAS), Grade 115/145,  
F-22; and ASTM D 910 (AVGAS)

MIL-T-5624, grade JP-4, NATO F-40, is the primary fuel for gas turbine aircraft, and the only alternate fuels shown are JP-8, JP-5 and ASTM D 1655 (commercial aviation fuels).

MIL-HDBK-114

TABLE IX. Fuel requirements for Army mobility engines for diesel engine, gasoline engine and turbines (AR 703-1).

<u>ENGINE SYSTEM</u>	<u>PRIMARY FUEL</u>	<u>ALTERANTE FUEL</u>	<u>EMERGENCY FUEL</u>
SPARK-IGNITION: GROUND EQUIPMENT			
CONUS	VV-G-1690 (MOGAS)	VV-G-1690 (MOGAS)	
OCONUS	MIL-G-3056 (MOGAS), F-46	MIL-G-5572 (AVGAS), F-18 F-49 (GASOLINE) F-50 (GASOLINE) ASTM D 439 (GASOLINE) MIL-G-53006 (GASOHOL)	
Aviation Equipment	MIL-G-5572 (AVGAS), Grade 100/130, F-18	MIL-G-5572 (AVGAS), Grade 115/145, F-22 ASTM D 910 (AVGAS)	
GAS TURBINE: Ground Equipment	VV-F-800 (DF-2), F-54	MIL-T-5624 (JP-4, JP-5), F-40, F-44 MIL-T-83133 (JP-8), F-34 MIL-F-16884, F-76 F-75 (NAVY DISTILLATE) ASTM D 975 (DIESEL) ASTM D 3699 (KEROSENE) ASTM D 1655 (AVIATION TURBINE FUEL) ASTM D 2880 (GAS TURBINE FUEL) ASTM D 396 (FUEL OIL, NOS. 1 & 2)	MIL-G-3056 (MOGAS), F-46 MIL-G-5572 (AVGAS), F-18 VV-G-1690 (MOGAS) MIL-G-53006 (GASOHOL) F-49 (GASOLINE) F-50 (GASOLINE)
Aviation Equipment	MIL-T-5624 (JP-4), F-40	MIL-T-83133 (JP-8), F-34 MIL-T-5624 (JP-5), F-44 ASTM D 1655 (AVIATION TURBINE FUEL)	

MIL-HDBK-114

TABLE IX. Fuel requirements for Army mobility engines for diesel engine, gasoline engine and turbines (AR 703-1). (Cont)

<u>ENGINE SYSTEM</u>	<u>PRIMARY FUEL</u>	<u>ALTERANTE FUEL</u>	<u>EMERGENCY FUEL</u>
COMPRESSION-IGNITION: GROUND EQUIPMENT TWO-CYCLE AND FOUR-CYCLE, NA(2) & TURBOCHARGED ENGINES	VV-F-800 (DF-2), F-54(1)	MIL-T-5624 (JP-5), F-44  ASTM D 975 (1-D & 2-D DIESEL)	MIL-T-83133 (JP-8), F-34  MIL-F-16884 F-76 F-75, (NAVY DISTILLATE) MIL-T-5624 (JP-4), F-40 ASTM D 2880 (TURBINE FUEL) ASTM D 3699 (KEROSENE) ASTM D 1655 (AVIATION FUEL) ASTM D 396 (No. 1 & No. 2) ASTM D 975 (4-D DIESEL)
FOUR-CYCLE, MAN(3) SYSTEM(MULTIFUEL) (4)	VV-F-800(DF-2), F-54	MIL-T-5624 (JP-4, JP-5) F-40, F-44 MIL-T-83133 (JP-8), F-34 F-75 (NAVY DISTILLATE) MIL-G-3056 (MOGAS), F-46 F-50 (GASOLINE) ASTM D 3699 (KEROSENE) ASTM D 1655 (AVIATION FUEL) ASTM D 2880 (TURBINE FUEL) ASTM D 975 (DIESEL)	VV-G-1690 LIMITED GRADE (MOGAS) ASTM D 439, ANTIKNOCK INDI CES 87 & 89 (GASOLINE) ASTM D 396 (Nos. 1 & 2)

- (1) F-54 IS INTENDED FOR OCONUS USE. WITHIN CONUS, GRADES DF-A, DF-1, AND DF-2 (CONUS) APPLY.  
(2) NORMALLY-ASPIRATED.  
(3) MACHINENFABRIK AUSBURG-NURNBERG, AG  
(4) ENGINES POWERING 2-1/2-T AND 5-T TRUCK SERIES.

## MIL-HDBK-114

## CHAPTER IX

FUEL PROPERTY - PERFORMANCE CORRELATIONS AND RELATIONSHIPS

9.1 General. Many properties of fuels are interrelated and as certain properties are changed due to composition others are affected. Gravity, either API or specific, is a good example of this interrelationship.

9.2 Gasolines. Gasolines typically have specific gravities in the range of 0.72 to 0.75 or API gravities between 57 and 65. The more volatile winter-grade gasolines have lower specific gravities (higher API) than the summer grade gasolines. On the other hand, higher aromatic content fuels have higher specific gravity (lower API) than fuels with less aromatic. Distillation, vapor pressure, and vapor-liquid ration are interrelated properties which are completely dependent on the composition of the gasoline with respect to low boiling point components.

9.3 Diesel fuel properties interrelationships. The API gravities for diesel fuels range from 29° API (sp.gr. 0.882) to 47° API (sp.gr. 0.793) and although this property is not a measure of quality and is not a requirement in most diesel fuel specifications, it gives useful information when considered with other tests. High specific gravity (low API gravity) is associated with aromatics and naphthenic hydrocarbons, and low specific gravity with paraffinic hydrocarbons. Of the properties of diesel fuels that could be specified, only a few are recognized as functional by an engine. These can be listed as in table X.

TABLE X. Functional properties of diesel fuels.

<u>Property</u>	<u>Why important</u>
Heating Value (Btu/gal)	Affects power and economy, smoke
Viscosity	Affects atomization, smoke, power
Cetane Number	Affects cold starting, combustion roughness, smoke
Cloud Point, Pour Point	Affects cold weather handling
Sulfur Content	Affects wear and deposits
Cleanliness	Affects fuel filter life, injector life

The first four can be shown to be related. Heating value is important to the consumer. Diesel injectors are volume limited, and the maximum power output depends on the fuel's net volumetric heating value. Despite its importance, heating value is seldom measured and almost never specified. This is because it is strongly related to fuel density and accurate correlations between fuel heating value and API gravity have been developed. Two such correlations were used to calculate net volumetric heating values for about 300 fuels from the 1968 Bureau of Mines' Survey and are illustrated graphically in figure 5<sup>(4)</sup>\*. The correlation from which the regression equation No. 1 in the figure was developed contains the variables: density, API gravity, aniline point,

\*Numbers in parenthesis indicate reference (see Chapter XII).

## MIL-HDBK-114

distillation temperatures at 10, 50, and 90 percent recovered, and sulfur content. The standard error was about 185 Btu/gal. the second correlation contained only gravity and sulfur content and appeared to give less accurate heating values. These correlations show that the net volumetric heating value increases as the API gravity decreases.

9.3.1 Other diesel fuel property correlations. Using the 1968 Bureau of Mines' survey of fuels, a correlation between kinematic viscosity at 100° F (38° C) 50-percent distillation temperature, and API gravity was developed. An equation relating cloud point to 50-percent distillation temperature was also developed with the data from the Bureau of Mines' survey of fuels. It is recognized that the higher boiling n-paraffin components of a diesel fuel are the first hydrocarbons to crystallize when a fuel is chilled and thus result in the cloud point. Therefore, the distillation temperatures at the 90- and 95-percent points are related to cloud and pour points of the fuel.

9.4 Fuel properties map. Bert and Amberg<sup>(4)</sup> plotted correlations developed using 1968 Bureau of Mines' Survey fuels for properties as follows: API gravity, heating value, 50 and 90-percent distillation temperatures, viscosity at 100° F, and cloud point. This resulted in a fuel properties map shown in figure 6. It shows approximate relationships among properties among properties of fuels which are not exact but are usable. Certain observations can be made from this map. A fuel with high viscosity will not have a low pour point. A fuel with high volumetric heating value and high cetane number will have high viscosity and cloud point.

9.5 Diesel fuel specifications. The ASTM specifications for 2-D diesel fuel in effect in 1970 were added to the property map as shown in figure 7. The 2-D requirements were a maximum viscosity of 4.3 cSt at 100° F and 90-percent distillation temperature maximum of 640° F (338° C). From the plot in figure 7, it can be seen that either property would provide virtually the same control. The minimum 90-percent temperature of 540° F (282° C) places approximately the same limitation as the minimum viscosity of 2 cSt; therefore, both are unnecessary. The minimum temperature at 90-percent distillation for ASTM 2-D fuels has since been dropped from the specification and does not appear in VV-F-800.

9.6 Air turbine fuels. The composition of aircraft turbine fuels is controlled more carefully through specification requirements, but even within the property limits, changes affect other properties.

9.6.1 Combustion quality. The combustion quality of these fuels is specified by several analyses including aromatic content, smoke point, luminometer number, aniline point, and heat of combustion. The hydrogen content is also important.

9.6.2 Jet fuel correlation. Siemssen described in 1973<sup>(5)</sup> several correlations that involved all the properties listed above and API gravity. Figure 8 shows the relationship between smoke point, aromatic content, and API gravity of kerosine-type jet fuels. Figure 9 depicts the relationship between luminometer number, aromatics, and API gravity. Figure 10 shows net heat of combustion related to aromatics and API gravity. Lastly, figure 11 presents

## MIL-HDBK-114

hydrogen content as it relates to aromatics and API gravity. These plots illustrate the change in combustion characteristics of fuels as the aromatic content increase and conversely the hydrogen content decreases.

9.7 Determination of fuel properties with minimal testing. Widespread application of the various relationships discussed above has been proposed to minimize the number of inspection tests required in fuel specifications.

9.7.1 Properties of gasolines from gas chromatography (GC). Prior to 1978 the Institute of Petroleum Mathematical Analysis Panel<sup>(6)</sup>, reviewed the principal gasoline test methods and proposed replacing them with new ones or with calculation routines. The new methods proposed are all gas-liquid chromatography (GLC) procedures adapted to the property being measured. GLC boiling point distributions can provide data to enable the calculation of ASTM distillation values, Reid vapor pressure (RVP) and vapor/liquid ratio temperatures. With refinements, it is anticipated that knock characteristics, lead content, and hydrocarbon-type analyses can be calculated from GLC data. Modern refineries make extensive use of gas chromatography for analysis of gasolines and other fuels as they are being manufactured.

9.7.2 Calculated RVP from distillation. A procedure for calculating Reid vapor pressure from D86 distillation data is described by Jenkins and White<sup>(7)</sup>. Using a wide range of fuels, which included alcohols blended up to 20-percent concentration in gasoline, multiple alcohols blended up to 20-percent concentration in gasoline, multiple regression analysis was employed to obtain three equations for calculating RVP from ASTM D86 distillation data.

9.7.3 Combustion properties of jet fuels. The Method Evaluation Sub-Committee of the Institute of Petroleum conducted a cooperative program in which determined and calculated properties for 312 worldwide kerosene-type jet fuel samples were compared<sup>(8)</sup>. The properties investigated were smoke point, luminometer number, and aromatics. The sub-committee concluded that calculated smoke point and luminometer numbers should be acceptable alternatives in jet fuel specifications; however, the calculated aromatics content is less satisfactory.

9.7.4 Properties of distillate fuels by gas chromatography. The calculation of physical properties of fuels based on gas chromatography (GC) has been demonstrated as feasible. Present, et al., have coupled this technique with computer programming to calculate automatically values for RVP, ASTM D 86, and ASTM D 1160 distillation, API gravity, flash point, and viscosity<sup>(9)</sup>.

9.8 Correlative methods for fuels properties. The interrelationship of fuel properties has been recognized in the petroleum industry for many years and has resulted in numerous correlative methods for calculating fuel properties. Most of the methods developed by ASTM for petroleum fuels are listed here.

D 2159 Test for Napthenes in Saturates Fraction by Refractivity Intercept. Density and refractivity index of saturates fraction of gasolines are used to estimate the concentration of napthenes in the gasoline.

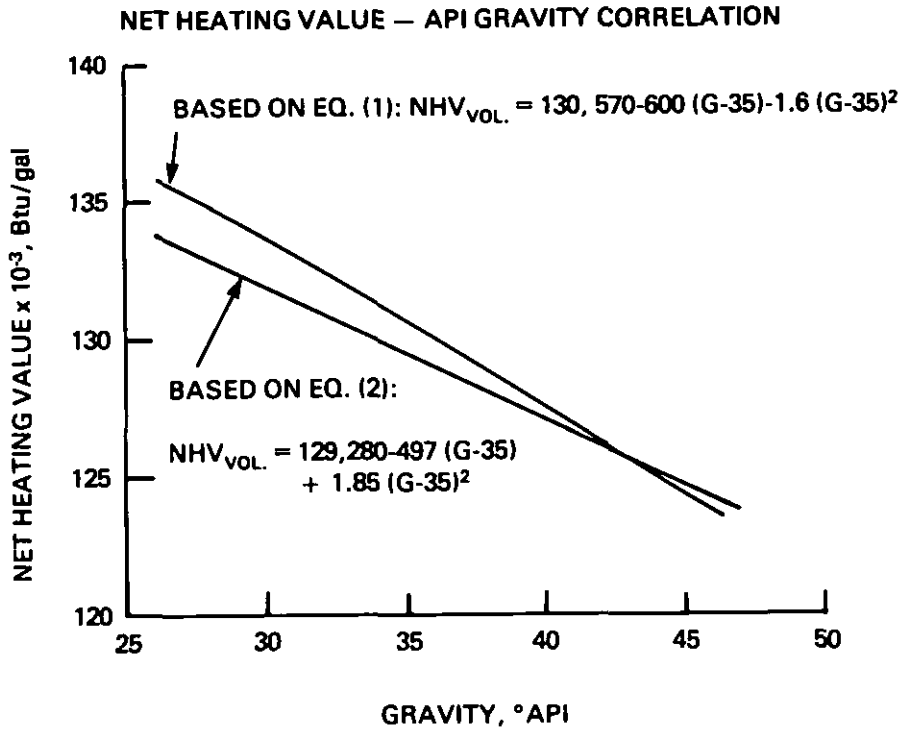
## MIL-HDBK-114

- D 2502 Estimation of Molecular Weight of Petroleum Oils From Viscosity Measurements. Viscosity measurements of the sample are made at 37.8 and 99° C (100 and 210° F) and the results are used to estimate molecular weight of the oil. This technique is applicable to oils with molecular weights in the 200 to 700 range.
- D 2598 Calculation of Certain Physical Properties of Liquified Petroleum (LP) Gases From Compositional Analysis. The composition of a sample of LP-gas is obtained from the analysis in liquid volume percent, the vapor pressure, specific gravity, and the motor octane number of the sample can be calculated.
- D 2878 Estimating Apparent Vapor Pressures and Molecular Weights of Lubricating Oils. Values obtained by ASTM D 972, Evaporation Loss of Lubricating Greases and Oils, are used to calculate apparent vapor pressures and molecular weights of oils. This technique applies to petroleum-base and synthetic ester lubricating oils; however, its applicability to greases has not been established.
- D 2889 Calculation of True Vapor Pressures of Petroleum Distillate Fuels. Distillation (D 86) data are used to calculate equilibrium flash vaporization temperatures of petroleum distillate fuels. These values, distillation data, and API gravity of the sample are used with a graphical correlation procedure to obtain the calculated true vapor pressure at a specified temperature.
- D 2890 Calculation of Liquid Heat Capacity of Petroleum Distillate Fuels. The liquid heat capacity of petroleum can be calculated, either graphically or mathematically, from correlation relating calculated heat capacity, temperature at which heat capacity is being calculated, determined API gravity, and the Watson Characterization factor K.
- D 3238 Calculation of Carbon Distribution and Structural Group Analysis of Petroleum Oils by the n-d-M Method. The refractive index and density of the oil are determined at 20° C. The molecular weight is determined experimentally or estimated from measurements of viscosity at 40 and 100° C (104 and 212° F). These data are then used to calculate the carbon distribution ( $\%C_a$ ,  $\%C_n$ ,  $\%C_p$ ) or the ring analysis ( $R_a$ ,  $R_n$ ) using the appropriate set of equations.
- D 3338 Estimation of Heat of Combustion of Aviation Fuels. A correlation has been established between the net heat of combustion and API gravity, aromatic content, and average of 10, 50, and 90-percent recovered temperatures determined by Method D 86.
- D 3343 Estimation of Hydrogen Content of Aviation Fuels. A correlation has been established between the hydrogen content of a fuel and its distillation range average of 10, 50, and 90-percent distillation data using Method D 86, API gravity, and aromatic content.

MIL-HDBK-114

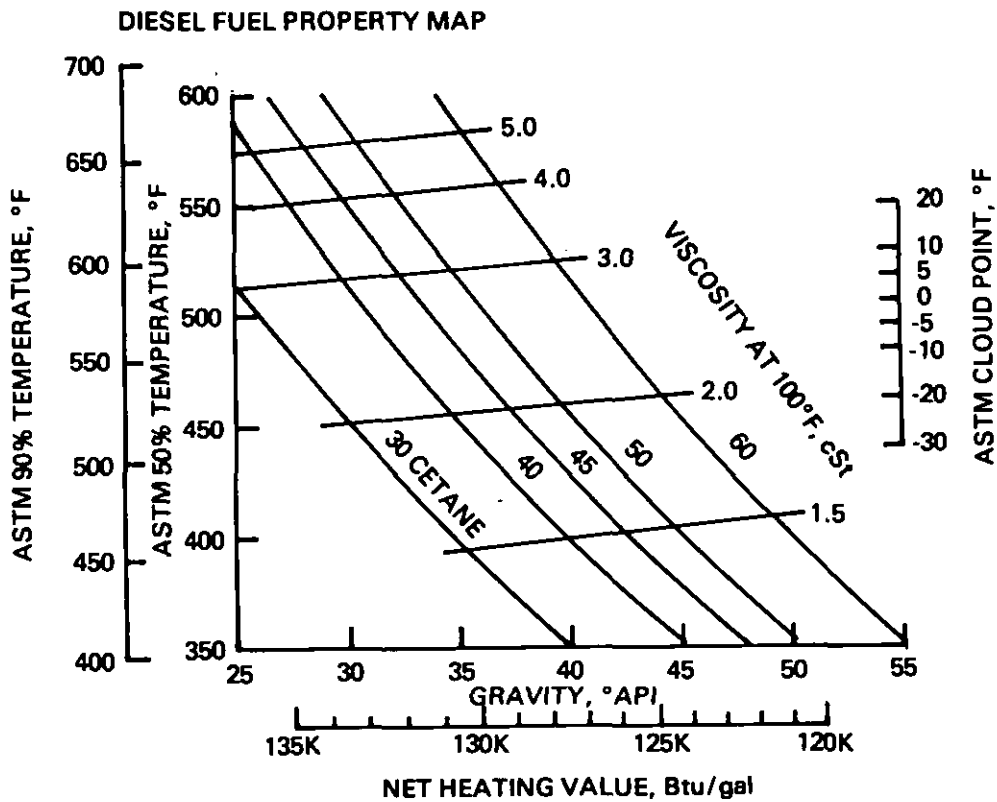
- D 3827 Estimation of Solubility of Gases in Petroleum and Other Organic Liquids. This method covers a procedure for estimating the equilibrium solubility of several common gases in petroleum and synthetic lubricants, fuels, and solvents, at temperatures between 0 and 215° C.
- D 4056 Estimation of Solubility of Water in Hydrocarbon and Aliphatic Ester Lubricants. This method covers a procedure for estimating the equilibrium solubility of water and its vapor in hydrocarbon and aliphatic ester lubricants at temperatures between 4 and 100° C. The method is limited to liquids of low to moderate polarity and hydrogen bonding, with predicted solubilities not over 1000 ppm by weight in hydrocarbons or 30,000 ppm by weight in oxygenated compounds at 25° C. Data required are the density, refractive index, and molecular weight of a hydrocarbon. The saponification number is also required for an ester.

MIL-HDBK-114



SOURCE: Reference 4

FIGURE 5.

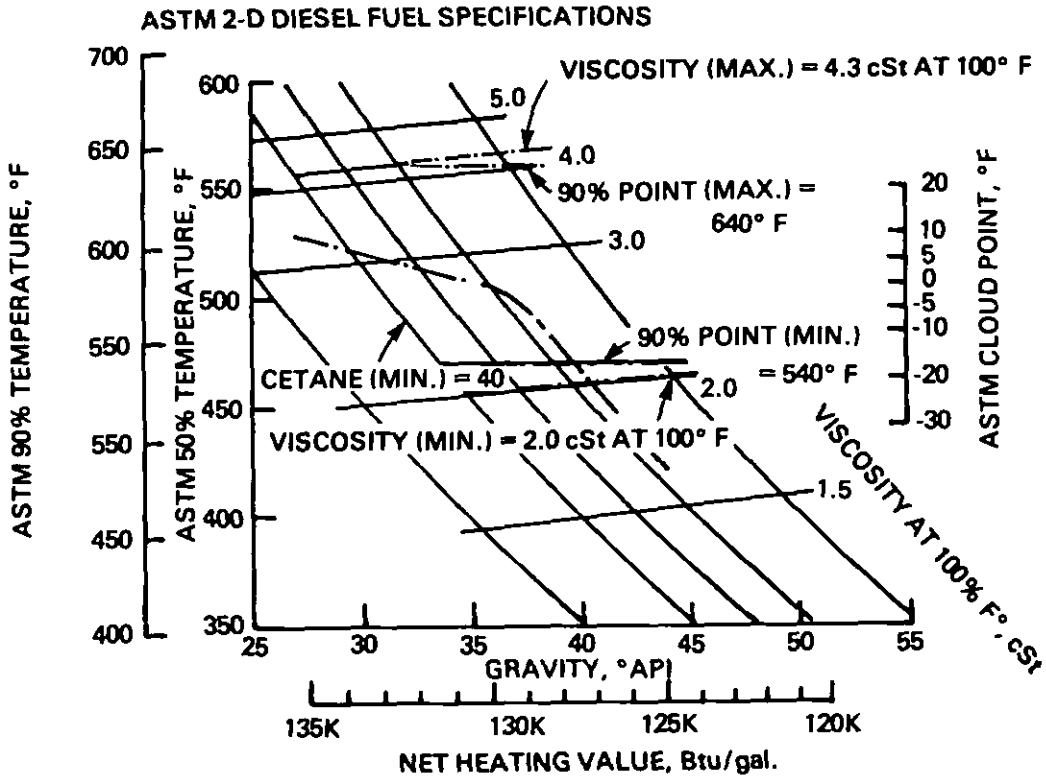


SOURCE: Reference 4

FIGURE 6.

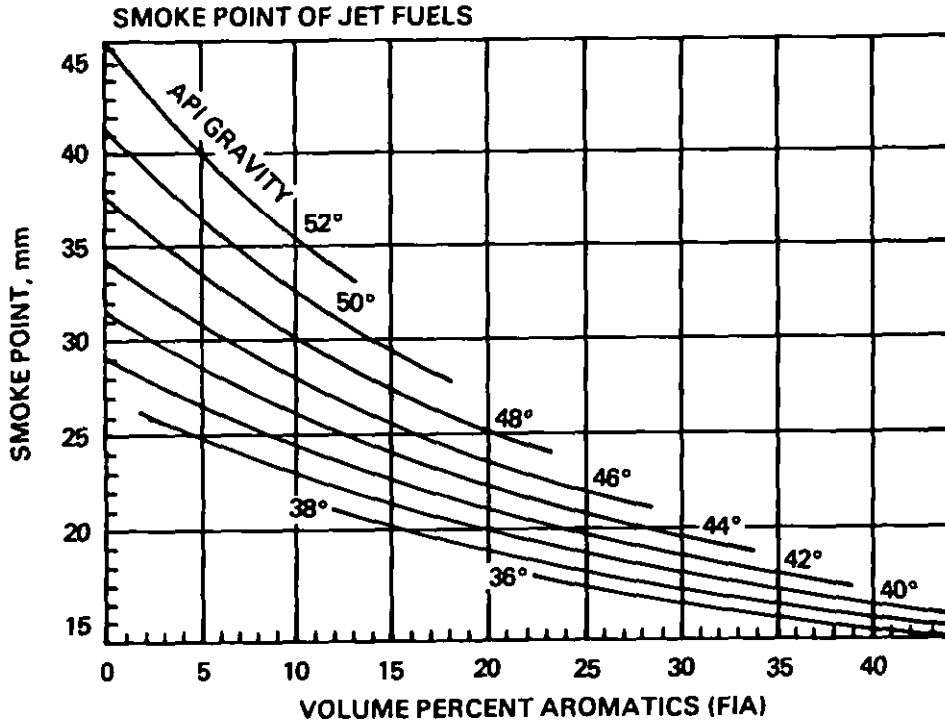
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MIL-HDBK-114



SOURCE: Reference 4

FIGURE 7.

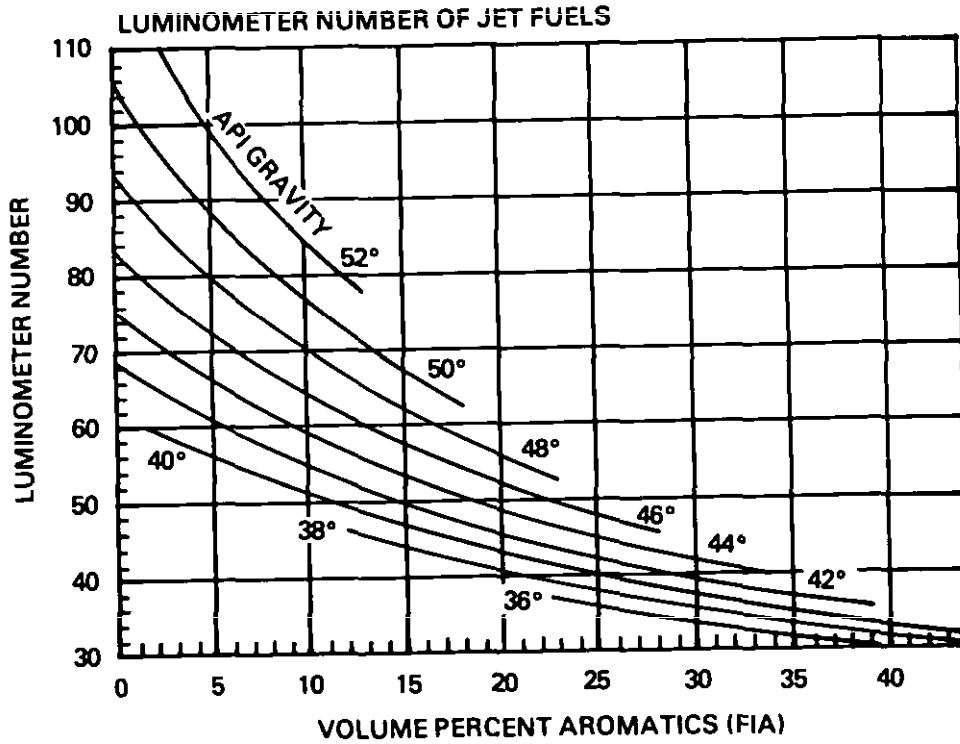


SOURCE: Reference 5

FIGURE 8.

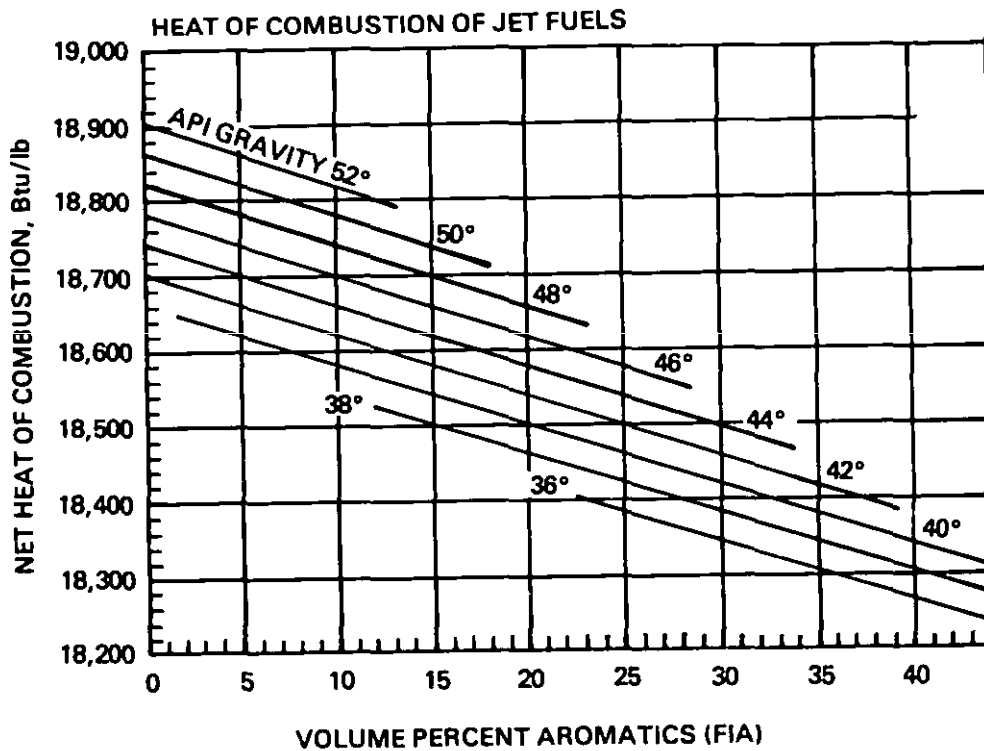
X-9143

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SOURCE: Reference 5

FIGURE 9.

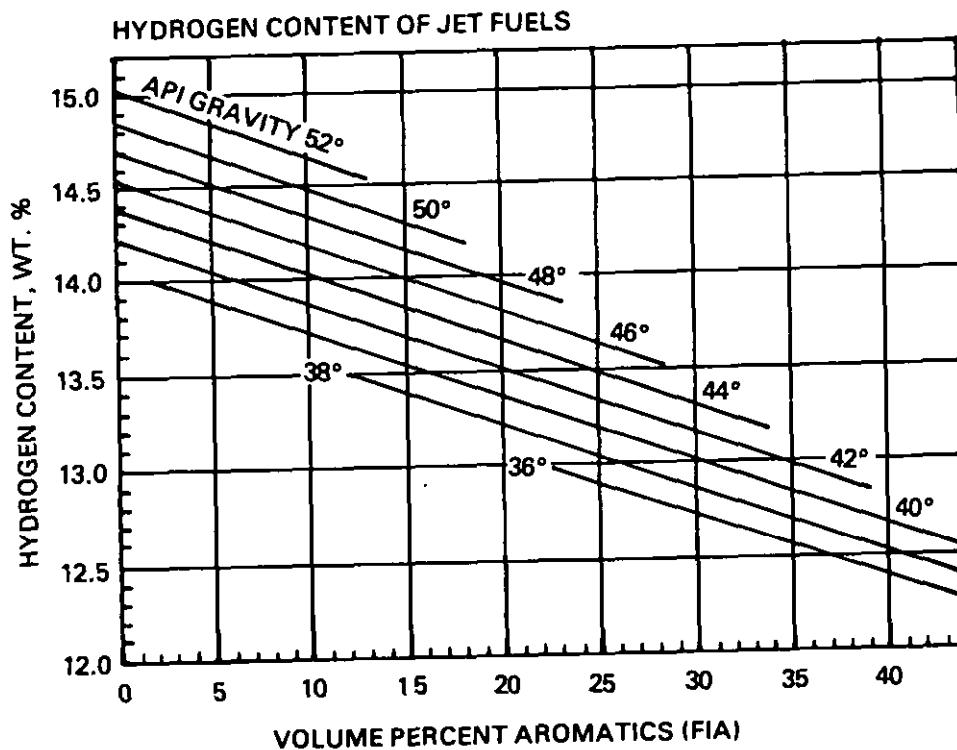


SOURCE: Reference 5

FIGURE 10.

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MIL-HDBK-114



SOURCE: Reference 5

FIGURE 11.

X-4145

## MIL-HDBK-114

## CHAPTER X

FUEL ADDITIVES COMMONLY USED BY REFINERS.

10.1 General. The additives currently utilized by refiners in meeting the required performance and quality levels have undergone considerable research and development and exhaustive testing in laboratory dynamometer engines and in controlled fleets prior to becoming a commercial reality. Not only must the additive do the specific job for which it was intended, but it must be trouble-free from the time it is blended at the refiner or bulk terminal until it enters the fuel tank of a vehicle and eventually is combusted. There currently exists, however, three military specifications which describe specific additives required for use in military aviation turbine fuels.

- a. MIL-I-25017, Inhibitor, Corrosion, Fuel Soluble.
- b. MIL-I-27686, Inhibitor, Icing Fuel System.
- c. MIL-I-85470, Inhibitor, Icing, Fuel System, High Flash.

The above specifications represent a slight departure from the existing procedures within the Department of the Army and the Defense Department wherein fuels are procured as a finished product (i.e., no other additives/ingredients are required as the fuel will meet the desired quality and performance level specified).

10.2 Gasoline additives. The types and different additives used in gasoline are provided in table XI. Not all of the additives mentioned in the table are allowed in each of the specifications. To know the proper concentrations and the additives allowed, check the respective specifications.

10.3 Diesel additives. One of the most important properties in the selection of diesel fuel is cetane number. This property can be modified with additives which will increase the cetane number to the desired level. This additive and others used to modify specific properties are shown in table XII. Always refer to the specification for the additives allowed and the proper dosage.

10.4 Turbine fuels additives. The additives used in turbine fuels are more restricted than in the Diesel and gasoline fuel. The additives commonly used in turbine fuels will be described by additive, function, and type in table XIII. Always refer to the latest specification for the correct additives and proper dosage.

## MIL-HDBK-114

TABLE XI. Gasoline fuels additives.

Additive	Type	Function
Oxidation inhibitors	Aromatic amines and hindered phenols	Inhibit gum formation and oxidation
Corrosion inhibitors	Carboxylic acids and carboxylates	Inhibit corrosion of ferrous metals
Metal deactivators	Chelating agent	Inhibit gum formation catalyzed by metals
Anti-icing additives	Surfactants and alcohols glycols	Prevent icing in carburetor fuel systems
Detergents	Amines and amine carboxylates, amides, imides, and imidazolines	Prevent deposits in carburetor throttle body
Deposit control additives	Polybutene amines, polyether amines, polymers, and top cylinder oils	Remove and prevent deposits throughout carburetor intake ports and valves
Blending agents	Ethanol, methanol tertiary butyl alcohol (MTBA), methyl tertiary butyl ether (MTBE)	Extend gasoline supply and increase octane quality
Antiknock compounds	Lead alkyl, organo-manganese compounds	Increase octane quality
Lead Scavengers	Organic bromides and chlorides	Prevent lead deposits in combustion chamber
Dyes	Hydrocarbon-soluble azo compounds and anthraquinone compounds	Color for identification

MIL-HDBK-114

TABLE XII. Diesel fuels additives.

Additive	Type	Function
Detergents	Polyglycols, basic nitrogen-containing surfactants	Prevent deposits and increase injector life
Dispersants	Nitrogen-containing surfactants	Peptize soot and products of fuel oxidation and extend filter life
Metal deactivators	Chelating agents	Inhibit gum formation catalyzed by metals
Rust and corrosion inhibitors	Amines, amine carboxylates and carboxylic acids	Prevent rust and corrosion in fuel system
Cetane improvers	Alkyl nitrate esters	Increase cetane number
Flow improvers	Polymers	Reduce pour point
Antismoke additives or smoke suppressants	Organic barium compounds	Reduce exhaust smoke
Oxidation inhibitors	Low molecular weight amines	Minimize deposits in filters and injectors
Biocides	Organic boron compounds	Inhibit growth of bacteria and microorganisms
Dyes	Hydrocarbon-soluble azo-compounds and anthraquinone compounds	Color for identification

## MIL-HDBK-114

TABLE XIII. Turbine fuels additives.

Additive	Type	Function
Antioxidant	Aromatic, amines and hindered phenols	Inhibit gum formation and oxidation
Metal deactivator	Chelating agents	Inhibit gum formation
Corrosion inhibitor	Carboxylatic acids and carboxylates	Prevent corrosion in fuel systems
Fuel system icing inhibitor	MIL-I-27686 EGME, MIL-I-85470 DGME	Prevent icing in fuel systems
Electrical conductivity	ASA-3, Stadis 450	Enhance the conductivity of the fuel
Lubricity additive	PWA-536	Improve fuel lubrication
Biocides	Biobor JF	Inhibit microbiological growth

## MIL-HDBK-114

## CHAPTER XI

GASEOUS MOBILITY FUELS11.1 General.

11.1.1 Gaseous mobility fuels are defined as compressed natural gas (CNG), liquefied natural gas (LNG), liquefied petroleum gas (LP gas or LPG). Natural gas is primarily composed of methane ( $\text{CH}_4$ ), whereas LPG is mainly composed of propane ( $\text{C}_3\text{H}_8$ ) with small concentrations of ethane ( $\text{C}_2\text{H}_6$ ) and butane ( $\text{C}_4\text{H}_{10}$ ). LPG also contains some olefins of the same carbon numbers, propylene ( $\text{C}_3\text{H}_6$ ), ethylene ( $\text{C}_2\text{H}_4$ ) and butylene ( $\text{C}_4\text{H}_8$ ).

11.1.2 There are four grades of LPG which are:

- a. Commercial propane which is predominantly propane and propylene.
- b. Commercial butane which is predominantly butanes and butylenes.
- c. Commercial B-P mixtures which are predominantly mixtures of butanes and butylenes with propane or propylene.
- d. HD-5 propane which has not less than 90 liquid volume percent propane and not more than 5 liquid volume percent propylene. HD-5 propane is the only grade of LP-gas suitable for use in automotive engines.

11.1.3 Gaseous fuels may be used as alternative fuels for spark ignition engines. Blending gaseous fuels with specification gasoline is highly impractical. This type of fuel therefore does not fit the "pour in a drum and stir with a stick" definition of an emergency fuel. However, gaseous fuels can be used as substitutes for spark ignition engines after the appropriate modifications or retrofit has been completed.

11.2 Advantages/disadvantages of the use of natural gas as fuel.11.2.1 Advantages.

- a. On an energy basis, gaseous fuels have efficiencies equivalent to that for gasoline. In the case of duty cycles with frequent stops and starts or frequent cold starts and warm-ups, gaseous fuels may even have greater energy efficiencies.
- b. Since the fuels are introduced in gaseous form, little or no fuel dilution occurs in cold weather due to condensation on cold cylinder walls.
- c. Spark plugs also tend to last longer because of more complete combustion.
- d. Gaseous fuels offer improved cylinder-to-cylinder distribution which results in a smoother running engine.
- e. Cold startability is also improved.
- f. Exhaust emissions are not increased when using gaseous fuels.

11.2.2 Disadvantages.

- a. Due to lower energy density, gaseous fuels may have as little as half the range of gasoline on equivalent volumes of fuel.

## MIL-HDBK-114

- b. It is only feasible for gasoline-fueled administrative vehicles.
- c. The cost for vehicles conversion and fueling station is approximately \$63,000.00 (this is for a 25 car fleet and for one fueling station).
- d. One cannot fill a tank 100 percent.
- e. Gaseous fuels burns cleanly; however, the absence of any liquid per se and the resultant increase in combustion temperature can, under sustained high-temperature operation, induce exhaust valve recession. Therefore, stellite valve inserts or induction-hardened valve seats must be incorporated into engine system retrofit.
- f. A metal barrier is required between driver and gaseous fuel storage tank which results in greater weight and reduces fuel economy.
- g. Engine oils for gaseous fueled engines operation are required to be virtually ashless products that must possess excellent oxidation stability. The combustion blow-by from gaseous fueled operation can intensify oil thickening at a significant rate because of oxidation/nitration reactions.
- h. The use of gaseous fuels is restricted in certain areas of cities and roadways (i.e., tunnels, bridges, etc.).

### 11.3 Safety.

11.3.1 Extreme caution should be exercised when utilizing gaseous fuels. Although commercial storage tanks are designed with many safety features, release of fuel vapors into the atmosphere can be dangerous due to hazards of asphyxiation, explosion or both. Fuel systems should be periodically checked for leaks with a soap-based leak tester. Refueling is probably the greatest source of accidents involved with gaseous fuel utilization. The following are guidelines for safe refueling of LPG or CNG.

- a. Stop motor, set brakes, block wheels before connecting hose.
- b. Check for open flames and other ignition sources in the immediate vicinity before connecting hose.
- c. Do not smoke while transferring LPG or CNG.
- d. Check the working pressure of the LPG or CNG cylinder being filled. This cylinder working pressure should be at least equal to the vapor pressure of the LPG or CNG to be transferred.
- e. Stand by the filling valve during the LPG or CNG transfer. Fill ONLY to "10 percent valve capacity". After filling LPG or CNG space cylinder stop pump motor before disconnecting hose.
- f. Walk completely around the vehicle before leaving fueling site, making sure all hoses are disconnected and properly secured.
- g. Purge all tanks before making any repairs or alterations.
- h. Keep fire extinguishers in good condition and handy. Refill immediately after use.
- i. Do not use an open flame to locate LPG or CNG leak.
- j. Do not fill any cylinder within ten feet of any building or recreational vehicle.

11.3.2 Overfilling tanks can be very dangerous. Normal expansion can cause release of the emergency pressure relief valve. If this occurs near an ignition source, the results could be disastrous.

MIL-HDBK-114

11.3.3 Explosion hazard due to vehicle collision is also increased when using gaseous fuels. Commercial storage tanks are quite sturdy and if tanks are shielded from the possibility of direct collision, this hazard can be greatly reduced.

11.3.4 Another source of possible danger is in the fuel regulators. These should be periodically inspected to ensure proper working condition. Pressure gauges should be closely monitored. Any abnormal pressures should be quickly analyzed or reconciled after first shutting off the main valve at the tank.

## MIL-HDBK-114

## CHAPTER XII

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## MIL-HDBK-114

## CHAPTER XIII

ACRONYMS AND ABBREVIATIONS

- 13.1 AMCP - Army Materiel Command Publication
- 13.2 API - American Petroleum Institute
- 13.3 ASTM - American Society for Testing and Materials
- 13.4 BMEP - Brake Mean Effective Pressure
- 13.5 CI - Compression Ignition
- 13.6 CO - Carbon Monoxide
- 13.7 cp - centipoise
- 13.8 CRC - Coordinating Research Council
- 13.9 cSt - centistoke
- 13.10 DARCOM - Department of the Army Materiel Development and Readiness Command
- 13.11 DOD - Department of Defense
- 13.12 DT - Development Testing I Through III; DTI, DTII, and DTIII.
- 13.13 E.P. - Extreme Pressure
- 13.14 FEF - Field Emergency Fuels.
- 13.15 FTMS - Federal Test Method Standard
- 13.16 FTM - Federal Test Method
- 13.17 GM - General Motors
- 13.18 g - gram
- 13.19 kg - kilogram
- 13.20 KOH - potassium hydroxide
- 13.21 mg - milligram
- 13.22 mL - milliliter
- 13.23 NATO - North Atlantic Treaty Organization
- 13.24 NO<sub>x</sub> - Nitrogen Oxides
- 13.25 N.R. - Not Required
- 13.26 ppm - parts per million
- 13.27 psi - pound per square inch
- 13.28 RAM-D - Reliability, Availability, Maintainability - Durability
- 13.29 SAE - Society Automotive Engineers
- 13.30 Seq. - Sequence
- 13.31 SI - Spark Ignition
- 13.32 TCP - Tricresyl Phosphate

## MIL-HDBK-114

## CHAPTER XIV

GLOSSARY OF TERMS

14.1 Introduction. The following is a listing of terms that are in general use among field personnel having contact with the storage, transportation, distribution, consumption, and utilization of mobility fuels.

14.2 Terms.

**Absolute pressure.** Pressure measured with respect to zero pressure, as distinct from pressure measured with respect to some standard pressure, such as atmospheric pressure. The absolute pressure in a perfect vacuum is zero. The sum of gage pressure and the atmosphere pressure equals the absolute pressure.

**Accelerated gum test.** A test to determine the amount of gum and lead precipitate formed in aviation fuels as a result of accelerated oxidation or aging. Potential gum is the amount of residue obtained by evaporating the fuel at the end of the specified aging period after any lead deposits have been removed (ASTM D 873).

**Acid.** A chemical compound usually having a sour taste, contains hydrogen that is replaceable by a metal and reacts with a base to form salt and water.

**Acidity.** The amount of free acid in a substance.

**Additive.** An agent used for improving existing characteristics or for imparting new characteristics to certain petroleum products.

**Air-fuel ratio.** The ratio of the weight of air to the weight of fuel used in an internal combustion engine or furnace. The ratio in a gasoline engine is about 12-15 to 1.

**Alcohol (fuel alcohol).** A class of organic compounds characterized by the presence of a hydroxyl radical in an alkyl molecular structure; specifically, for fuel use, methanol or ethanol used alone or as a fuel extender blended in a hydrocarbon fuel.

**Alternate fuel.** A fuel which can be used continuously when the Army Standard fuel is not available, without reduction of power output (AR-703-1).

**Alternative fuel.** A fuel produced from a source other than petroleum or a product not typically used as fuel for engines.

**American Petroleum Institute (API).** The institute represents and is supported by the petroleum industry. It standardizes the tools and equipment used by the industry and promotes the advancement of research in the petroleum field.

## MIL-HDBK-114

American Society for Testing and Materials (ASTM). A national scientific and technical organization formed for the development of standards on characteristics and performance of materials, products, systems, and services and the promotion of related knowledge.

Anhydrous. Free of water, especially water of crystallization.

Aniline point. The minimum temperature for complete miscibility of equal volumes of aniline and the sample under test. ASTM Method D 611 describes procedures for determining aniline point and mixed aniline point of petroleum products and hydrocarbon solvents. A product of high aniline point will be low in aromatics and naphthenes and, therefore, high in paraffins. In conjunction with API gravity, the aniline point may be used to calculate the net heat of combustion of aviation fuels.

Antiknock. Resistance to detonation or pinging in spark-ignition engines.

Antiknock agent. A product which, when added in small amounts to the fuel charge of an internal-combustion engine, tends to lessen knocking.

Antioxidant. A chemical added to gasoline, lubricating oil, and certain other petroleum products to inhibit oxidation.

API gravity. (Also see specific gravity.) An arbitrary scale expressing the gravity or density of liquid petroleum products. The measuring scale is calibrated in terms of degrees API. The gravity of any petroleum product is corrected to 16° C (61° F). It may be calculated in terms of the following formula:

$$\text{Degrees API gravity at } 16^{\circ} \text{ C (61}^{\circ} \text{ F)} = \frac{141.5}{\text{sp.gr.}} - 131.5$$

Appearance. Refers to the visual examination of fuels. Terms used to describe appearance are clear, bright, hazy, and cloudy.

Aromatic. Unsaturated hydrocarbon identified by one or more benzene rings or by chemical behavior similar to benzene and produced by a reforming process.

Ash content. The percent by weight of residue left after combustion of a sample of fuel oil or other petroleum oil. In the United States, ash content is usually determined by ASTM Method D 482.

ASTM. (See American Society for Testing and Materials.)

ASTM-CFR engine. A special engine developed by the Coordinating Fuel and Equipment Research Committee of the Coordinating Research Council, Inc., to determine the knock tendency of gasolines.

## MIL-HDBK-114

- Atmospheric distillation.** Distillation of crude oil conducted at approximately atmospheric pressure with the object of obtaining gasoline, kerosene, gas oils and heavier residue.
- Atmospheric pressure.** 1. The pressure of air; more specifically, the pressure of the air at sea level. 2. As a standard, the pressure at which the mercury barometer stands at 760 millimeters or 29.92 inches (equivalent to approximately 14.7 pounds per square inch).
- Auto-ignition temperature.** Temperature of spontaneous ignition of a petroleum product in the absence of a flame when tested in accordance with the provisions of ASTM Method D 2155.
- Autoignition.** The spontaneous ignition, and the resulting very rapid reaction, of a portion or all of the air-fuel mixture in an engine. The flame speed is many times greater than that which follows normal spark ignition. The noise associated with it is called knock.
- Automotive gasoline (MOGAS).** A hydrocarbon fuel in the approximate composition range  $C_5 H_{12}$  to  $C_9 H_{20}$  for use in internal combustion engines and procured by the military under three specifications.
- Average boiling point.** The sum of the ASTM distillation temperatures from the 10-percent point to the 90-percent point, inclusive, divided by 9. Sometimes half the initial and half the maximum distillation temperatures are also added, and the sum is then divided by 10.
- Average sample.** A sample that consists of proportionate parts from all levels of the product. For example, an average sample from horizontal, cylindrical tank, or from a spherical tank, should contain more material from the middle of the tank where the diameter is greatest.
- Aviation fuels (AVFUELS).** Those refined petroleum products specifically formulated and blended for use in aircraft engines, both jet (reaction) engines and piston (reciprocating) engines. AVGAS (below) is an aviation fuel.
- Aviation gasoline (AVGAS).** A hydrocarbon fuel for use in reciprocating piston-type aircraft engines. AVGAS is characterized by low vapor pressure and distillation range and higher tetraethyllead content.
- Barrel (bbl.).** A common unit of measurement of liquids in the petroleum industry. It equals 42 U.S. standard gallons.
- Beaker.** A cylindrical glass vessel with straight sides, a flaring rim, and pouring lip used in the laboratory.
- Benzene.** Colorless liquid hydrocarbon,  $C_6H_6$ , with six carbon atoms and six hydrogen atoms arranged in hexagonal ring structure. It is used in the manufacture of various products, as a solvent, and as a component of high-octane gasoline.

## MIL-HDBK-114

- Benzol.** The general term which refers to commercial or technical benzene.
- Bitumen.** Generally, an inflammable, naturally-occurring hydrocarbon mixture such as asphalt; specifically, the heavy hydrocarbons found in tar sands.
- Blending.** 1. Mixing refinery products to suit market conditions. 2. Mixing on-specification fuel with off-specification fuel to bring the latter to specification or use limits (a method of reclamation). 3. Mixing an interface with either or both adjacent products, or with a third product without degrading any of them beyond use limits.
- Blending tolerance.** 1. The percentage of one product that can be blended with, or tolerated by, a second product without throwing the second product so far off specification as to be beyond use limits. 2. The practice of dividing interfaces between adjacent products.
- Blow-by.** The escape of combustion gases or unburned fuel from the combustion chamber past the pistons and rings into the crankcase in internal-combustion engines, during the power stroke or the compression stroke.
- Boiling point (b.p.).** The temperature at which a substance boils or is converted into vapor by bubbles forming within the liquid. The temperature varies with atmospheric pressure.
- Boiling range.** The range of temperature, usually determined at atmospheric pressure in standard laboratory apparatus, which characterizes a fraction by its initial and final boiling points.
- Bottom sediment and water (BS&W).** Amount of sediment and water measured in the bottom of a tank.
- Breathing.** The movement of gas (product vapors or air) in and out of the vent lines of storage tanks as a result of alternate heating and cooling.
- British Thermal Unit (B.t.u.).** The quantity of heat required to raise by 0.5° C (1° F) the temperature of 1 pound of water at or near the temperature of maximum density, 3.92° C (39° F).
- Bulk petroleum products.** Those petroleum products (fuels, lubricants, etc.) which are normally transported by pipeline, rail tank car, tank truck, barge or tanker and stored in tanks or containers having a capacity of more than 55 gallons, except fuels in 500-gallon collapsible containers which are considered to be packaged. (See packaged petroleum fuels.)
- Bunker C fuel oil.** A heavy residual fuel oil used by ships, industry, and large-scale heating installations. The Navy calls it Navy Heavy; industry often refers to it as No. 6 fuel.
- Burning quality.** Refers generally to burning characteristics of fuels used in lamps, stoves, ranges, and space heaters; refers particularly to kerosene (ASTM Method D 187).

## MIL-HDBK-114

**Butane.** Either of two isomeric, flammable, gaseous hydrocarbons,  $C_4H_{10}$ , of the paraffin series, n-butane or isobutane. Bottled, butane is referred to as LPG and is used for domestic and laboratory purposes and for general brazing.

**Calibration.** 1. The graduation of a measuring instrument. 2. The determination of accuracy of graduation in a measuring instrument.

**Calorie (cal. or Cal.).** 1. The amount of heat required to raise the temperature of 1 gram of water  $1^\circ C$ , at or near the temperature of maximum density. This unit is called a small calorie or gram-calorie and is abbreviated cal. 2. The amount of heat required to raise the temperature of 1 kilogram of water  $1^\circ C$ . This unit is called a large calorie or kilogram-calorie and is abbreviated Cal.

**Calorific value.** The heat liberated by the combustion of a unit quantity of fuel, e.g., British thermal units per pound of fuel, calories per gram of fuel.

**Calorimeter.** An apparatus for measuring quantities of heat, such as the bomb calorimeter, which is used to determine the heat of combustion or the thermal value of a fuel in calories or British thermal units.

**Carbon dioxide.** A heavy, colorless gas,  $CO_2$ , which will not support combustion (therefore being useful as a fire-extinguishing agent). It is exhaled as a waste gas by lung-possessing animals and absorbed by certain plants, which then release oxygen as a waste gas.

**Carbon monoxide.** A colorless, odorless, and poisonous gas,  $CO$ , resulting from the incomplete combustion of carbon.

**Carbon residue.** A residue formed after evaporation and pyrolysis of a petroleum product. The residue is not entirely composed of carbon, but is a coke which can be further changed by pyrolysis (ASTM D 189 and D 524).

**Carbon tetrachloride.** A colorless, nonflammable liquid,  $CCl_4$ , used as a solvent, detergent, and drying agent for electrical parts. It is no longer used as an extinguishing agent because of its toxic qualities.

**Catalyst.** A substance that promotes chemical action without the substance undergoing chemical change.

**Cathodic protection.** An electrolytic method of protecting a buried pipeline or other metal structure against corrosion by surrounding it by an electrical blanket strong enough to overpower the currents seeking to leave the metal to go into the soil. The method involves putting electrical current into the soil so that it flows to and into the line or structure. The protective current may be obtained by the galvanic action between magnesium anodes and the steel of the pipeline or structure or by a rectifier to convert alternating current to direct current. The current is put into soil through a scrap metal graphite ground-bed.

## MIL-HDBK-114

**Centigrade scale.** A thermometer scale on which the interval between the freezing point and boiling point of water is divided into 100 parts or degrees centigrade, 0° C corresponding to 32° F, and 100° C to 212° F. Also called Celsius after Anders Celsius who first described it.

**Centipoise.** A unit of absolute viscosity; 0.01 poise (see viscosity, absolute).

**Centistoke.** A unit of kinematic viscosity; 0.01 stoke (see viscosity, kinematic).

**Centrifuge.** A whirling instrument for separating liquids or liquids and solids of different specific gravity by use of centrifugal force.

**Cetane.** A paraffin hydrocarbon (normal hexadecane),  $C_{16}H_{34}$ , used as a standard in determining or measuring the ignition qualities of diesel fuels.

**Cetane number.** The percentage by volume of normal cetane (100 cetane number), in a blend with alphas-methylnaphthalene (0 cetane number), which matches the ignition quality of the diesel fuel under test when compared by the procedure specified in ASTM Method D 613. The determination of the cetane number of diesel fuel is similar to the determination of the octane number of gasoline. Currently heptamethylnonane has replaced alphas-methylnaphthalene as a primary reference fuel; however, it is assigned a cetane number of 15.

**Chemical stability.** Resistance to chemical change; indicates that the various elements present in oil or grease will not undergo change, nor will the product as a whole change as a result of action taking place within itself.

**Class III. POL: Petroleum fuels: lubricants, hydraulic and insulating oils, preservatives, liquid and compressed gases, chemical products, coolants, deicing and antifreeze compound, together with components and additives of such products and coal.**

**Class of fires.** 1. Class A, fires of ordinary combustibles, such as paper, wood, textiles, or rubbish, and extinguished by water. 2. Class B, fires of flammable liquids like gasoline, oil, grease, and extinguished by smothering. 3. Class C, fires involving electrical equipment, and extinguished by nonconducting agents. 4. Class D, fires involving burning metal.

**Clean and bright.** Clean is the absence of visible solids, a cloud, a haze, an emulsion, or free water in the product. Bright is the sparkle of clean, dry product in transmitted light.

**Clean product.** Products such as aviation and motor gasolines, jet fuel, diesel fuel, kerosene, and lubricating oil; contrasting with black oil.

**Clear gasoline (water white).** An unleaded gasoline.

## MIL-HDBK-114

Cleveland open-cup tester. Apparatus used for determining the flashpoints and fire points of all petroleum products flashing above 79.4° C (175° F), except fuel oils. The tester is usually used as prescribed in ASTM Method D 92.

Closed tester. (See flash point).

Cloud point. The temperature at which paraffin wax or other solid substance in an oil begins to crystallize or separate, causing the oil to appear cloudy or hazy. Cloud point is described in ASTM Method D 2500.

Coal-liquids (coal-derived liquids). Liquids derived from peat, lignite, bituminous coals, or other coals by direct or indirect liquefaction processes.

Coalescing. 1. Drawing together, combining, or uniting to form one body.  
2. A method of separating finely divided or suspended water from a petroleum product by passing the product through filter media of a filter/separator.

Color stability. The resistance of oil to discoloration due to light, aging, etc.

Combustion. Burning or rapid oxidation caused by the union of oxygen and any material capable of being ignited.

Combustion lag. The lapse of time between the ignition of the compressed charge of fuel vapors and the time when maximum pressure is developed in the combustion chamber.

Compatibility. Refers to the ability of additives or of lubricating oils of different composition or from different sources to mix together without separation or reaction.

Composite sample. A mixture of individual samples represent the bulk from which they were taken. A complete sample is not the same as a mixed sample.

Compound. A substance formed by combining two or more ingredients in definite proportions by weight. A compound possesses physical and chemical properties entirely different from those of the combining ingredients if used separately.

Compression ignition. Ignition in a diesel engine, in which the heat of compression ignites the fuel, in contrast to the spark ignition in a gasoline engine.

Compression pressure. The pressure of the gases in the cylinder of an internal-combustion engine at the end of the compression stroke.

## MIL-HDBK-114

**Compression ratio.** The ratio of the volume enclosed in an engine cylinder at the beginning of the compression stroke to the volume at the end of the compression stroke. The higher the compression ratio the higher the efficiency and output of the engine, the greater the tendency to knock, and the greater the need for high-octane fuel.

**Contaminant.** A foreign substance in a product.

**Contaminated product.** A product in which one or more grades or types of products have been inadvertently mixed; or a product containing foreign matter such as dust, dirt, rust, water, or emulsions.

**Contamination.** The addition to a petroleum product of some material not normally present. Common contaminants are water, dirt, sand, rust, mill scale, and other petroleum products.

**Continuous sample.** A sample taken from a flowing pipeline in such a manner that the sample is a representative average of the stream during the period of sampling.

**Conversion factor.** A constant used to change or convert dimensional units into other dimensional units, such as barrels to cubic feet and inches to millimeters.

**Coordinating Fuel and Equipment Research Committee (CFR).** This committee is composed of engine-manufacturing, petroleum-refining, petroleum-marketing, university, Government, and other technical representatives who supervise cooperative testing and study of engine fuels for the Coordinating Research Council, Inc.

**Coordinating Research Council, Inc.** An organization supported jointly by the American Petroleum Institute and SAE. The council administers the work of the Coordinating Fuel and Equipment Research Committee (CFR) and other committees pertaining to correlation of test work on such things as fuels, lubricants, and engines. (See Coordinating Fuel and Equipment Research Committee.)

**Copper Strip Corrosion.** A qualitative method of determining the corrosivity of a product by its effects on a small strip of polished copper suspended or placed in the product (ASTM Method D 130).

**Corrosion.** Corrosive action of petroleum products on metals; test intended to evaluate, under specified conditions, corrosive tendencies of a product with respect to copper.

**Corrosion fatigue.** Metal fatigue accompanied and aggravated by corrosion.

**Critical compression pressure (CCP).** The highest possible pressure in an air-fuel-mixture before spontaneous ignition takes place.

## MIL-HDBK-114

- Crude.** In a natural state; not altered, refined, or prepared for use by any process, as crude oil or crude petroleum.
- Crude oil (petroleum).** (See petroleum.)
- Defense Fuel Supply Point (DFSP).** Any military or commercial bulk fuel terminal storing products owned by the Defense Logistic Agency.
- Defense Logistic Agency (DLA).** The agency, at the Department of Defense level, charged with providing the most effective and economical support of common supplies and services to military departments and other designated Department of Defense components. It is the agency under which the Defense Fuel Supply Center operates.
- Degree of purity.** A term applied to chemical reagents used in analytical laboratories to indicate grade or quality and compliance with appropriate specification. Common designations are c.p. (chemically pure), ACS (American Chemical Society), USP (United States Pharmacopoeia) and Technical.
- Demulsibility.** Ability of an oil to separate from water as measured under standardized conditions.
- Denaturant.** An agent that is used to make (alcohol) unfit for drinking without impairing usefulness for other purposes.
- Density.** Specific weight or mass of a substance per unit volume (pounds per cubic foot or gallon or grams per cubic centimeter). Specific gravity is the ratio of the mass of any volume of a substance to the mass of an equal volume of some standard substance (water in the case of liquids and hydrogen or air in the case of gases) at 40° C.
- Design fuel.** Fuels most likely to be transported by military pipeline are aviation fuels, motor gasoline, and diesel fuel. The heaviest fuel making up 24 percent or more of the total requirement will be taken as the design fuel.
- Detergency.** The ability of a substance to clean and to wash away undesirable substances. Detergents may be either oil soluble or water soluble. Soap and synthetic detergents help to wet, disperse, and deflocculate solid particles. Oil-soluble detergents are used in motor oils to disperse, loosen, and remove carbon, dirt, and other undesirable materials from interior surfaces of internal-combustion engines.
- Detonation.** Sharp explosion. The term is used to described the knock-producing type of combustion in spark-ignition, internal-combustion engines.
- Dew point.** The temperature at which vapor starts to condense.

## MIL-HDBK-114

**Diesel engine.** An internal-combustion engine in which air drawn in by the suction stroke is so highly compressed that the heat generated ignites the fuel, which is automatically sprayed into the cylinder under high pressure.

**Diesel fuel.** A hydrocarbon fuel used in diesel engines.

**Diesel fuel additive.** Material added to diesel fuel to improve its properties.

**Diesel index.** An expression for ignitability of a fuel relative to its aniline point.

$$\text{Diesel index} = \frac{\text{aniline point } (^{\circ}\text{F}) \times \text{API gravity}}{100}$$

**Diffusion.** Spontaneous mixing (as opposed to mixing by mechanical means) of the molecules of two or more fluids, as in the case of gasoline vapor in air and alcohol in water.

**Dike.** An embankment or firewall erected around a storage tank to contain the product if tank leakage or rupture should occur.

**Diluent.** A liquid used to dilute or thin another liquid.

**Direct injection.** An ignition system in which the fuel is injected directly into the cylinder or manifold instead of into a precombustion chamber.

**Direct liquifaction (of coal).** The production of liquid products from coals as the direct result of pyrolysis, hydrogenation or solvent refining.

**Dispersion.** The fairly permanent suspension of finely divided (undissolved) particles in a fluid.

**Dissolved water.** (See water, dissolved.)

**Distillate.** That portion of a liquid which is removed as a vapor and condensed during a distillation process.

**Distillation.** Vaporization of a liquid and its subsequent condensation in a different chamber. In refining, it refers to the separation of one group of petroleum constituents from another by means of volatilization in some form of closed apparatus, such as a still, by the aid of heat. ASTM distillation. Any distillation made in accordance with an ASTM distillation procedure; especially, a distillation test made on such products as gasolines, jet or turbine fuels, and kerosene to determine the initial and final boiling points and the boiling range (ASTM Method D 86).

**Distillation loss.** The difference between the volume of liquid originally introduced into the distilling flask and the sum of the residue and the condensate recovered.

## MIL-HDBK-114

- Doctor test.** A qualitative test used to detect compounds in light petroleum distillates that react with sodium plumbite. The test involves combining two parts of sample and one part doctor solution (sodium plumbite), shaking, adding a pinch of pure dry sulfur, shaking again, and allowing the mixture to settle. If the sulfur film is discolored or flecked with brown or black, the sample is reported positive (or sour); if the sulfur is not discolored, the sample is reported negative (or sweet). (ASTM D 484)
- Drum.** A 16- or 18-gage steel cylindrical container (generally, 55 gallon size) for petroleum products.
- Drum, collapsible.** A 500-gallon collapsible fabric drum. (All other sizes of liquid fuel collapsible containers are considered tanks, not drums.)
- Drum filler.** An apparatus for filling drums automatically to a fixed volume or weight.
- Drum thief.** A metal or plastic tube 3.75 cm (1 1/2 in) in diameter and 75 cm (30 in) long, used to withdraw samples from drums.
- Emergency fuel.** A fuel used when the primary or alternate fuel is not available. The use of this fuel may result in increased maintenance and reduced engine life. (AR-703-1)
- Emulsion.** A suspension or dispersion of fine droplets of one liquid in another. An oil emulsion, a common form emulsion, is oil suspended in water. A water emulsion is water suspended in oil. The lighter the product, the more rapidly emulsions breakdown; the heavier the product, the more persistent emulsions become. An emulsifier or emulsifying agent is a substance used to promote formation of emulsions; demulsifying or demulsification is breaking down emulsions. The emulsifying tendency of lubricating oils is determined by FTM No. 3201-5. The emulsifying tendency of soluble cutting oils is determined by FTM No. 3205.1. The resistance of uninhibited turbine oils to emulsifying (the steam emulsion number) is determined by ASTM D 1401.
- Endothermic.** Heat absorbing (cooling); an endothermic reaction is one in which heat is absorbed, as in the cooling effect of expanding gas (the principle of refrigeration) or in the evaporation of gasoline (resulting in carburetor icing).
- End point (ep).** The point indicating the end of some operation or at which a certain definite change is observed. In titration, this change is frequently a change in the color of an indicator which has been added to the solution, or the disappearance or excess of one of the reactants which is colored. In the distillation of liquids, such as gasoline, the end point is the maximum temperature which occurs during the test.

## MIL-HDBK-114

**Engine deposit.** A general term applicable to any of the following: gum, sludge, carbon, acid, and all other combustion products which the engine produces from fuel and oil. The term also covers the foreign substances which enter and accumulate throughout the inside of the engine.

**Ethane.** A gaseous paraffinic hydrocarbon,  $\text{CH}_3\text{CH}_3$ , occurring in natural gas.

**Ethylene.** A colorless olefinic gas,  $\text{C}_2\text{H}_4$ , with a characteristic sweet odor and taste. The gas is derived from the cracking of petroleum.

**Ethylene glycol.** A colorless, odorless, sweet-tasting dihydric alcohol,  $\text{CH}_2\text{OHCH}_2\text{OH}$ , used as an antifreeze.

**Evaporation.** The conversion of a liquid into vapor, usually by means of heat.

**Evaporation loss.** Evaporation loss is the loss of a liquid volume or weight due to the free evaporation of the liquid usually in a storage tank at atmospheric pressure. It varies with the temperature, the amount of liquid surface exposed, the temperature of vaporation of the lightest components of the liquid, the velocity of air currents over the surface exposed, and the degree of vapor tightness of the tank roof. Since petroleum products are not homogeneous liquids, the rate of evaporation is not constant. The rate of evaporation is greatest at the beginning when the largest percentage of light volatile hydrocabons are present and slowest when evaporation has proceeded so far that only heavy residues are left.

**Evaporation test.** The test applied to volatile petroleum products to determine the completeness or rapidity of evaporation.

**Existent gum test.** (See gum test.)

**Exothermic.** Relating to or designating a reaction which occurs with the evolution of heat, so that the temperature of the reacting bodies is raised; e.g., an exothermic reaction occurs when sulfuric acid is mixed with water.

**Explosive limits.** The limits of percentage composition of mixtures of gases and air within which an explosion takes place when the mixture is ignited. The lower limit of flammability corresponds to the minimum amount of combustible gas and the upper limit to the maximum amount of combustible gas capable of conferring flammability on the mixture. (Also referred to as flammable limits and explosive range.)

**Fahrenheit scale.** A thermometer scale on which the freezing point of water is  $32^\circ$  and the boiling point is  $212^\circ$  (at sea-level atmospheric pressure).

**Federal Test Method Number (FTM No.).** This number refers to the standard test method described in Federal Test Method Standard No. 791 for testing petroleum products when there is no applicable ASTM test method available or standardized.

## MIL-HDBK-114

**Filter.** A porous material on which solid particles are caught and retained when a mixture of liquids and solids is passed through it.

**Filter/separator.** A device used to separate both solid contaminants and water from a petroleum fuel.

**Final boiling point (fbp).** (See end point.)

**Fire point.** The lowest temperature at which, under specified conditions in a standardized apparatus, a petroleum product vaporizes rapidly enough to form an air-vapor mixture above its surface which burns continuously when ignited by a small flame.

**Firewall.** (See dike.)

**Flame arrester.** An assembly of perforated plates or screens enclosed in a case and attached to the breather vent on a petroleum storage tank. The device prevents a flame from entering the tank through the vent.

**Flame propagation.** The spread of the flame in a combustible body from the point at which combustion began.

**Flammable.** A term describing any combustible material which can be ignited easily and which will burn rapidly. Petroleum products which have flashpoints of 26.7° C (81° F), or lower are classed as flammable.

**Flammable limits.** (See explosive limits.)

**Flash point.** The lowest temperature at which vapors arising from a petroleum product will ignite momentarily (i.e., flash) on application of a flame under specified conditions. Laboratory methods for determining flash point are ASTM Method D 56 (for all mobile liquids flashing below 79.4° C), and ASTM Method D 93 (for fuel oils, viscous materials, and suspensions of solids). The Pensky-Martens closed tester is used to determine flashpoint and fire point of oils (ASTM D 93).

**Fractional distillation.** The separation of the components of a liquid mixture by vaporizing and collecting the evaporated fractions, or cuts, which condense in different temperature ranges.

**Free water.** (See water, free.)

**Fuel System Icing Inhibitor (FSII).** An agent to be used only as an anti-icing additive for jet turbine engine fuels.

**Gage.** To measure the contents or capacity, as of a tank.

**Gallon (gal.).** A unit of measure of volume. A U.S. gallon contains 231 cubic inches or 3.785 liters; it is 0.83268 times the imperial gallon. One U.S. gallon of water weighs 8.3374 pounds at 15.6° C (61° F).

## MIL-HDBK-114

Gas. A form of matter. A fixed gas is a substance, natural or manufactured, which exists as a gas under ordinary conditions. The term is often used loosely to refer to a fume or vapor.

Gas detector. An instrument for determining the explosibility of a gas-air mixture; explosimeter.

Gasoline. (See automotive gasoline, aviation gasoline.)

Gas turbine. An engine in which vapor (other than steam) is directed, under pressure, against a series of turbine blades. The energy contained in the rapidly expanding vapors is converted into rotary motion.

Gravity. (See API gravity and specific gravity.)

Grounding. Electrically connecting single or bonded units to a ground rod so that any static potential that might exist or that might be generated will be discharged into the earth. If two or more units are bonded and one is grounded, the whole system is effectively grounded.

Ground products. These refined petroleum products normally intended for use in administrative, combat, and tactical vehicles, materials-handling equipment, special-purpose vehicles, and stationary power and heating equipment.

Gum. Varnish-like, tacky, nonvolatile insoluble deposits formed during the deterioration of petroleum and its products, particularly gasoline. The amount of gummy material in gasoline is known as its gum content, which is determined by ASTM Methods D 381 and D 873. (See gum test.)

Gum test. 1. An analytical method for determining the amount of existing gum in gasoline by evaporating a sample from a glass dish on an elevated-temperature bath with the aid of circulating air. 2. Any gum test carried out in accordance with an ASTM gum test procedure. (ASTM Method D 381 and ASTM Method D 873 are generally used in the United States for determining gum content in motor gasoline.)

Gunk. (See sludge.)

Heavy ends. The highest boiling portion of a petroleum fraction.

Heptane. Normal heptane is a hydrocarbon ( $C_7H_{16}$ ) of the paraffin series with an octane rating of zero. It is used in combination with iso-octane, a paraffin with an octane rating of 100, to determine octane ratings of test fuels.

Horsepower (mechanical). Power is the rate of doing work. One mechanical horsepower equals 33,000 ft.-lbs. per minute or 550 ft.-lbs. per second.

Hot refueling. Refueling a rotary-wing aircraft while its engines are running.

## MIL-HDBK-114

**Hot spot.** An area in the combustion zone of an engine which remains at a higher temperature than the surrounding metal, which can aggravate detonation or preignition.

**Hydrocarbon.** A compound containing only hydrogen and carbon. The simplest hydrocarbons are gases at ordinary temperatures; but with increasing molecular weight, they change to the liquid form and, finally, to the solid state. Hydrocarbons are the principal constituents of petroleum.

**Hydrolysis.** A chemical decomposition in which a compound is broken up and resolved into other compounds by reaction with water. In many cases, it is induced by the presence of small amount of dilute acid or of an enzyme.

**Hydrolytic stability.** Water tolerance of aviation fuels; the interaction of water and aircraft fuels (solubility of water in aviation fuels). (ASTM D 1094.)

**Hydrometer.** A graduated instrument for determining the gravity of liquids. It is usually made of hollow glass and weighted at one end so as to float upright. The depth to which the instrument sinks when immersed in a liquid is determined by the density of that liquid - the lighter the liquid, the lower the instrument sinks. Some hydrometers are marked to read percentage of constituents, or some other property related to gravity. Hydrometers used in measuring petroleum products usually read degrees API or specific gravity.

**Icing.** The solidification of particles of moisture in the fuel system, especially the carburetor, of an aircraft or ground vehicle. The moisture may either be contained in the fuel, or it may enter the system through the air intake. Icing may cause either partial or complete loss of power.

**Ignition.** (See compression ignition.)

**Ignition point.** The point on a temperature scale at which a substance may be ignited to produce combustion.

**Ignition quality.** The ability of a fuel to ignite upon injection into the engine cylinder.

**Ignition temperature.** (See auto-ignition temperature.)

**Ignition quality of diesel fuel.** (See cetane number.)

**Indirect liquefaction (of coal).** The production of liquid products from coals by first converting the coal into synthesis gas (hydrogen and carbon monoxide) and then converting the gas into a hydrocarbon liquid by a catalytic reaction, as in the Fischer-Tropsch process.

**Inhibitor.** A substance naturally occurring or added in small amounts to a petroleum product to prevent or retard undesirable chemical changes from

## MIL-HDBK-114

taking place in the product or in the condition of the equipment in which the product is used. In general, the essential function of inhibitors is to prevent or retard oxidation or corrosion.

**Initial boiling point (IBP).** The temperature at which the first drop of liquid falls from the end of the condenser (ASTM Method D 86).

**Internal-combustion engine.** An engine which operates by means of combustion of a fuel within its cylinders.

**Is-octane.** A colorless, paraffinic liquid,  $C_8H_{18}$ , with a boiling point of  $99^\circ C$  ( $210.2^\circ F$ ) and an arbitrary octane rating of 100. It is used for organic synthesis; in motor fuels; and with normal heptane (zero octane rating), to prepare standard mixtures for use in determining the octane ratings of test fuels.

**Jet engine.** An engine which converts air and fuel into a fast-moving stream of hot gases which effect propulsion of the device of which the engine is a part.

**Jet fuel.** Fuel meeting the required properties for use in jet engines and aircraft turbine engines. Jet fuels are procured for the Armed Forces in several grades

**Kerogen.** The main organic material in oil shale, often used to denote total organic matter in shale oil, consisting primarily of carbon and hydrogen with quantities of sulfur, nitrogen and oxygen, which upon pyrolysis will yield gas, raw shale oil and coke.

**Kerosene.** A refined petroleum distillate used in space heating units, in wick-fed lamps, in bomb-type flares, for cleaning certain machinery and tools, and as a vehicle for liquid insecticide sprays.

**Kinematic viscosity.** The ratio of the absolute viscosity to the density at the temperature of the viscosity measurement. The metric units of kinematic viscosity are the stoke and centistoke, which correspond to the poise and centipoise of absolute viscosity.

**Knock.** Noise associated with internal combustion engines, also called ping. Due to the fact that after the spark ignites the charge it burns smoothly until part of it is burned; then if either the fuel or engine operating conditions are unsuitable the remaining portion burns with a suddenness, thus a knock or ping.

**Knock characteristics.** Methods of test for determining the knocking or detonation characteristics of motor, diesel, and aviation gasoline and the ignition characteristics of diesel fuels. (Motor Method D 2700, Research Method D 2699, performance number of aviation gasoline D 909, and Ignition Quality of Diesel Fuels, Cetane Number D 613).

## MIL-HDBK-114

**Lead.** A general term used to denote tetraethyllead or other organometallic lead antiknock compounds used as gasoline additives.

**Lead acetate test.** A test used to detect the presence of hydrogen sulfide in a sample.

**Leaded gasoline.** Gasoline containing an organometallic lead antiknock compound, such as tetraethyllead.

**Lead poisoning.** Poisoning caused by tetraethyllead or another of the organometallic lead antiknock compounds used as additives in gasoline. It may result from ingestion, absorption through skin, or inhalation of fumes.

**Lead susceptibility.** The ability of gasoline to respond to the addition of an organometallic lead antiknock compound, such as tetraethyllead. This characteristic is measured in terms of increase of antiknock quality per increment of lead.

**Light ends.** The most volatile portions of a hydrocarbon mixture, the low boiling components that boil off first in distillation; opposed to heavy ends.

**Liquefied petroleum gas (LPG).** A mixture of light hydrocarbon material which exists as a gas under normal conditions but which has been converted to a liquid state by increase of pressure or lowering of the temperature. Commercial liquefied gas consists of propane, butane, or a mixture of the two.

**Liter (L).** A metric unit of capacity equal to 0.9081 dry quart (US) or 1.0567 liquid quarts (US).

**Manifold.** A piping arrangement which permits a stream of liquid or gas to be divided into two or more streams, or which permits several streams to be collected into one.

**Mass.** Quantity of matter. Mass remains constant, but the weight of a mass varies with the pull of gravity. Weight equals mass times the pull of gravity.

**Mechanical efficiency.** The indication of the power required to run an engine. It is equal to the power available at the flywheel divided by the actual power developed by the engine cylinders.

**Melting point (m.p.).** The temperature at which a solid substance melts or fuses. The melting points of asphalts, waxes, and paraffins are determined by several methods, especially ASTM Method D 87 (for paraffin wax) and ASTM Method D 127 (for petroleum and microcrystalline wax). ASTM melting point is the temperature at which wax first shows a minimum rate of temperature change; also known as the English melting point.

## MIL-HDBK-114

- Mercaptans.** Sulfur compounds, analogous to alcohols, in which the sulfur has replaced oxygen. The simplest forms have repulsive, garlic-like odors, which become less pronounced with increased molecular weight and higher boiling points. Mercaptides are compounds of metals with mercaptans; lead mercaptides are formed in the sweetening process (ASTM D 1219).
- Methane.** A light, odorless, flammable gas,  $\text{CH}_4$ ; the first member of the paraffin series. It is the principal constituent of natural gas.
- Micron ( ).** One micron is a thousandth part of one millimeter (approximately 24,400 microns equal 1 inch). The average human hair is about 100 microns in diameter.
- Mixture.** The intermingling of two or more substances in which each retains its original properties.
- Molecular weight.** The sum of the atomic weights of the atoms composing a molecule.
- Molecule.** Unit of matter; the smallest particle of an element or compound that retains chemical identity with the substance in mass.
- Motor fuel.** (See automotive gasoline, aviation gasoline, and jet fuel.)
- Motor method.** A test for determining the knock rating, in terms of ASTM motor octane numbers, of fuels for use in spark-ignition engines. The knocking tendency of the fuel under test is compared with knocking tendencies of reference fuels of known octane number (ASTM Method D 2700).
- Naphtha.** A general term applied to refined, partly refined, and unrefined petroleum products and liquid products derived from natural gas which distill chiefly between  $175^\circ \text{C}$  ( $347^\circ \text{F}$ ) and  $237.8^\circ \text{C}$  ( $462^\circ \text{F}$ ).
- Naphthene.** One of a group of cyclic hydrocarbons with the general formula  $\text{C}_n\text{H}_{2n}$ . Naphthenes are also termed cycloparaffins or cycloalkanes.
- Naphthenic crude.** Crude oil with a relatively high percentage of naphthenes.
- Natural gas.** Naturally occurring mixtures of hydrocarbon gases and vapors, the more important of which are methane, ethane, propane, butane, pentane, and hexane.
- Natural gasoline.** A mixture of liquid hydrocarbons extracted from natural gas by various methods and stabilized to obtain a liquid product suitable for blending with refinery gasoline.
- Neutralization number.** Indication of the acidity or alkalinity of an oil; the number is the weight in milligrams of acid (hydrochloric) or base (potassium hydroxide) required to neutralize one gram of oil.

## MIL-HDBK-114

- Normal combustion.** A more or less orderly movement of the flame front across the combustion chamber. The knocking process shows similar flame progress for part of the way but terminates with the sudden ignition of the remainder of the unburned portion of the air-fuel mixture.
- Octane number.** Term used to indicate numerically the relative knock-resistance of a fuel for spark-ignition engines.
- Oil-shale.** A sedimentary rock (generally a marlstone) containing a relatively high (5 to 30 percent) content of kerogen from which shale oil can be produced by pyrolysis.
- Off-specification product.** A product which fails to meet one or more of the physical, chemical, or performance requirements of the specification.
- Olefin.** One of the major series of hydrocarbons that appear chiefly in refinery operations. The substances have the general formula of naphthenes and the chain structures of paraffins, but differ from both in being unsaturated. Molecular structure and nomenclature correspond to paraffins having the same amount of carbon. Ethylene or ethene, is the lowest member of the olefins, and the series is sometimes called the ethylene series for this reason.
- Opalescence.** Milkiness or cloudiness; a term applied to an oil that contains visible wax.
- Open-cup tester.** An instrument used to determine flashpoint. (See flash point.)
- Oxidation.** 1. The process of combining with oxygen, a process which all hydrocarbons are capable of doing. 2. Oxidation characteristics of crankcase lubricating oils include their resistance to oxidation, their bearing corrosion characteristics, and the deposit of contaminants that result from oxidation and other changes as determined by FTM 3402. Oxidation stability of aviation fuels refers to the amount of gum and lead precipitate formed as a result of accelerated oxidation (potential gum), determined by ASTM D 873. Oxidation stability of lubricating greases refers to resistance of greases to change under static conditions for long periods; for example, when applied to antifriction bearings or motor parts, as determined by ASTM D 942.
- Oxygenated fuel.** A class of fuels often produced from non-petroleum sources. These fuels would include both alcohols (methanol, ethanol) and ethers such as methyl tertiary butyl ether.
- Packaged petroleum fuels.** Those fuels that are stored, transported, or issued in containers having a capacity of 55 gallons or less or in 500-gallon collapsible containers.
- Paraffin.** Any of the white, tasteless, odorless, and chemically inert waxy substances composed of saturated hydrocarbons obtained from petroleum.

## MIL-HDBK-114

Pensky-Martens closed-cup tester. (See flash point.)

Performance number (PN). An indication of relative engine performance, the relative knock-free power or output a supercharged aircraft engine can develop. Avgrade 115/145, for example, indicates a rating of 115 at lean mixture and a rating of 145 at rich mixture. The rating of 145 indicates that the engine can develop 145 percent as much knock-free power with the fuel at rich mixture as it could under the same conditions with a fuel having a performance number of 100.

Petrochemical. A contraction of the words "petroleum" and "chemical", originally coined to designate chemicals of petroleum origin. At present, petrochemical is so loosely used and covers such a wide variety of products that it cannot be defined specifically.

Petrol. A British term for petroleum; gasoline.

Petrolatum. A purified mixture of liquid or semisolid hydrocarbons. Jelly-like petrolatum is used as a basis for ointments and as a lubricant of limited application.

Petroleum. Crude oil. Petroleum is a mixture of gaseous, liquid, and semisolid hydrocarbons varying widely in gravity and complexity. Petroleum is capable of being removed as a liquid from underground reservoirs of accumulation, and it is capable of being separated into various fractions by distillation and recovery. Petroleum burner fuels include those fuels burned under boilers or in furnaces for power or heat. Petroleum distillates include the groups of hydrocarbons yielded by distillation, or gasolines, naphthas, kerosenes, gas oils, fuel oils, and lubricating oils. Petroleum gases include butane, propane, natural gas, and manufactured gas. Petroleum lubricants include lubricating oils and greases. Petroleum products is a general term that includes all petroleum fuels, lubricants, and specialties.

Petroleum measurement table. ASTM-IP tables provided for the calculation of quantities of petroleum and its products under the required conditions in any of three systems of measurements. Tables are provided for the reduction of gravity and volume to standard states over normal operating ranges, for calculation of weight-volume relationship, and for inter-conversion of a wide variety of commercially useful units (ASTM D 1250).

Petroleum, oil and lubricants. (See POL.)

Phase. A uniform, physically distinct, and separable part of a mixture containing two or more unlike parts. An example of a three-phase mixture is ice, water, and water vapor. An example of a two-phase mixture is oil suspended in water or water suspended in oil in the form of an emulsion.

pH value. The degree of acidity or alkalinity of a solution on a scale of 1 to 14. Pure water and neutral solutions have a pH value of 7; acid solutions have values less than 7; alkaline solutions have values greater than 7.

## MIL-HDBK-114

**POL.** Petroleum, oil, and lubricants. Included within the meaning of this term are petroleum, fuels, lubricants, hydraulic and insulating oils, temporary protectives, liquid coolants, deicing and antifreeze compounds, together with components and additives of such products.

**Polymerization.** Changing a substance of given molecular weight to another substance with chemical ingredients in the same proportions as in the first, but with a new molecular weight that is a multiple of the first, depending upon how many molecules of the first have been combined. It is a method of changing hydrocarbon gases into high octane gasoline.

**Potential gum.** A determination of the tendency of aviation reciprocating, turbine, and jet engine fuels to form gum and deposits under accelerated aging conditions, when performed in accordance with ASTM Method D 873.

**Pour depressor.** A lubricating oil additive which lowers the pour point of an oil containing a wax by reducing the tendency of the wax to form a solid mass in the oil. Also called pour-point depressor; pour depressant.

**Pour point.** The lowest temperature at which an oil will continue to flow (ASTM D 97).

**Pour test.** The chilling of a liquid under specified conditions to determine the pour point. Observations are generally made over 3° C (5° F) intervals of temperature.

**Pre-ignition.** Premature ignition of the air-fuel mixture in a spark-ignition engine by some means other than the spark. Pre-ignition is often caused by overheated plugs valves or by carbon deposits glowing with heat.

**Pressure.** A force or impulse. Pressure differential is incremental pressure, or the difference between suction and discharge pressure of a pump. Pressure gage is an instrument used to measure and indicate pressure in a fluid. Pressure head is the pressure produced by pump or by the weight of a column of liquid. Pressure lock is a device for gaging a pressure vessel. It consists of a gaging tape and bob housed in a vapor tight assembly with a shutoff valve and mounted on top of the tank. Pressure reducing valve is a diaphragm-operated, spring-loaded pressure regulator used on long downgrade slopes to prevent the buildup of excessive hydrostatic pressures when the line is shut down. Pressure vessel is an enclosed tank or other container in which a pressure greater than atmospheric is maintained. Pressure viscosimeter is the apparatus developed by Esso Research and Engineering for testing greases at elevated temperatures and pressures. Pressure viscosity is the increase in viscosity due to pressure observed in lubricating oils.

**Pressure drop.** The decrease of pressure in pounds per square inch, or head in feet, of a fluid flowing in a piping system from one point to another point downstream from the first point. Pressure drop may be caused by friction, increase of elevation, or increase of velocity.

## MIL-HDBK-114

**Propane.** A gaseous hydrocarbon ( $C_3H_8$ ), present in natural gas and used as a fuel.

**Qualified products list (QPL).** A list prepared by the procuring service of civilian-type or off-the-shelf items that comply with appropriate specifications and have been found to be acceptable to the Government.

**Qualitative test.** A determination of the nature of a compound or substance or the identity of its ingredients.

**Quality surveillance.** The aggregate of measures taken to insure that petroleum products accepted by the Government as being of the required quality are still of the required quality when delivered to the user. Quality surveillance includes watching over and caring for products during all storage and handling operations, adherence to handling methods and procedure designed to protect quality, and examination and testing of products in storage and on change of custody.

**Quantitative test.** A determination of the amount of one or more constituents present in a compound or substance.

**Reaction.** Chemical change that takes place when two or more substances are brought together. Reaction is accompanied by exchange of molecules and formation of other substances.

**Reagent.** A chemical substance capable of causing a reaction with another substance. Each reagent used has a known effect on certain elements and compounds. Qualitative and quantitative tests are performed on unknowns by observing the effects produced by various reagents on them. When a particular effect has been produced by a particular reagent, an effective identification of the unknown has been made.

**Receiving tests.** Tests prescribed by MIL-HDBK-200 as being the means of rapidly supplying enough information on the quality of products received to plan their disposition.

**Reid vapor pressure (RVP).** The measure of pressure exerted by a product on the interior of a special container under specified test conditions due to its tendency to vaporize (ASTM D 323).

**Repeatability.** The quantitative expression of the random error associated with a single operator in a given laboratory obtaining successive results with the same apparatus under constant operating conditions on identical test material.

**Reproducibility.** The quantitative expression of the random error associated with operators working in different laboratories, each obtaining single results on identical test material when applying the same method.

**Residual oil.** Fuel oil that remains after removal of valuable distillates (like gasoline) from petroleum.

## MIL-HDBK-114

Reynolds Number (Re). A dimensionless value equal to velocity in feet per second times diameter in feet times kinematic viscosity in square feet per second.

$$Re = \frac{DV\rho}{\mu}$$

Rust. Ferrous oxide. The product resulting from the oxidation of iron or steel in water or moist air.

Rust preventive. A preservative oil used to provide a waterproof film over iron or steel surfaces exposed to oxidation.

Safe refueling rate. Maximum rates for refueling the different types of wheeled and tracked vehicles for greatest safety. These rates are listed in TB 746-93-1.

Safety equipment set. A standard item provided for the safe cleaning of storage tanks, tank cars and trucks, and tank trailers. The set contains fresh air respirators, centrifugal air blower, rubber boots and gloves, and an explosimeter or gas detector.

Safety valve. Relief valve. An automatic valve used to release pressure above a given setting. The valve is a means of insuring that safe pressures are not exceeded.

Sample. A quantity of product taken as prescribed in ASTM D 4057 for examination and testing. (See specific kind of sample.)

Saturated hydrocarbon. A hydrocarbon of such composition that the valence, or combining power, of all carbon atoms present is fully satisfied. Such a hydrocarbon is a stable substance and does not oxidize readily. The degree of unsaturation is a measure of instability.

Saybolt viscosity. (See viscosity, Saybolt Furol and Universal.)

Scale. 1. A tool or instrument with a series of marks along a line at regulated or graduated distances, used for measuring or computing. 2. A formation of oxide in a flaky film or in thin layers.

Screen. A filter, sieve, or barrier made of meshed wire or perforated metal, intended to remove solid matter from a flow stream or to segregate size of solid matter. The size of matter removed or segregated depends upon the size of mesh or perforations.

Seasonal balancing. Adjusting the volatile components of fuels that affect starting characteristics in an automobile engine to compensate for seasonal temperature changes.

Seconds (as applied to Saybolt Viscosity). The number of seconds required for a given quantity of oil (60 cc) to flow through a standard orifice at

## MIL-HDBK-114

specified temperature (usually 100°, 130°, and 210° F). The Saybolt Furol second (SFS) and Saybolt Universal second (SUS) are measures of viscosity (see viscosity, Saybolt).

**Sediment.** Foreign matter other than water that settles to the bottom of a container.

**Settling time.** The elapsed time that a product remains undisturbed or unagitated between receipt of product into and discharge from storage.

**Shale oil.** The product of in situ or surface retorting of oil shale (raw shale oil); or the product of limited processing of the raw shale oil to remove entrained solids, arsenic compounds, or similar materials without substantial change in the distillation curve of the oil (treated shale oil).

**Siphon.** A tube bent into legs of unequal length and used to transfer liquid from a container at one elevation to a container at a lower elevation. A necessary condition is that the liquid must first be raised in the shorter leg higher than the sidewalls of the first container. The system must first be filled before flow can take place. Flow then begins because the greater weight of liquid in the longer leg overbalances the weight of liquid in the shorter leg. Atmospheric pressure keeps the shorter leg filled and flow continues as long as the inlet is covered.

**Slate.** A report used by the military service for listing requirements of petroleum. The petroleum products written slate is a stock status and planned requirements report compiled monthly by an overseas commander to requisition bulk petroleum products and certain packaged fuels. The petroleum products message slate is an advanced requirements report submitted monthly by electrical transmission by Joint Petroleum Offices and later confirmed by a written slate. There are two types:

**Overseas Bulk Petroleum Slate (Overseas Slate).** The planned 5-month delivery requirements for overseas ports or ocean terminals. It is submitted by Unified Commands (JPO) via AUTODIN to DFSC.

**CONUS Bulk Petroleum Products Slate (CONUS Slate).** The planned 4-month delivery requirements for CONUS tanker discharge ports or ocean terminals. It is prepared by DFSC Field Offices and is normally developed from data submitted by service activities within the area of responsibility of the individual field offices.

**Slop.** Any liquid petroleum product known to be off specification; storage tanks may be reserved for such products while waiting for analysis, reclamation, or other disposition; interfaces not disposed of in the adjacent products, or not fit for such disposition, should be taken off in slop tanks pending disposition.

**Sludge.** A heavy sedimentation or deposit on the bottom of storage tanks consisting of water, dirt, and other settleings; gunk. Crude oils and residuals form the heaviest sludges, and light products form lesser

## MIL-HDBK-114

sludges. Engine sludge is a particular kind of sludge containing products of combustion deposited in internal combustion engines.

Slurry fuel. A mixture of a pulverized combustible solid (such as coal) and a liquid carrier that might either be combustible, as in the case of fuel oil or alcohol, or non-combustible, as in the case of water.

Smoke point. The maximum height in millimeters of the flame of a test lamp at which a jet fuel will burn without smoking (ASTM D 1322).

Soluble. Capable of dissolving or passing into solution; solubility is the extent of being soluble, usually expressed as the weight in grams of substance, the solute, that can be dissolved in 100 milliliters of a solvent to form a solution.

Solution. A uniform mixture of a solute in a solvent from which the solute can be separated by crystallization or other physical means; called a physical solution when no chemical changes take place; otherwise called a chemical solution.

Sour. A term applied to gasolines, naphthas, and refined oils that show a positive doctor test; that is, contain hydrogen sulfide or mercaptans.

Spark ignition engine. An internal combustion engine in which the air-vapor mixture is ignited by a timed spark from a spark plug; contrasted with compression ignition engine (diesel).

Specific gravity (Sp. Gr.). The ratio of the weight of any quantity of matter, a petroleum product for example, to the weight of an equal quantity of water; usually determined by use of a hydrometer. (See API gravity.) The formula for converting degrees API gravity to specific gravity is as follows.

$$\text{Specific gravity} = \frac{141.5}{\text{API} + 131.5}$$

Specific heat. The ratio of the quantity of heat required to raise the temperature of a body 1 degree to that required to raise an equal mass of water 1 degree.

Specification. Prescribed limits of control test used to maintain uniformity of a specific product.

Spontaneous combustion. Self-ignition of combustible materials caused by accumulation of heat through slow oxidation; cannot take place if the heat is dissipated as fast as it is generated.

Spontaneous ignition temperature. (See autogenous ignition temperature.)

Spray. A jet or stream of liquid broken up in small droplets; the first step in forming the air-vapor mixture in a carburetor, a spray being more easily vaporized than a solid stream.

## MIL-HDBK-114

- Stable emulsion.** A suspension of one substance within another that does not separate readily on standing; depending upon whether an emulsion is desired, agents can be added that tend to stabilize the suspension.
- Stability.** Refers to resistance to chemical change in petroleum products, saturated hydrocarbons being more stable than unsaturated. Gum or oxidation stability is the resistance of a gasoline to forming gum in storage due to oxidation.
- Standardization fuels.** Fuels that are highly sensitive to changes in engine operating conditions. Such fuels are not intended for making octane ratings, but only for checking engine operating conditions.
- Standby.** A term for equipment used only in emergencies or on a rotational basis as in the case of pumping units in a pump station, for uniformity of wear and for maintenance purposes.
- Static electricity.** Stationary, electric potential generated by friction between unlike substances and in the atmosphere; contrasted with voltaic or current electricity.
- Straight run gasoline.** Gasoline produced directly from crude oil or from an uncracked distillate by distillation and without cracking.
- Suction.** An effect at atmospheric pressure. Pumps cannot exert a negative force on liquids in the intake line. They can only exhaust or pump out the air from the line, and atmospheric pressure, acting on the source of supply, pushes or lifts liquid up to the pump. The limit of such a lift is the height to which a force of 14.7 pounds per square inch can raise the product. Reciprocating pumps can pump air better than centrifugal pumps, and it is for this reason that centrifugal pumps usually have to be primed or filled with the product to displace the air. Suction pressure should be understood to mean pressure on the suction side of the pump.
- Supercharge method.** A method for determining the knock-limited power, under supercharge rich-mixture conditions, of fuels for use in spark-ignition aircraft engines. It is carried out as prescribed in ASTM D 909. The knock characteristics of the fuels are expressed as octane numbers below 100 and as performance numbers above 100.
- Supercharger.** A compressor of the rotary-vane or centrifugal type used to supply air-vapor mixture to an internal combustion engine at a pressure greater than atmospheric to improve volumetric efficiency; usually driven by the engine itself or by an exhaust as in the gas turbine.
- Surfactant.** A surface active agent which enhances fuel/water emulsification and can interfere with removal of entrained water from fuels.
- Suspension.** Dispersion in a liquid or in a gas of small particles of a solid substance or of small droplets of a liquid. Smoke is a suspension of particles of carbon in gases of combustion; fumes are a suspension of

## MIL-HDBK-114

solid particles in air. Fog is a dense suspension of water droplets in air. Mist is a less dense suspension of water droplets in air. An emulsion is a suspension of oil droplets in water or of water droplets in oil.

Synthetic crude (syncrude). The total liquid hydrocarbon mixture of wide boiling range made by a process which molecularly rearranges a charge stock, such as coal or shale oil and is suitable for use as a feedstock to a conventional refinery.

Synthetic fuel (synfuel). A liquid, gaseous or solid fuel produced by molecularly rearranging a charge material such as coal or oil-shale that is intended to be used as a conventional material such as oil, natural gas, or coal.

Sweet. A term applied to petroleum products that show a negative doctor test; that is, do not contain hydrogen sulfide or mercaptans.

Tank. A storage container for liquid products. Tankage refers to tanks collectively. Tank car is a cylindrical metal tank mounted on a frame and on railway freight car trucks. Tank bottoms are the contents below the suction or drawoff line. Tank or tank car heater is a steam coil on the tank bottom used to reduce viscosity for easy handling of product. Tank farm is a group of storage tanks connected by pipe and manifold. Tank gaging is measurement of innage or outage and observation of temperature and specific gravity to determine volume of contents at 38° C (100° F). Tank truck (or semitrailer) is a tank shell mounted on a chassis for highway travel. Tank and pump unit is an assemblage of small-sized tanks and a dispenser assembly suitable for mounting in a cargo truck.

Tar sand. A mixture in varying proportions of heavy hydrocarbons, sand, clay minerals, water, and naturally-occurring debris (roots, branches, etc.) found in consolidated or unconsolidated state in various parts of the world, e.g., the Athabasca tar sands of Canada and the Asphalt Ridge tar sand of Utah, USA.

Temperature. Degree of heat or cold as measured by thermometer. Temperature centigrade (C) is measured on a scale on which water freezes at 0° and boils at 100°. Temperature Fahrenheit (F) is measured on a scale on which water freezes at 32° and boils at 212°. Temperature measurements are described in ASTM D 1086.

Tetraethyllead (TEL). A volatile lead compound developed to improve antiknock rating of gasoline (ASTM D 526). (See lead susceptibility.)

Tetramethyllead (TML). Another lead compound used for the same purpose as TEL. The new compound is more volatile and has a slower rate of reaction during combustion which makes it more effective than TEL and less is required.

Thermal efficiency. The ratio of work out to the total heat units in the fuel consumed.

- Thermal jet engine.** A power unit in which air is taken in from the atmosphere, heated by combustion of a hydrocarbon, and then exhausted at a greater velocity than that at which it was taken in. (See turbojet engine.)
- Thermal stability.** The resistance to change caused by heat, FTM No. 2503.1 for grease, and FTM No. 346.1 for boiler fuel oil.
- Thermal value.** A caloric value, calories per gram or British thermal units per pound per gallon (ASTM D 240).
- Thermocouple.** An electrical device for measuring temperature. The device consists of two wires of different metals joined together. When the junction is heated, a current is generated and the amount is proportional to the temperature. A thermopile is the same kind of device, but more sensitive, consisting of several dissimilar metals arranged alternately.
- Thinner.** A diluent; a hydrocarbon mixture in the gasoline and kerosene range used as a solvent.
- Titration.** A method of chemical analysis; refers to adding a measured volume of an unknown to a known volume or weight of a standard substance until a change in color is observed. The change indicates the beginning or end of a chemical reaction. The amount of the unknown under test needed to produce this effect can be calculated, and from the result, the quantity or strength of the unknown can be determined.
- Tolerance.** An allowable variation from a specified limit. A blending tolerance, for example, is the greatest percentage of a substance that can be added to a product without putting the product too far off specification.
- Trace.** An amount large enough to be detected, but not to be measured.
- Turbojet engine.** An engine in which air is compressed by a rotating compressor, is heated by fuel combustion at compressor pressure, released through a gas turbine which drives the compressor, and finally ejected at high velocity through the rearward exhaust nozzle.
- Unconventional fuel.** Any fuel that may be used in place of a conventional fuel (for example, any fuel such as alcohol that may be used instead of gasoline in an Otto-cycle engine).
- Unsaturated hydrocarbon.** An unsaturate; a hydrocarbon with a molecular structure containing one or more double or triple links between adjacent carbon members. Olefins and aromatics are the principal groups of such substances. In addition to being unsaturated, these substances are also unstable, and are more capable of undergoing change than the saturates (paraffins and naphthenes). Oxidation is an example of undesirable change in a product.
- Upgrading.** A process or processes for improving the quality of a synfuel.
- Usable inventory.** Inventory contained between non-recoverable tank bottom and current product level (excluding pipeline fill).

## MIL-HDBK-114

**Usable storage capacity.** That part of storage capacity from maximum fill level to, but not including, non-recoverable tank bottoms for tanks currently in service.

**Use limits.** Tolerances established by MIL-HDBK-200 to permit use, under certain conditions, of products that do not fully meet specifications.

**Vacuum.** A space entirely devoid of matter (called specifically "absolute vacuum"); a space, as the interior of a closed vessel, exhausted to some degree by an air pump or other artificial means. (Any vacuum less than absolute is a partial vacuum.) When a pump removes a part of the air from its suction line (creates a partial vacuum), atmospheric pressure lifts fluid up to the intake. The theoretical limit of this lift (in the case of a perfect vacuum), is the height to which the fluid can be lifted by a pressure of 14.7 pounds per square inch (atmospheric pressure at sea level). Usually measured in Torrs (Torrecelly).

**Vapor.** The gas-like form of a substance that is normally a solid or a liquid; any gaseous substance that can be condensed by cooling or compression. Vapor density is the relative weight of a gas or vapor compared with the weight of an equal volume of a standard substance like air or hydrogen. Vapor lock is a condition in a fuel system, or in a pumping system, in which vaporized fuel, or product, is blocking or retarding flow.

**Vent.** An opening in a tank or other container that permits inflow of air during periods of falling temperature or when pumping or pouring from the container; or permit the air and vapor to exit during periods of rising temperature or when filling the container. Some vents have controls that are set to prevent intake of air or release of vapors until the vacuum or pressure reaches a critical point.

**Venturi tube.** Two short sections of pipe of decreasing diameter joined at the small ends by a shorter section of straight pipe called the throat. Its purpose stems from the decreases and velocity of flow increases. The large end of the venturi and the throat are connected by tubing to some form of manometer, permitting pressures to be measured. The device is used to meter volume of flow (venturi meter) or to create suction at the point of maximum velocity.

**Viscosimeter.** Viscometer; a device used to measure viscosity of internal resistance to flow. Examples are Saybolt Universal and Saybolt Furol (ASTM D 88), and Ubbelohde (ASTM D 445).

**Viscosity.** Internal resistance to flow; usually measured as time in seconds for a given quantity of sample to flow through a standard capillary tube. Viscosity index is a means of rating resistance to change in viscosity with change in temperature. Oils of high viscosity index are more resistant to change; oils of low viscosity index thicken quickly when chilled and thin out too much when hot. The following definitions of viscosity are used in petroleum laboratories:

## MIL-HDBK-114

**Viscosity, Absolute.** The force which will move 1 square centimeter of plane surface with a speed of 1 centimeter *per second* relative to another parallel plane surface from which it is separated by a layer of the liquid 1 centimeter thick. This viscosity is expressed in dynes per square centimeter, its unit being the poise, which is equal to 1 dyne-second per square centimeter. A unit of one-hundredth of a poise, designated as a centipoise, is of more convenient magnitude, and is commonly used (see centipoise).

**Viscosity, kinematic.** The kinematic viscosity is defined as the absolute viscosity divided by the density at the temperature of the viscosity measurement. The metric units of kinematic viscosity are the stoke and centistoke, which correspond to the poise and centipoise of absolute viscosity (see centistoke).

**Viscosity, Saybolt Furol.** A viscosity test similar in nature to the Saybolt Universal viscosity test, but one more appropriate for testing high-viscosity oils. Certain transmission and gear oils and heavy fuel oils are rated by this method. The results obtained are approximately one-tenth the viscosity which would be shown by the Saybolt Universal method (see seconds).

**Viscosity, Saybolt Universal.** The time, in seconds, for 60 milliliters of fluid to flow through a capillary tube in a Saybolt viscometer under specified conditions (see seconds).

**Viscous.** Heavy, thick-bodied, gluey, or slow in motion.

**Volatile.** Tending to evaporate or vaporize readily; volatility is the extent to which a liquid vaporizes or the ease with which it turns to vapor.

**Water.** An odorless, colorless, transparent liquid compound  $H_2O$ . Water in fuels is described as follows:

**Water, dissolved.** All fuel will contain water in solution but the amount will vary considerably as the temperature of the fuel varies. A rule-of-thumb estimate of the amount can be made by stating that the water-saturation value of the fuel is equal to PPM (parts per million) by volume to the fuel temperature in degrees Fahrenheit. The percent of dissolved water can only be determined by a laboratory test such as the Karl Fischer analysis. This water cannot be separated from fuel by filtration or by mechanical means.

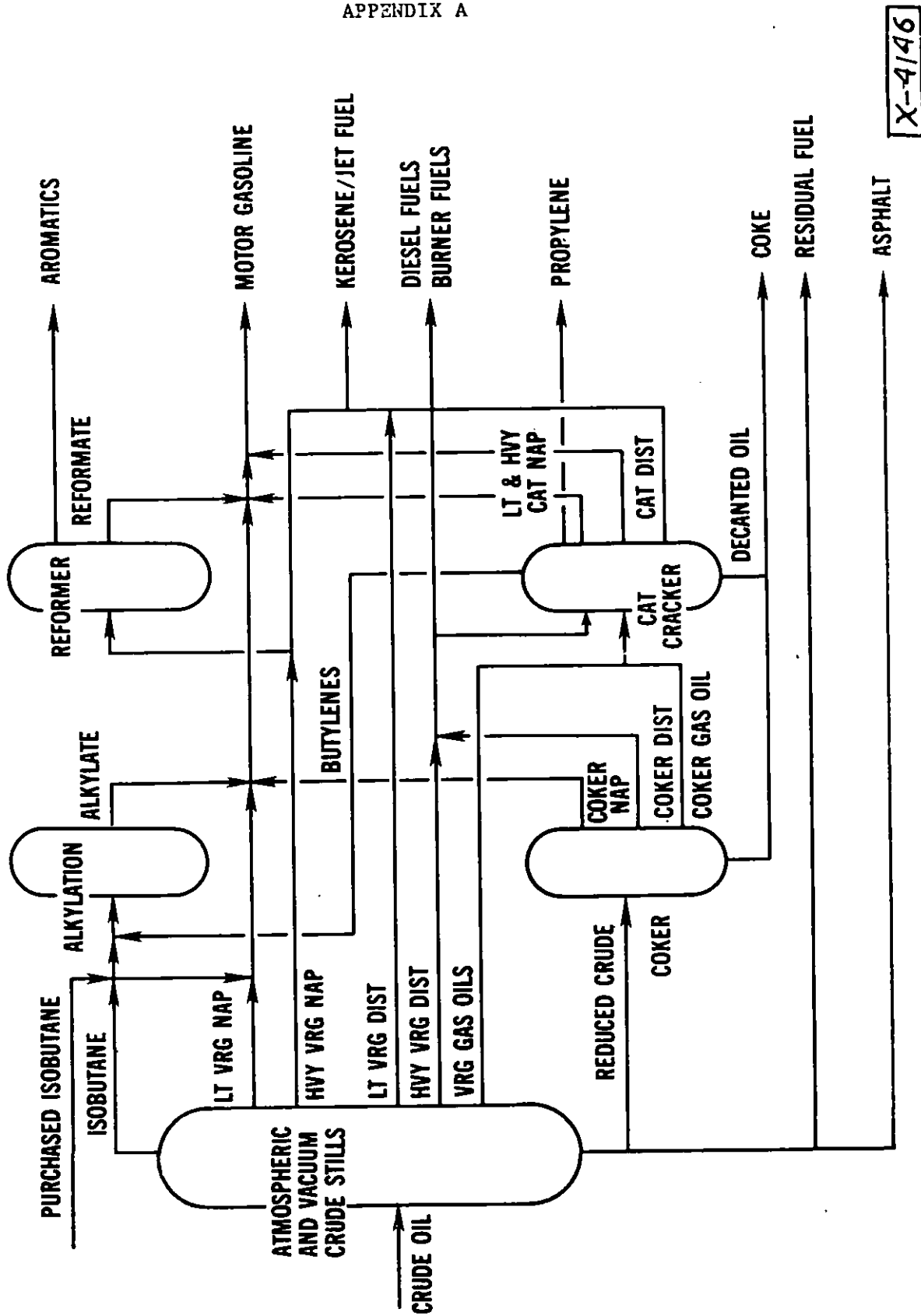
**Water, entrained.** "Free" water which is suspended throughout a fuel sample and has not settled to the bottom of the container is considered "entrained" water.

**Water, free.** All water present in the fuel which has not been dissolved by the fuel is considered "free" water. This water should be separated from fuel by ground servicing equipment.

## MIL-HDBK-114

- Water and sediment.** A test method of determining water and sediment in crude oil and fuel oils by centrifuge (ASTM D 96).
- Water bottom.** Any part of the tank below the suction line left filled with water because of leakage; more generally, that part of the tank occupied by water and sediment.
- Water by distillation.** A test method of determining water in a sample of bituminous material by distillation with a volatile solvent (ASTM D 95).
- Water contamination.** Water present in a fuel in any form; includes dissolved water similar to moisture in the air, entrained water suspended in the form of minute droplets, and free water.
- Water indicating paste.** A preparation which changes color on contact with water and is applied to the innage bob or gaging tape. The purpose of the paste is to aid in measuring quantities of product and water.
- Water-white.** A grade of color in oil; defined as plus 21 or higher in the Saybolt chromometer scale.
- Water-white distillate.** A kerosene cut, or refined oil cut, coming from crude stills, before this distillate is treated or rerun.
- Weak acid.** An acid that ionizes little and yields few hydrogen ions in aqueous solution; for example, acetic acid.
- Weathering.** Loss of the most volatile components of crude oils and light products during storage and handling, and the formation of products of oxidation.
- Wet gas.** A gas that contains a relatively high proportion of hydrocarbons recoverable as liquid products.
- Wetting agent.** A substance added to a liquid to increase its spreading quality on a surface or its penetrating quality in a material. When added to water, the substance makes a more effective fire extinguishing agent.
- Custodians:**  
 Army - ME  
 Navy - SH  
 Air Force - 68
- Preparing activity:**  
 Army - ME  
 Project 9130-0113
- Review activities:**  
 Army - AT  
 Navy - YD
- User activities:**  
 Army - AR, AV  
 Navy - AS, MC

# SIMPLIFIED REFINERY PROCESSING



X-4146

MIL-HDBK-114

APPENDIX B

TYPICAL VALUE AND SPECIFICATION

REQUIREMENTS FOR GASOLINE FUEL

MIL-HDBK-114  
APPENDIX B

TYPICAL INSPECTION PROPERTIES  
OF SUMMER AND WINTER GRADE  
MOTOR GASOLINES\*

<u>Properties</u>	Values	
	<u>Summer</u>	<u>Winter</u>
Distillation, °C(°F)		
Initial boiling point	33(91)	25(77)
10% evaporated	49(120)	41(106)
20% evaporated	62(144)	54(129)
50% evaporated	104(219)	100(212)
90% evaporated	170(338)	169(336)
Endpoint	211(412)	209(408)
Residue, vol%	1.0	1.1
Loss, vol%	1.0	2.4
Temperature at V/L = 20, °C(°F)	57(135)	48(118)
Reid vapor pressure, psi	9.9	13.1
Reid vapor pressure, kPa	68.3	90.4
Gravity, °API	59.2	61.0
Specific gravity, 15/15°C	0.7420	0.7351
Lead, g/l	none	none
Sulfur, wt%	0.031	0.026
Aromatics, vol%	32	29
Olefins, vol%	9	11
Saturates, vol%	59	60
Benzene, vol%	1.13	1.19
Copper corrosion at 50° C (122° F)	1	1
Unwashed gum, mg/100 mL	9.1	6.4
Existent gum, mg/100 mL	1	1
Octane number, research	91.9	91.8
Octane number, motor	83.0	82.9
Antiknock index, (R+M)/2	87.4	87.4

\*Average values from DOE/BETC Motor Gasoline Surveys, Summer 1981 and Winter 1981-1982, and MVMA National Gasoline Surveys, Summer 1981 and Winter 1981-1982.

MIL-HDBK-114  
APPENDIX B

## SUMMARY OF FUEL SPECIFICATION PROPERTIES OF MOTOR AND AVIATION GASOLINES

SPECIFICATION: PRODUCT:	MIL-G-3056	MIL-G-5572	VV-G-1690				
	Type I Motor Gasoline F-46	100/130 Avgas F-18	Class A Gasoline	Class B Gasoline	Class C Gasoline	Class D Gasoline	Class E Gasoline
NATO CODE NO.							
PROPERTIES							
<u>DISTILLATION, °C(°F)</u>							
10% evaporated	50 to 70 (122 to 158)	75 max (167) max	70 max	65 max	60 max	55 max	50 max
40% evaporated	---	75 min (167) min	---	---	---	---	---
50% evaporated	88 to 115 (190 to 239)	105 max (221) max	77-121	77-118	77-116	77-113	77-110
90% evaporated	132 to 180 (270 to 356)	135 max (275) max	190 max	190 max	185 max	185 max	185 max
End point	---	170(338) max	225 max	225 max	225 max	225 max	225 max
Sum of 10 and 50% evaporated temperature	---	153(307) min	---	---	---	---	---
Residue, vol%, max	2	1.5	2	2	2	2	2
Loss, vol%, max	---	---	---	---	---	---	---
TEMPERATURE, °C(°F), min	60(140)	---	60	56	51	47	41
At V/L = 20							
REID VAPOR PRESSURE	7 to 9	5.5. to 7	---	---	---	---	---
psia at 37.8° C (100° F)							
kg/cm <sup>2</sup> at 37.8° C (100° F)	0.49 to 0.63	0.38 to 0.49	---	---	---	---	---
kPa at 37.8° C, max	---	---	62	69	79	93	103

The following requirements apply to all volatility classes.

MIL-HDBK-114  
APPENDIX BSUMMARY OF FUEL SPECIFICATION PROPERTIES OF MOTOR AND AVIATION GASOLINES  
(Continued)

SPECIFICATION: PRODUCT:	MIL-G-3056	MIL-G-5572	VV-G-1690				
	Type I Motor Gasoline F-46	100/130 Avgas F-18	Class A Gasoline ---	Class B Gasoline ---	Class C Gasoline ---	Class D Gasoline ---	Class E Gasoline ---
NATO CODE NO.							
PROPERTIES							
FREEZING POINT, °C, (°F), max	---	-60(-76)					
WATER REACTION							
interface rating, max	---	2					
Vol change, mL, max	---	2					
LEAD, g/L (g/gal), max	0.50(1.88)	0.85(3.22)			1.1 (4.2) for leaded; 0.013 (0.05) for unleaded		
PHOSPHOROUS, g/L (g/gal), max	---	---			0.0013 (0.005) applies to unleaded only		
SULFUR, wt%, max	0.10	0.05			0.15 for leaded; 0.10 for unleaded		
AROMATICS, vol%, min	---	5.0			55 vol% max for limited and regular unleaded grade		
COPPER CORROSION @ 50° C (122° F), max	1	---			1		
COPPER CORROSION @ 100° C (212° F), max	---	1			---		
OXIDATION STABILITY, minutes, min	480	---			240		
WATER & SEDIMENT, vol%, max	0.01	---			0.01		
UNWASHED GUM, mg/100 ml, max	4	---			10		
EXISTENT GUM, mg/100 ml, max	---	3.0			5		
POTENTIAL GUM, mg/100 ml, max	---	6.0			---		
PRECIPITATE, mg/100 ml, max	---	2.0			---		
HEATING VALUE:							
Net heat of combustion							
Btu/lb	---	18,700			---		

SUMMARY OF FUEL SPECIFICATION PROPERTIES OF MOTOR AND AVIATION GASOLINES  
(Continued)

SPECIFICATION: PRODUCT:	MIL-G-3056	MIL-G-5572	VV-G-1690				
	Type I	100/130	Class A	Class B	Class C	Class D	Class E
	Motor Gasoline F-46	Avgas F-18	Gasoline	Gasoline	Gasoline	Gasoline	Gasoline
NATO CODE NO.			---	---	---	---	---
<u>PROPERTIES</u>							
OCTANE NUMBER, research method, min	91.0	---	The octane requirements vary depending on fuel grade and location of fuel use.				
OCTANE NUMBER, motor method, min	83.0	---					
KNOCK VALUE, lean mixture Aviation rating, min	---	100			---		
KNOCK VALUE, rich mixture Supercharge rating, min	---	130			---		
COLOR	Red	Green			---		
BENZENE	---	---			---		Report

MIL-HDBK-114

APPENDIX C

TYPICAL VALUES AND SPECIFICATION REQUIREMENTS  
FOR DIESEL AND BURNER FUEL

MIL-HDBK-114  
APPENDIX C

TYPICAL INSPECTION FOR AUTOMOTIVE DIESEL FUEL

<u>Properties</u>	<u>Values*</u>
Distillation, °C(°F)	
IBP	187(369)
10% recovered	217(423)
50% recovered	263(505)
90% recovered	314(597)
EP	345(653)
Density, kg/L	0.8514
Carbon residue on 10% bottoms, wt%	0.20
Kinematic viscosity at 40°C, cSt	2.65
Cloud point, °C(°F)	-14(7)
Pour point, °C(°F)	-20(-4)
Flash point, °C(°F)	64(147)
Ash, wt%	<0.002
Aromatics, vol%	30
Sulfur, wt%	0.28
Cetane number	47

\*Average for #2 regular diesel fuel, Summer 1981 MVMA Diesel Survey.

MIL-HDBK-114  
APPENDIX C

## SUMMARY OF FUEL SPECIFICATION PROPERTIES OF DIESEL AND DISTILLATE FUELS

SPECIFICATION:	VV-F-800				MIL-F-16884
	DF-A	DF-1	DF-2 CONUS	DF-2 OCONUS	
PRODUCT:	---				NATO F-54
NATO CODE NO.	---				DIESEL FUEL
Properties	---				F-76
DISTILLATION, °C(°F):	---				---
50% evaporated, max	Report	Report	Report	Report	---
90% evaporated, max	288 (550)	288 (550)	338 (640)	357 (675)	357 (675)
End point, max	300 (572)	330 (626)	370 (698)	370 (698)	385 (725)
Residue, % vol, max	---	---	---	---	3
FLASH POINT, °C(°F), min	37.8 (100)	37.8 (100)	51.7 (125)	56 (133)	60 (140)
CLOUD POINT, °C(°F), max	-51 (-60)	1/	1/	2/	-10 (30)
POUR POINT, °C(°F), max	Report	Report	Report	Report	-6 (20)
VISCOSITY @ 40° C (104° F), cSt	1.2 to 2.5	1.4 to 3.0	2.0 to 4.3	---	1.7 - 4.3
VISCOSITY @ 20° C (68° F), cSt	---	---	---	1.8 to 9.5	---
TOTAL ACID NUMBER, mg KOH/g, max	0.05	---	---	0.10	0.30
SULFUR, % wt., max	0.25	0.05	0.05	0.70	1.0
COPPER STRIP CORROSION 3 hrs @ 50° C (122° F), max	3	3	3	1	---
3 hrs @ 100° C (212° F), max	---	---	---	---	1
ASH, % wt., max	0.01	0.01	0.01	0.02	0.005
GRAVITY, API	---	---	---	---	Record
DENSITY at 15° C, kg/L	Report	Report	Report	0.815-0.860	---
ACCELERATED STABILITY, total insolubles, mg/100 ml, max 4/	1.5	1.5	1.5	1.5	1.5
WATER & SEDIMENT, % vol, max	0.01	0.01	0.01	0.01	---
CARBON RESIDUE ON 10% bottoms, % wt., max 5/	0.10	0.15	0.35	0.20	0.2

MIL-HDBK-114  
APPENDIX CSUMMARY OF FUEL SPECIFICATION PROPERTIES OF DIESEL AND DISTILLATE FUELS  
(Continued)

SPECIFICATION: PRODUCT: NATO CODE NO.	VV-F-800			NATO F-54 DIESEL FUEL		MIL-F-16884 F-76
	DF-A ---	DF-1 ---	DF-2 CONUS ---	DF-2 OCONUS F-54	---	
<u>Properties</u>						
<u>PARTICULATE CONTAMINATION</u> mg/L, max	10	10	10	10	10	---
<u>CETANE NUMBER, min</u>	40	45	45	45	45	45
<u>APPEARANCE, visual</u>	clear & bright	clear & bright	clear & bright	clear & bright	clear & bright	clear & bright
<u>COLOR (ASTM D 1500) max</u>	---	---	---	---	5	3
<u>DEMULSIFICATION, minutes</u> max	---	---	---	---	---	10

- 1/ See Appendix A of VV-F-800C for limiting temperature value.
- 2/ DF-2 destined for Europe and S. Korea shall have a maximum limit of 9° F (-13° C). For other OCONUS areas, the maximum limit must be specified by the procuring activity.
- 3/ DF-2 destined for Europe and S. Korea shall have a maximum limit of 0° F (-18° C). For other OCONUS areas, the maximum limit must be specified by the procuring activity.
- 4/ This requirement is applicable only for military bulk deliveries intended for tactical, OCONUS, or long term storage (greater than six months) applications (i.e., Army depots, etc.).
- 5/ See Appendix B of VV-F-800C. The maximum limits do not apply for samples containing cetane improvers. In those instances, the test must be performed on the base fuel blend.

## SUMMARY OF FUEL SPECIFICATION PROPERTIES OF BURNER FUELS

VV-F-815

	1	2	4 (light)	4	5 (light)	5 (heavy)	6
SPECIFICATION:	---	---	---	---	---	---	---
PRODUCT:	---	---	---	---	---	---	---
NATO CODE NO:	---	---	---	---	---	---	---
PROPERTIES	---	---	---	---	---	---	---
DISTILLATION, °C(°F)	215(419)	---	---	---	---	---	---
10% recovered, max	---	282(540) <u>1/</u>	---	---	---	---	---
90% recovered, min	---	338(640) <u>1/</u>	---	---	---	---	---
90% recovered, max	288(550)	---	---	---	---	---	---
FLASH POINT, °C(°F),	38(100)	38(100)	55(131)	55(131)	55(131)	60(140)	---
min	---	---	---	---	---	---	---
POUR POINT, °C(°F),	-18(0) <u>2/</u>	-6(21) <u>2/</u> , <u>3/</u>	-6(21) <u>2/</u> , <u>3/</u>	-6(21) <u>2/</u>	---	---	<u>4/</u>
max	---	---	---	---	---	---	---
VISCOSITY at 38° C	---	---	---	---	---	---	---
(100° F) <u>5/</u>	---	(32.6-37.9)	(32.6-45)	(4.5-12.5)	(12.5-300)	(300-900)	(900-9000)
Saybolt Seconds	---	---	---	---	---	---	---
Universal	---	---	---	---	---	---	---
Kinematic, cSt	---	---	---	---	---	---	---
VISCOSITY at 50° C	---	---	---	---	---	---	---
(122° F) <u>5/</u>	---	2.0-3.6 <u>3/</u>	2.0-5.8	5.8-26.4 <u>6/</u>	26.4-65 <u>6/</u>	65-194 <u>6/</u>	---
Saybolt Seconds Furol	---	---	---	---	---	---	---
Kinematic, cSt	---	---	---	---	---	---	---
Saybolt Seconds	---	---	---	---	---	---	---
Universal	---	---	---	---	---	---	---
VISCOSITY at 29° C	---	---	---	---	---	---	---
(85° F)	---	---	---	---	---	---	---
Saybolt Seconds	---	---	---	---	---	---	---
Universal	---	---	---	---	---	---	---
SULFUR, % wt, max	0.5 <u>7/</u>	1.0 <u>7/</u>	---	---	---	---	---
COPPER STRIP CORROSION	---	---	---	---	---	---	---
3 hrs @ 122°	---	---	---	---	---	---	---
(50° C), max	3	3	---	---	---	---	---
SULFATED ASH, wt%	---	---	0.05	0.10	0.15	0.15	100

MIL-HDBK-114  
APPENDIX C

MIL-HDBK-114  
APPENDIX CSUMMARY OF FUEL SPECIFICATION PROPERTIES OF BURNER FUELS  
(Continued)

SPECIFICATION:	VV-F-815					
	1	2	4 (light)	4	5 (light)	5 (heavy)
PRODUCT:	---	---	---	---	---	---
NATO CODE NO:	---	---	---	---	---	---
PROPERTIES						
SPECIFIC GRAVITY	0.8499	0.8762	0.8762 min	---	---	---
60/60°F max						
GRAVITY, °API, min	35	30	30 max	---	---	---
CARBON RESIDUE on 10%						
bottoms, wt%, max	0.15	0.35	---	---	---	---
neat, wt%, max	---	---	---	---	---	---
WATER BY DISTILLATION,	0.05	0.05	0.05	0.40	0.80	1.50 8/
vol%, max						
SEDIMENT BY EXTRACTION,	0.02	0.02	0.03	0.10	0.20	0.50
wt%, max						
THERMAL STABILITY	---	---	---	---	---	---
EXPLOSIVENESS	---	---	---	---	---	---
HEAT OF COMBUSTION	Report	Report	Report	Report	Report	Report

- 1/ On occasion, it may be impossible to obtain 90 percent distillation values because of cracking. When this occurs, the percent recovery, residue, and loss should be noted.
- 2/ Pour points other than those shown may be specified whenever required by conditions of storage and use, if agreed upon by purchaser and seller. For cold weather use, the pour point should be at or below the 10th percentile minimum temperature (see Appendix 1 of VV-F-815D).
- 3/ When pour point less than -18° C is specified, the minimum viscosity for Grade No. 2 shall be 1.8 cSt and the minimum 90 percent point shall be waived.
- 4/ Where low sulfur fuel oil is required, Grade No. 6 will be classified as low pour (+15° C Max) or high pour (no Max). Low pour fuel oil should be used unless all tanks and line are heated.
- 5/ Viscosity values in parenthesis are for information only and not necessarily limiting.
- 6/ Where low sulfur fuel oil is required, fuel oil falling in the viscosity range of a lower numbered grade down to and including No. 4 may be supplied by agreement between purchaser and supplier. This viscosity range of the initial shipment shall be identified and advance notice shall be required when changing from one viscosity range to another. This notice shall be in sufficient time to permit the user to make the necessary adjustments.

MIL-HDBK-114  
APPENDIX C

SUMMARY OF FUEL SPECIFICATION PROPERTIES OF BURNER FUELS  
(Continued)

- 7/ For all grades of fuel, sulfur limits shall be as specified by the applicable contract, the Environmental Protection Agency, or the state or community where the fuel is to be used, whichever is more restrictive. The values appearing in the table apply outside the U.S.A.
- 8/ A deduction in quantity shall be made for all water and sediment in excess of 1.0%.

MIL-HDBK-114

APPENDIX D

TYPICAL VALUES AND SPECIFICATION  
REQUIREMENTS FOR TURBINE FUEL

MIL-HDBK-114  
APPENDIX D

TYPICAL INSPECTION PROPERTIES

FOR JP-4 AND JP-5 FUELS\*

<u>Properties</u>	Values	
	<u>JP-4</u>	<u>JP-5</u>
Distillation, °C(°F)		
10% recovered	95(203)	196(385)
50% recovered	134(273)	218(424)
90% recovered	200(392)	248(478)
Flash point, °C(°F)	N.A.	63(145)
Vapor pressure, kPa (psi)	17.9(2.6)	N.A.
Water separation index, modified	91	83
Aromatics, vol%	13.5	19.1
Olefins, vol%	0.8	1.1
Mercaptan sulfur, wt%	0.001	0.001
Sulfur, wt%	0.03	0.04
Gravity, °API	53.9	40.1
Density, kg/L	0.7629	0.8242
Thermal stability, pressure drop mn of Hg	2.5	2.5
Existent gum, mg/100 mL	0.6	0.9
Heating value		
Aniline - gravity product	6,802	5,634
Net heat of combustion, MJ/kg	43.479	42.130
Net heat of combustion, Btu/lb	18,692	18,504
Smoke point	26.1	21.4

N.A. = Not applicable

\*Average values not shown in DOE/BETC Aviation Turbine Fuel, 1981, survey.

MIL-HDBK-114  
APPENDIX D

## SUMMARY OF SPECIFICATION PROPERTIES FOR AVIATION TURBINE ENGINE FUELS

SPECIFICATION: PRODUCT: NATO Code No. PROPERTIES	MIL-T-5624		MIL-T-83133
	Grade JP-4 F-40	Grade JP-5 F-44	Grade JP-8 F-34
<u>DISTILLATION TEMPERATURE,</u> °C, D 86 (D 2887 limits in parentheses)			
10% recovered, max temp	---	205(185)	205(186)
20% recovered, max temp	145(130)	---	---
50% recovered, max temp	190(185)	---	---
90% recovered, max temp	245(250)	---	---
End point, max temp	270(320)	290(320)	300(330)
Residue, vol%, max (for D 86)	1.5	1.5	1.5
Loss, vol% max (for D 86)	1.5	1.5	1.5
FLASH POINT, °C (°F), min	---	60(140)	38(100) <u>1/</u>
VAPOR PRESSURE, 37.8° C (100° F), kPa (psi)	14-21 (2.0-3.0)	---	---
FREEZING POINT, °C(°F), max	-58(-72)	-46(-51)	-50(-58)
VISCOSITY, at -20° C, cSt, max	---	8.5	8.0
<u>WATER REACTION</u>			
Interface rating, max	1b	1b	1b
Separation rating, max	---	---	---
<u>WATER SEPARATION INDEX,</u> mod, min	<u>2/</u>	85	<u>2/</u>
TOTAL ACID NO, mg KOH/g, max	0.015	0.015	0.015
AROMATICS, vol%, max	25.0	25.0	25.0
OLEFINS, vol%, max	5.0	5.0	5.0
MERCAPTAN SULFUR, wt%, max	0.001	0.001	0.001
SULFUR, total wt%, max	0.40	0.40	0.3
COPPER STRIP CORROSION, 2 hr at 100° C (212° F) max	1b	1b	1b
DENSITY, kg/L, min (*API, max) at 15° C	0.751(57.0)	0.788(48.0)	0.775(51.0)
DENSITY, kg/L, max (*API, min) at 15° C	0.802(45.0)	0.845(36.0)	0.840(37.0)
<u>THERMAL STABILITY (JFTOT)</u>			
Change in pressure drop, mm of Hg, max	25	25	25
Preheater deposit code, less than	3	3	3
EXISTENT GUM, mg/100 ml, max	7.0	7.0	7.0
PARTICULATE MATTER, mg/L, max	1.0	1.0	1.0
FILTRATION TIME, minutes, max	15	---	---

MIL-HDBK-114  
APPENDIX D

SUMMARY OF SPECIFICATION PROPERTIES FOR AVIATION TURBINE ENGINE FUELS  
(Continued)

SPECIFICATION: PRODUCT: NATO Code No. PROPERTIES	MIL-T-5624		MIL-T-83133
	Grade JP-4 F-40	Grade JP-5 F-44	Grade JP-8 F-34
HEATING VALUE,			
Aniline-gravity product, min or Net heat of combustion	5,250	4,500	---
MJ/kg (Btu/lb), min	42.8(18,400)	42.6(18,300)	42.8(18,400)
Hydrogen content, wt%	13.6	13.5	13.5
min, or			
Smoke point, mm, min, or	20.0	19.0	19
Smoke point, mm, min, and	---	---	---
Naphthalenes, vol%, max	---	---	---
LUMINOMETER NUMBER, min	---	---	---
FUEL SYSTEM ICING INHIBITOR, vol%	0.10-0.15	0.10-0.15	0.10-10.15
FUEL ELECTRICAL CONDUCTIVITY pS/m	200-600	---	200-600

1/ ASTM D 3243 shall be the referee method. Note that D 56 may give results 1.7° C (35° F) above D 3254 results and D 93 may give results 2.7° C (37° F) above D 3243 results.

2/ The minimum water separation index, modified, rating shall be 85 for JP-4 and JP-8 fuels without both the corrosion inhibitor and the electrical conductivity additives present or 70 for fuels containing all required additives except for the electrical conductivity additive.

MIL-HDBK-114

APPENDIX E

SAFETY HAZARDS OFBLENDING DIESEL FUEL AND GASOLINEIntroduction

Blending gasoline into diesel fuel to improve cold weather flow of the diesel fuel can create serious safety hazards due both to the extreme flammability of gasoline itself and the explosive potential of gasoline/diesel fuel mixture. Also, keep in mind that though diesel fuel is relatively safe, contamination of gasoline in diesel fuel will render it more dangerous than gasoline. These dangers were stressed in a recent letter from the American Petroleum Institute (API) to the Fuels and Lubricants Department of the General Motors Research Laboratories. The letter referred to an Oldsmobile "Dealer Information Bulletin" recommending the addition of unleaded gasoline to No. 2 diesel fuel in cold weather emergencies. The API letter pointed out several safety concerns relating to the practice of blending gasoline and diesel fuel. The following discussions are based upon the warnings and recommendations contained in that letter.

Static electricity can ignite gasoline/diesel vapors

While vapors in a gasoline tank are too rich to burn, and those in a diesel tank too lean to burn, a blend of gasoline and diesel fuel can produce vapor concentrations in the vehicle fuel tank that fall within the explosive range at normal ambient temperatures. Subsequent fueling with diesel fuel can build up static charge during the process and cause a spark that could violently ignite the vapors. This phenomenon is essentially the same as that which has been experienced during "switch loading" of tank trucks (i.e., loading a fuel product of different characteristics than that previously contained in the tank). For example, when a tank truck containing vapors from a previous load of gasoline is loaded with a distillate fuel such as No. 2 diesel fuel or kerosene, explosions and fires can occur, due to sparks produced by static electricity generated in the pumping and filtering system.

Other hazards

The presence of an explosive mixture in the fuel tank vapor space can also be a hazard to anyone performing mechanical work on the vehicle fuel system. For example, draining of the fuel tank could result in ignition of the fuel vapor by a spark from tools or a cigarette.

Also, in the event of an accident that causes the fuel tank to rupture, a gasoline/diesel fuel mixture will increase the possibility of explosion or fire.

