Winterizing Diesel Fuel

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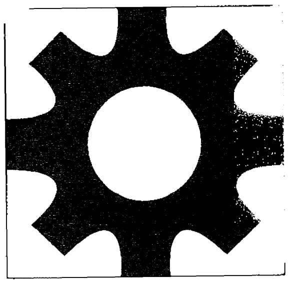

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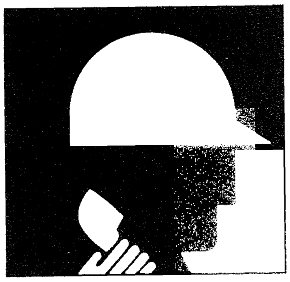

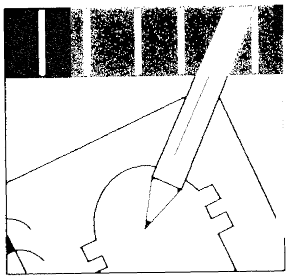

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Preface

In order to assure proper engine operation, diesel fuel must meet or exceed all operational requirements for the system in which it will be used. The properties that define diesel fuel are listed in general specifications.

If fuel is intended for short time usage, some properties become less of a concern when compared to other properties. However, in order to have a suitable amount of fuel available for immediate use, it is often necessary to procure large amounts of fuel and store fuel for long periods of time. When this storage period crosses seasons and extreme temperature changes are experienced, the user must pay closer attention to fuel properties associated with fuel transfer and use.

The supply of fuel is an ever changing commodity. Many production decisions are made based on general use rates and seasonal concerns. The supplier does not produce fuel especially for niche markets unless there is an economic benefit. Since most nuclear power plants typically store fuel from year to year, it becomes the responsibility of the plant to maintain and monitor their diesel fuel to ensure its usefulness under all potential operating conditions.

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1.0 Introduction

There have been several recent situations that have affected diesel fuel usage in the United States. In October 1993, a U.S. Mandate (40CFR80.29) required that all fuel slated for US highway use must have a sulfur content below 0.05% by weight (called Low Sulfur Fuel). This requirement affected primarily No. 1-D and 2-D fuels. This regulation also required that a means be established to differentiate low sulfur from high sulfur fuels because of different tax rates.

Dye is used to differentiate high and low sulfur fuels. The high sulfur fuel should be dyed to identify it for tax purposes. The use of dye has not been thoroughly evaluated for its affects on shipping facilities (e.g., pipe lines), storage tanks, and engines. Also the type of dye has been changed from blue to red.

There have been other changes in fuel blending such as lowering the aromatic content of fuel. The lowering of aromatics and sulfur content has caused concerns that relate to the lubricating capability (lubricity) of certain fuels.

In addition to the aforementioned changes associated with diesel fuel, the winter of 1993-'94 was an especially cold season in the northeast United States. Many users in California and the New England states (New Hampshire in particular) experienced many operability problems with storage and transfer systems. Some engines also experienced performance problems.

The following excerpts describe concerns from two states:

- **California:** Diesel-powered truck and vehicle operators experienced higher than normal incidence of diesel pump failures due to low lubricity diesel fuel, leaky fuel system, and failures due to elastomer shrinkage. Chevron spokesman stated that the problem was smaller than publicized and mostly related to marginal pressure timed and in-line injectors, and more significantly, small engine rotary injectors with most of the problems associated with elastomer failures.

- **New Hampshire:** Low sulfur fuel was initially cited as the cause of diesel fuel gelling during a colder than usual winter. This caused severe, wide spread operability problems for the whole ground transport sector and for home heating systems. At the request of Congressman Zeliff (R-NH), Mobil conducted a study, as a contributing member of the American Petroleum Institute (API). The study focused on diesel fuel in

New England and concluded that there were no substantial differences in the low temperature properties (cloud point, low temperature filtering test, and kerosene blending) between “old” high sulfur diesel fuel and low sulfur diesel fuel. The basic problem was the “lower than expected” winter temperatures. As an example, temperatures in Berlin, NH were below the ASTM 10th percentile minimum for January on fifteen days, and on four days, the actual temperature was 20 degrees Fahrenheit below the ASTM 10th percentile minimum.

If it is not certain that stored fuel will meet the operating requirements under certain cold weather conditions, there have been several methods employed to “winterize” diesel fuel. Winterizing of diesel fuel through the use of fuel additives or fuel blending is a deliberate attempt to make diesel fuel meet low-temperature weather conditions. Winterization of a diesel fuel by a supplier/distributor or user may be necessary to assure that the diesel fuel will flow without clumping or plugging pipes or filters.

Proper cold weather properties are important to the receipt and storage of fuels exposed to outside temperatures. In this discussion, we have assumed that the emergency stand-by electrical generator fuel system including a day tank are inside a climate controlled room and are not exposed to outside temperatures. This note focuses on fuel systems that have partial or complete fuel storage outside with exposed piping, pumps and filter systems (both standard and remedial) that are susceptible to cold weather exposure and should receive special considerations.

This note covers many of the technical as well as practical aspects of fuels, engines, and fuel systems affected by cold weather. Information related to fuel properties including specifications, interpretation of test results and their significance, and planning for sustained operation under all weather conditions are included in this document.

2.0 National Specification for Diesel Fuel (ASTM D 975)

ASTM D 975-93, “Standard Specification for Diesel Fuel Oils,” covers five grades of diesel fuel: No. l-D, No 2-D, No. 4-D, Low Sulfur No. l-D, and Low Sulfur No. 2-D. Property limits called out in the specification include:

- Flash Point
- Water & Sediment
- Distillation
- Kinematic Viscosity
- Ash
- Sulfur
- Copper Strip Corrosion
- Cetane Number
- Cloud Point
- Ramsbottom Carbon on 10% Distillation Residue
- Aromaticity or Cetane Index Limits for Low Sulfur

A footnote of ASTM D975-93 related to cloud point states:

> It is unrealistic to specify low temperature properties that will ensure satisfactory operation at all ambient conditions. However, satisfactory operation should be achieved in most cases if the cloud point (or wax appearance point) is specified at 6°C above the tenth percentile minimum ambient temperature for the area in which ambient temperatures for U.S. locations are shown in Appendix X2 of ASTM D975.

For No. 2-D fuel, the foot note for the minimum distillation temperature of 282°C, for 90% volume recovered, states:

> When a cloud point less than -12°C is specified, the minimum flash point shall be 38°C, the minimum viscosity at 40ºC shall be 1.7 mm^2/s and the minimum 90% recovered temperature shall be waived.

This foot note recognizes the difficulty of making low cloud point No. 2-D diesel without blending low-cloud kerosene (readily available as Aviation Turbine Jet A or Jet A-l).

2.1 Requirements Related to Low-Temperature Operability

Appendix X2 to D 975 covers the "Tenth Percentile Minimum Ambient Temperatures For The United States (Except Hawaii)."

The ambient temperature information is shown on 12 maps and was derived from an analysis of historical hourly temperature readings recorded over a period of 15 to 21 years from 345 weather stations in the United States. The tenth percentile minimum ambient temperature is defined as the lowest temperature that should occur 90% of the time. In other words, there is only a 10% expectation that the minimum daily temperature will be lower than the tenth percentile minimum temperature.

These map temperatures were derived from CCL Report No. 316, published by the U.S. Army. This report is available as Publication No. AD756-420 from the National Technical Information Service. This is the same source for ambient temperatures used in the Federal Specification, W-F-800D, for diesel fuel oil.

In D 975, it is recommended that the cloud point be set at 6°C above the tenth percentile temperature which varies by month over the period September to March. This possibly means that fuel bought in the summer will not have a cloud point as low as September fuel and the fuel bought in September will not be as low as that bought in February. While these temperature data can be used to specify low temperature operability requirements, consideration should be given to factors that may affect low temperature operability such as fuel system design, normal equipment protection for cold weather operation, type of operation, use of fluidity improver additives, area in which the equipment will be used and any unusual weather or operating conditions.

2.2 Comparison to VV-F-800 Low-temperature requirements

In the Federal Specification, VV-F-800D, for diesel fuel oil, the "Tenth Percentile Minimum Ambient Temperatures for Defining Satisfactory Low Temperature Properties of Diesel Fuel" are the same as in D 975, but are given in tables rather than as maps. The tenth percentile minimum temperature values for the United States and Outside the Continental United States (OCONUS) areas are shown in Tables 2.1 and 2.2. Satisfactory operation should be expected in most cases if the cloud point is specified at or below the 10th percentile minimum temperature. As in D 975, this guidance is of a general nature such as some equipment design, use of flow improvers, fuel properties, and type of operating conditions may require higher or lower cloud point fuels.

Table 2.1 - United States 10th Percentile Minimum Temperatures, °C							
State	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March
Alabama	13	4	-3	-6	-7	-3	-2
Alaska:1/							
Northern	-7	-25	-37	-45	-49	-47	-43
Southern	-1	-11	-13	-18	-32	-32	-29
Southeast	1	-4	-11	-16	-19	-13	-12
Arizona							
N 34°LAT	1	-4	-12	-14	-17	-16	-12
s 34°LAT	13	7	0	-2	-4	-3	-1
Arkansas	9	2	-4	-7	-11	-7	-3
California 1/							
N and S Coast	6	4	0	-2	-2	-1	-1
Interior and SE	6	1	-6	-8	-11	-7	-6
Colorado:							
E 105° LONG	4	-2	-12	-14	-19	-15	-12
W105° LONG	-3	-8	-18	-25	-30	-24	-16
Connecticut	4	-1	-7	-16	-17	-16	-9
Delaware	8	2	-3	-10	-11	-10	-6
Florida	17	7	1	-1	-3	-1	4
Georgia	12	3	-2	-6	-7	-6	-2
Idaho	2	-4	-13	-18	-21	-18	-13
Illinois	5	-1	-9	-19	-21	-18	-11
Indiana	6	-1	-7	-16	-18	-16	-9
Iowa	4	-2	-13	-23	-26	-22	-16
Kansas	4	-2	-11	-15	-19	-14	-13
Kentucky	7	1	-6	-13	-14	-11	-6
Louisiana	14	5	-1	-3	-4	-2	1
Maine	1	-3	-10	-23	-26	-26	-18
Maryland	8	2	-3	-10	-12	-10	-4
Massachusetts	3	-2	-7	-16	-18	-17	-10
Michigan	1	-2	-11	-20	-23	-23	-18
Minnesota	-1	-4	-18	-30	-34	-31	-24
Mississippi	13	3	-3	-6	-6	-4	-1
Missouri	8	1	-7	-14	-16	-13	-8
Montana	-1	-7	-18	-24	-30	-24	-21
Nebraska	3	-3	-13	-18	-22	-19	-13
Nevada							
N38 °LAT	-2	-7	-14	-18	-22	-18	-13
S38 °LAT	14	8	0	-3	-4	-2	1
New Hampshire	1	-3	-8	-18	-21	-21	-12
New Jersey	0	2	-3	-11	-12	-11	-6
New Mexico	5	-2	-11	-14	-17	-14	-11
New York	1	-3	-8	-21	-24	-24	-16
North Carolina	6	-1	-7	-10	-11	-9	-5
North Dakota	1	-4	-20	-27	-31	-29	-22
Ohio	4	-1	-7	-16	-17	-15	-9
Oklahoma	9	1	-8	-12	-13	-8	-7
Oregon							
E122° LONG	-1	-6	-11	-14	-19	-21	-9
W122° LONG	4	0	-4	-5	-7	-4	3
Pennsylvania	0	-3	-8	-19	-20	-21	-15
Rhode Island	6	1	-3	-12	-13	-13	-7
South Carolina	15	5	-1	-5	-5	-3	-2
South Dakota	3	-4	-14	-24	-27	-24	-18
Tennessee	7	1	-5	-9	-12	-9	-4

Table 2.1 - (continued) United States 10th Percentile Minimum Temperatures, °C

State	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March
Texas N31° LAT S31° LAT	9 16	3 9	-6 2	-9 -2	-13 -3	-9 -1	-7 2
Utah	4	-2	-11	-14	-18	-14	-8
Vermont	3	-3	-8	-20	-23	-24	-15
Virginia	8	2	-3	-9	-11	-9	-4
Washington E 122° LONG W 122° LONG	2 3	-2 0	-8 -3	-11 -3	-18 -7	-11 -4	-8 -3
West Virginia	3	-3	-8	-11	-16	-11	-8
Wisconsin	2	-3	-14	-24	-28	-24	-18
Wyoming	1	-4	-15	-18	-26	-19	-16

1/ Details of state division are in Table 3 of Appendix A of VV-F-800D.

Table 2.2 - OCONUS 10th Percentile Minimum Temperatures, °C

Country	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March
Austria	-1	-5	-12	-10	-9	-6	-1
Belgium	o	-3	-9	-7	-6	-6	-3
Denmark	-1	-3	-6	-7	-7	-7	-3
France	0	-2	-9	-9	-5	-5	-1
Germany	-2	-5	-13	-13	-12	-9	-5
Greece	5	0	-3	-3	-2	-1	3
Iceland	-1	-5	-7	-9	-7	-7	-4
Italy	1	-3	-6	-8	-7	-3	-1
Korea	1	-6	-13	-20	-15	-7	-1
Luxembourg	1	-3	-7	-7	-6	-4	-2
Netherlands	0	-2	-8	-8	-6	-5	-2
Norway	-6	-14	-16	-18	-18	-16	-6
Portugal	8	4	1	1	1	1	5
Turkey	-1	-6	-10	-16	16	-6	-1
United Kingdom	0	-4	-4	-4	-6	-4	-4

Fuel specified by D 975 will have cloud points that are 6°C higher than fuel specified under VV-F-800D. While both of these specifications indicate that the user will define their own requirements based on equipment, location, etc., the supplier will generally determine the type of fuel that will be available. Thus, it can be very difficult to procure low-cloud fuel in the summer for long-term storage that may need to be used in February. Routine replenishment during the whole year is possible if available fuel will have cloud points well below the system cloud point requirements.

2.3 Other User-Specific Requirements

If a user has specific requirements which demand a fuel cloud point lower than what is available in the local market area, a supplier in another area may be able to provide the fuel or the local fuel can be treated with additives or blended with a fuel having properties such that the blend will meet the user's specifications.

3.0 Low Temperature Properties of Diesel fuel

Middle distillate fuels are composed of hydrocarbon distillate from atmospheric crude oil distillation units and usually other distillate streams such as vacuum gas oil and cracked material. A large quantity of the diesel fuel is paraffinic hydrocarbons which have limited volubility in the fuel and will come out of solution at sufficiently low temperatures. The normal paraffins have freezing points at which wax crystals will form in the fuel. This wax can cause problems in engine fuel systems at low temperatures; thus, a number of wax-related tests have been developed to define at what temperature the following properties may be observed:

- **Cloud Point:** The temperature at which the separation of wax out of solution is first observed.
- **Pour Point:** The temperature at which the amount of wax is sufficient to cause complete gelling of the fuel.
- **Low-Temperature Flow Test:** The temperature at which the amount of wax is considered sufficient to restrict flow in an engine/vehicle fuel system.

3.1 Cold Weather Operability Measurements

Cloud point and pour point are the two primary measures used to assure fuel usefulness under cold weather conditions. These properties have been often debated as to their relative importance. The following discussion will highlight the usefulness of each of these parameters.

3.1.1 ASTM D 2500 Cloud Point Considerations

To determine the cloud point, the sample is cooled at a specified rate and examined periodically. The temperature at which a cloud is first observed at the bottom of the test jar is recorded as the cloud point (reported to the nearest l°C) which is confirmed by continued cooling. A wax cloud or haze is always noted first at the bottom of the test jar where the temperature is lowest. A slight haze throughout the entire sample, which slowly becomes more apparent as the temperature is lowered, is usually due to traces of water in the fuel. Generally this water haze will not interfere with the determination of the wax cloud point. The ASTM D2500 test method provides approaches for removing water from the fuel, if needed.

The cloud point is a guide to the temperature at which the fuel may clog filter systems and restrict flow in small fuel lines. The finer the filter, the more readily it will become plugged by small quantities of precipitated wax.

3.1.2 ASTM D 97 Pour Point Considerations

To determine the pour point, the sample is cooled at a specified rate (after preliminary heating) and examined at intervals of 3°C for flow characteristics. The lowest temperature at which movement of the specimen is observed is recorded as the pour point.

The pour point of a fuel is an indication of the lowest temperature at which the fuel can be pumped. Pour points often occur 4.5 to 5.5°C below cloud points, and differences of 8 to ll°C are not uncommon.

The following statement fairly summarizes the relationship between cloud point and pour point and how each relates to fuel operability or usefulness:

> **No wax precipitation problems are encountered at temperatures above the cloud point and satisfactory operation is unlikely at temperatures below the pour point.**

3.1.3 ASTM D 4539 Low Temperature Filter Plugging Test (LTFT) Related to Operability

The temperature level between the cloud point and the pour point at which trouble-free operation is just possible is a function of the design and layout of the fuel system. A system that contains exposed lines and filters in cold locations will be more prone to early failure than a system in which the lines are unrestricted and sheltered with all fine filters located in heated areas. Attempts to develop suitable flow tests have been only moderately successful due primarily to the limited amount of firm field operability data. Consequently, there has been a great reluctance to depart from the known and accepted cloud and pour-point tests as the major low-temperature performance criteria.

Nevertheless, low-temperature operability tests based on the plugging of cold filters have now been accepted by France (AFNOR-549), Germany (DIN0051 770), and Sweden (S1S 155 122). ASTM has also standardized such a test, Test Method for Filterability of Diesel Fuels by the Low Temperature Flow Test (LTFT) Method (D 4539).

In the LTFT test, the temperature of a series of samples of test fuel is lowered at a controlled cooling rate. Commencing at a desired test temperature and at l°C interval thereafter, a separate sample from the series is filtered through a 17-micrometers screen until a minimum LTFT pass temperature is obtained. The minimum LTFT pass temperature is the lowest temperature, (expressed as a multiple of l°C) at which a minimum of 180 ml of sample, when cooled under the prescribed conditions, can be filtered in 60 seconds or less. An alternative is to use a single sample cooled as before but tested at a specified temperature to determine whether it passes or fails at that temperature.

The LTFT results are indicative of the low temperature flow performance of the test fuel in some diesel vehicles (per Coordinating Research Council Report No. 528). The test method is especially useful for the evaluation of fuels containing flow improver additives.

3.1.4 Cold Filter Plugging Point (CFPP)

Cold Filter Plugging Point (IP 309) is a test that has become widely accepted in Europe and other temperate regions of the world, but does not correlate well with fuels in North American equipment. The CFPP test was developed in the U.K. It uses the same concept as the LTFT test by requiring a quantity of chilled fuel to pass through a fine mesh screen within a short period of time, but detail features are different. The CFPP test measures the lowest temperature at which 20 ml of fuel will pass through a fine wire mesh screen of 45 micrometers nominal aperture in less than 60 seconds.

3.2 Cold-Weather operability Considerations for Diesel Powered Generators

In this discussion, we have assumed that the emergency stand-by generator engine fuel system, including a day tank, are inside a climate controlled room and are not exposed to outside temperatures. Cold weather considerations become an important operability consideration when the bulk of seven day fuel oil supply is in a tank with fill lines, filters, screens, and piping that are exposed to cold temperatures.

Engine Fuel System components including duplex filters are usually kept between room temperature and the engine oil system temperature of 100°F (38°C). When operating, the fuel system experiences a range of temperatures, which are expected to approach or exceed 100°F (38°C), including the day tank that receives hot return fuel from the fuel injectors.

Fuel Storage Systems can vary from buried tanks to unsheltered above-ground tanks with various degrees of exposure to outside conditions. Some systems have inlet screens with/without outlet filters. These filters can be simple paper filters or tight filter/coalescer separators. Pumps are usually located between the tank and filter systems.

Heat tracing and/or in-line heaters can be used to keep the fuel above the cloud point. Avoid over-heating the fuel as this will hasten fuel oxidation. This extra heat can also provide an environment that may stimulate microbial growth under normal operating conditions. The heated metal surfaces in contact with the fuel should not contain copper or other catalytic material that could speed up fuel autoxidation.

API above ground storage tank design guidelines include insulating and/or heating of fuel tanks, piping, and filter systems. Fuel stability and cleanliness considerations are addressed in the appendix of D 975.

4.0 Methods for Fuel Winterization

Care must be exercised when winterizing diesel fuel by additives or fuel blending. Fuel properties must remain within specification even when the engine is not experiencing cold weather conditions. Certain important properties such as cetane number, viscosity, lubricity, distillation, and flash point must be maintained. However, there are certain additives that have been developed to improve fuel cold weather usefulness.

4.1 Additives

The application of additives to improve the cold flow properties of middle distillate fuels dates from around 1960, after the development of a pour point depressant for domestic heating oil. The selection of additives available at the present time has evolved from pour point depressants to include filterability or flow improvers, cloud point depressants, and additives which lessen the tendency for wax crystals to settle in the fuel. Additives that improve low-temperature properties are generally known as wax crystal modifiers.

4.1.2 Pour Point Depressants

Pour point depressants work by interacting with the waxes in the middle distillate fuel to modify their size and shape, making them more compact and less able to form interlocking structures that would prevent fuel from flowing.

One of the first applications for a fuel pour point depressant was for domestic heating oils in Canada, where the severe winter climate caused problems in the distribution and use of stove oil. Pour point depressants are still used in countries where pour point is the low-temperature specification. Usually it is easy to modify wax crystals and achieve a substantial pour point depression.

Diesel vehicle road tests in North America and Europe during the 1960s also confirmed the additive's effectiveness in lowering the minimum temperature at which satisfactory operation was possible.

Unfortunately, the improvement in vehicle operability was smaller than that indicated by the reduction in pour point and a more satisfactory predictive test method was required. The development of such a test resulted in the Cold Filter Plugging Point (CFPP) and other similar flow tests.

Due to the presence of the additive molecules, modified wax crystals are also less prone to attach themselves to each other and form agglomerates that could restrict the flow of liquid fuel through the lines and filters in vehicle systems. Modified wax crystals are able to pass the fairly coarse prefilters and strainers that are fitted to hold back large items of foreign material but they are too large to go through the main filter (typically made of paper, felt or cloth) protecting the closely machined clearances of the fuel injection equipment. Because of the shape of the modified crystals, the wax layer on the filter remains permeable, allowing liquid fuel to pass through; whereas, the large unmodified platelet crystals readily interlock, making a structure that will impede flow through the waxy layer on the main filter or even the coarse, woven mesh strainers.

As for most additives, flow improvers are subject to the law of diminishing returns. The CFPP improvement decreases as the treat rate is raised, effectively reducing its cost-effectiveness.

4.1.3 Cloud Point Depressants

Cloud point depressants are another type of wax-modifying additive developed for use in distillate fuels. Producing a diesel fuel with satisfactory properties for winter use is a major constraint on a refiner. Before flow improvers were used, winter quality was achieved by blending fuels to obtain a lower cloud point. This improved the low-temperature characteristics by eliminating some of the heavier distillate components but it also reduced the amount of fuel produced. This is the reason why most diesel fuel specifications generally allow seasonal cold property grades.

Previously it was considered impossible for a small amount of a chemical additive to influence the wax volubility of a diesel fuel to sufficiently affect cloud point. However, close studies into the effect of wax modifiers have shown that some olefin-ester copolymers appear capable of suppressing wax crystallization by a few degrees.

The amount of cloud point depression obtainable, even with high treat rates, is relatively small (rarely exceeding 3 or 4°C), whereas flow improver additives provide CFPP improvements two or three times greater at much lower treatment levels.

4.1.4 Wax Antisettling Additives

The wax crystals formed in a flow-improved fuel are smaller and more compact than the normal platelet crystals of an untreated fuel, and they have a greater tendency to settle to the bottom of the fuel tank. This is not a new phenomenon. Wax settling has been observed since flow improvers have been in use.

Additives that inhibit the wax settling tendency are being used routinely by some refiners and are also available for secondary treatment of finished fuels.

Treatment levels are similar to those for flow improvers (in the range of 100 to 500 ppm).

4.2 Fuel Blending

If Grade 1-D is available during winter months, it is often blended with stored 2-D fuel. If 1-D is not available, but the 2-D is not of high enough winter quality, blending with kerosene jet fuels may be an acceptable approach. Other types of fuels can be considered for blending such as No. 1 heating oil, kerosene, or jet fuel. Only kerosene-type jet fuel should be used (Grades Jet A, Jet A-1, or JP-5 and JP-8). Naphtha-type jet fuels must be avoided (Grades Jet B or JP-4) because they would reduce the flash point and cause a hazard in storage and handling. They would also reduce cetane number (CN) drastically.

The calculations for blend properties are the same for either 1-D or kerosene blending. The following examples will focus primarily on the mixing of 1-D into 2-D fuel. The use of other fuel types is also discussed in limited detail.

4.2.1 Typical Fuel Properties

To assure that the fuel will meet a defined quality, it is necessary to consider key fuel properties that define a particular grade of fuel. These properties will provide some indication that the fuel will meet engine operating requirements.

Cetane Index

The cetane index of a blend can be estimated by adding proportionally by volume the calculated cetane index of the individual components, however, a more accurate value can be obtained by calculation based on the API gravity and the 50% off temperature of the blend. While the D 976 calculated cetane indices of fuels and blends are not a reliable prediction of cetane number, those predicted by proportionate addition of indices may serve as a conservative guess. In VV-F- 800D, when cetane index is used in lieu of cetane number (which has a minimum of 40) the minimum cetane index shall be 43.

Cetane Number

The cetane number (CN) of a blend may be estimated by plotting the cetane number (when known) of each component linearly by volume, or by Eq. 2 in section 4.2.3. It is not normal practice to determine cetane numbers on turbine or burner fuels since the specifications for these fuels do not require cetane number.

API Gravity and Specific Gravity

The specific gravity of a blend may be estimated by plotting each quantity linearly by volume. The relationship between API gravity and specific gravity scales is non-linear, thus API gravity must be calculated by Eq. 5 in section 4.2.3.

50-Percent Distillation Temperature

The 50-percent distillation temperature of a blend of two fuels of similar boiling range can be approximated by multiplying the 50% off temperatures by the quantity of each blending component. An example is 1-D fuel with 50% off at 410°F (210°C) and a 2-D fuel with 50% off at 483°F (251°C). If the two are blended to 40% of 1-D and 60% of 2-D, the 50% off temperature for the blend will be 454°F (234°C).

Viscosity and Lubricity

Experience with JP-8 (Jet A-1 plus required additives) used in military ground equipment suggests that pressure timed and in-line injection equipment can operate adequately with these lower viscosity fuels These injectors appear to be more tolerable than rotary injectors when exposed to low viscosity and lubricity fuels.

Lubricity

Lubricity, sometimes referred to as film strength, is the ability of a liquid to lubricate.

Poor lubricity is often associated with low-viscosity fuel. In some areas where the climate necessitates the supply of a kerosene-type fuel as winter-grade diesel, a lubricity agent is sometimes added to the fuel to limit wear in the injection equipment.

At present lubricity is included in only one diesel fuel specification, draft VV-F-800E, since it is considered that some injection equipment may be at risk if operated on fuels of low viscosity or of non petroleum origin. The Scuffing Load Test was developed by the US Army to measure fuel lubricity. This test is currently being considered for ASTM standardization.

4.2.2 The Influence of Viscosity on Engine Performance

Viscosity is an important property of a diesel fuel because of its affect on fuel injector performance, particularly at low temperatures. At low temperatures, the increase in viscosity affects the fluidity of the fuel. The viscosity must also be high enough to avoid engine-starting difficulties at high temperatures.

Diesel specifications usually impose an upper limit on viscosity to ensure that the fuel will flow readily during cold starting. An additional minimum limit is often specified to avoid possibile power loss at high temperatures.

The viscosity range allowed in British specification for automotive diesel fuel (BS 2869) is 2.5 to 5.0 cSt at 104°F (40°C). The cold and hot start up risk points for the UK climate as defined by Lucas Diesel Systems, an injector manufacturer, are 47 cSt at -4°F (-20°C) and 1.6 cSt at 158°F (70°C), the estimated pump temperature during operation in UK winter and summer ambient conditions, respectively. The British specification has been revised and the changes included a tightening of the viscosity tolerance band by lowering the upper limit and raising the lower limit, effectively bringing them into line with the two risk-point recommendations.

Kinematic Viscosity

The viscosity of a blend may be predicated using the viscosity-blending chart shown in Figure 4.4. This chart is based on the 0-100°F (-18-38°C) portion of the temperature scale found in the ASTM Viscosity-Temperature chart, ASTM D 341 Chart V; however, the intervals on the abscissa, which on the ASTM chart become smaller as the temperature increases from O to 100°F, have been modified to be equal for blending estimates. The viscosity at constant temperature versus component percentage may be graphically illustrated for a binary blend. For convenience, the higher viscosity is marked at the 100 abscissa, the lower viscosity marked at the 0 abscissa, and a straight line drawn to connect these two points. The viscosity of any blend of these two components is read on this line at the point representing the volume percent of the high viscosity component. Other techniques for blending petroleum fractions to a given viscosity have been published and utilized successfully.

4.2.3 Blending 1-D and 2-D Fuels

Grade 2-D diesel fuel is normally lower in cost than 1-D fuel. Readily available 2-D fuels may be available with superior properties, although smoke emissions are usually worse. Many operators are using, or have considered, blends of the two grades. Before deciding on a blend, it is worthwhile to obtain information on the properties it will have. Several blended fuel properties can be calculated from the properties of the individual components. Other properties require laboratory measurements. The properties can be classified into three groups depending on the methods used for determining the blend properties:

1. **Linear properties,** where the final blend property lies on a straight line between the properties of the two components. Specific gravity is a

linear property. The cetane index can be approximated by this method, but to be consistent with other blend properties and accurate, it should be recalculated using the blend API gravity and 50% boiling point.

2. **Nonlinear properties,** where the properties of a blend are between the properties of the two components, but lie on a curved line. One solution is to generate the curve with laboratory data. The other approach is to use a correlation or blending index to change the curve to a straight line. Examples are viscosity, flash point, cloud point, and pour point.

3. **Empirical properties,** where the result should be determined in the laboratory. This would occur when information is lacking on one or both components, or when there is no reliable correlation or method of calculation, an example of which is corrosion. The distillation curve (except 50% point) and Cetane number (especially when cetane improver is in one of the components) are in this group and should be measured by laboratory tests. In petroleum based fuels of very similar properties, CN is almost a linear property.

An example of calculated blend properties is given in Table 4.1, using a low-cetane 1-D fuel and a higher cetane 2-D fuel. The blend properties were calculated for 40 percent 1-D fuel and 60 percent 2-D fuel based on volume. Details of the calculations and the necessary graphs are presented later.

The calculated properties indicate several effects that are typical of 1-D and 2-D blends:

- Relative to the 1-D fuel, the blend has slightly higher specific gravity and heat of combustion. This is in the direction of improving fuel economy, but the difference is very small.

- If the flash points of both blend stocks are above the minimum requirement, the blend flash point will also be above the minimum, but it will be slightly lower than what a straight-line approximation would indicate. In this case, the difference was two degrees.

- Compared to the 1-D fuel, the blend has poorer low-temperature properties. The 1-D fuel would allow operation down to -25°F (-32°C). The blend cloud point is 3°F (-16°C). Temperatures of 0°F (-18°C) and colder could cause fuel filter plugging. The blended fuel would be usable in locations or seasons when moderate temperatures are expected.

- The sulfur content is more than four times as high but is still within acceptable levels at 0.087 weight percent.

- The carbon residue shows a slight decrease in the blend, which is unusually low to begin with in the 2-D fuel. In this case the carbon residue of the 2-D was lower than the l-D; both fuels were low relative to the ASTM specification.

- The effect on smoke emissions cannot be readily predicted from the blend properties. The boiling range will be higher, which may increase smoke. The carbon residue is lower and cetane index (CI) is higher, both of which tend to decrease smoke.

- The CI of the blend indicates better ignition properties than for the 1-D fuel. It should be noted that the CI of the 2-D fuel was two numbers higher than the CN. If a similar relationship holds in the blend, the actual improvement in ignition properties may not be quite as good as indicated by the CI. A cetane engine measurement would be desirable to confirm the estimate, but even two units below the CI would be acceptable at a value of 44.5. The estimated CN is 44.8.

Table 4.1
Blending Calculation Example for a 1-D and 2-D Diesel Fuel Blend

Requirement	Diesel Fuel Grade		
	1-D	2-D	Blend
Composition, Vol % No. 1-D No. 2-D	 100 0	 0 100	 40 60
Gravity, *API	41.4	38.3	39.5
Specific Gravity;y. 60° F	0.8184	0.8333	0.8273
Density, lb/gal, 60° F	6.816	6.940	6.890
Flash Pint, °F	132	148	140
Cloud Point, °F	-26	+12	+3
Pour Point, °F	-35	-5	-14
Sulfur, wt%	0.021	0.130	0.087
Carbon residue on 10%A bottoms, wt%	0.06	0.044	0.050
Cetane number	41.5	47.0	44.8*
Cetane index	41.2	49.0	46.5
Distillation, °F IBF 10% 50% 90% EP	 344 372 410 456 524	 372 414 483 588 632	 * * 454 *
Viscosity @ 40°C, cST	1.6	3.4	2.45
Gross Heat of Combustion, Btu/gal	134,880	136,580	135,900
*Laboratory measurement is required			

Calculation Methods

Some blend properties are calculated on a weight basis, whereas others are calculated on a volume basis. In the example used in Table 4.1, the blend was specified as 40 percent 1-D and 60 percent 2-D by volume, so it was necessary to calculate the weight fractions.

Specific gravity at 60°F (16°C) is calculated from the API gravity with Eq.1:

$$SG = 141.5/(131.5 + G) \qquad \text{Eq. 1}$$

where:

SG = specific gravity at 60°F (16°C) (g/ml)

G = API gravity

For the 1-D fuel, the **specific gravity** is: SG = 141.5/(131.5 + 41.4) = 0.8184 g/ml. Similarly, the 2-D fuel's calculated specific gravity is 0.8333 g/ml.

The blend specific gravity is calculated on a volume basis using Eq. 2:

$$V_1 P_1 + V_2 P_2 = P_B \qquad \text{Eq. 2}$$

where:

V = Volume fraction

P= Property

Subscripts 1 and 2 refer to the components and B refers to the blend. If blending more than two components, Eq. 2 and Eq. 3 can be generalized to include all the components. The blend specific gravity using Eq. 2 is: SG_B = (0.4)(0.8184 + (0.6)(0.8333) = 0.8273.

The weight fraction is given by Eq. 3:

$$W = V\,(SG/SG_B) \qquad \text{Eq. 3}$$

Using Eq. 3, the **weight fraction** of 1-D fuel is: W = (0.4)(0.8184/0.8273) = 0.3957. Similarly, the weight fraction of the 2-D fuel is 0.6043.

The blend properties, which are calculated on a weight basis, can now be obtained with Eq. 4:

$$W_1P_1 + W_2P_2 = P_B \qquad \textit{Eq. } 4$$

where:

W = Weight fraction

P = Property

The subscripts have the same meaning as in Eq. 2. For example, the **sulfur** content is calculated as follows: **Sulfur in blend = (0.3957)(0.021) + (0.6043)(0.130) = 0.087 wt%.**

To calculate the blend cetane index, it is necessary to calculate the blend API gravity and the blend 50 percent distillation point. The API gravity is given by Eq. 5:

$$G = (141.5 - 131.5xSG)/SG \qquad \text{Eq. } 5$$

Using Eq. D-5, the **API gravity** is: G = (141.5 - 131.5x0.8273)/0.8273 = 39.5API. The 50% boiling point is calculated volumetrically, so Eq. 2 is used: 50% boiling point = (0.4)(410) + (0.6)(483) = 453.8°F. The **cetane index** can now be calculated using the D 976 equation:

$$CI = -420.34 + 0.016(API)^2 + 0.192(API)\log 50\%\text{off } °F + 65.0l(\log 50\%\text{off } °F)^2 - 0.0001809(50\%\text{off } °F)^2$$

$$CI = -420.34 + 0.016(39.5)^2 + 0.192(39.5)\log 453.8 + 65.0l(\log 453.8)^2 - 0.0001809(453.8)^2$$

$$CI = -420.34 + 25.01 + 20.15 + 458.90 - 37.25$$

$$CI = 46.5$$

The heat of combustion and some other properties are sometimes given on either weight or volume basis. They can be converted from one to the other using the **density in pounds per gallon, which is 8.328 times the specific gravity.**

The cloud point, pour point, and flash points do not blend linearly. A graph is used to obtain index values, which do blend linearly on a volume basis. Eq. 2 is then used to obtain the blend index; then the graph is used again to obtain the blend value. Figures 1, 2, and 3, which are based on the work of Hu and Burns ("Predicting Pour, Cloud, and Flash Points of Distillate Blends," Paper No. WR-70-67 National Petroleum Refiners Association Western Regional

Meeting, Salt Lake City, September 22, 1970), provided blend index curves for cloud point, pour point, and flash point, respectively.

The cloud point of the 1-D fuel in the blending example was -26°F (-32°C). Using Fig. 1 gives the index value of 1.5. Similarly, the 2-D, which has a cloud point of 12°F, has a cloud point index value of 8.2. Eq. 2 yields a blend cloud point index = (0.4)(1.5) + (0.6)(8.2) = 5.5. This index value is now used in Fig. 1 to fmd the corresponding cloud point, which is 3 .0°F for the blend.

The same procedure is used for the pour point and the flash point. Table 4.2 gives example index values obtained in using Figs. 4.2 & 4.3, respectively, along with Eq. 2.

TABLE 4.2
Example of Intermediate Results in Calculating a Blend Pour Point

	1-D Fuel	2-D Fuel	Blend
Composition, vol% 1-D fuel 2-D fuel	100 0	0 100	40 60
Component pour points, °F Pour point index Blend pour point, F	-35 1.3 NA	-5 3.1 NA	NA 2.4 -14
Component flash points, °F Flash point index Blend flash point, °F	132 15.0 NA	148 9.5 NA	NA 11.7 140
NA = Not Applicable			

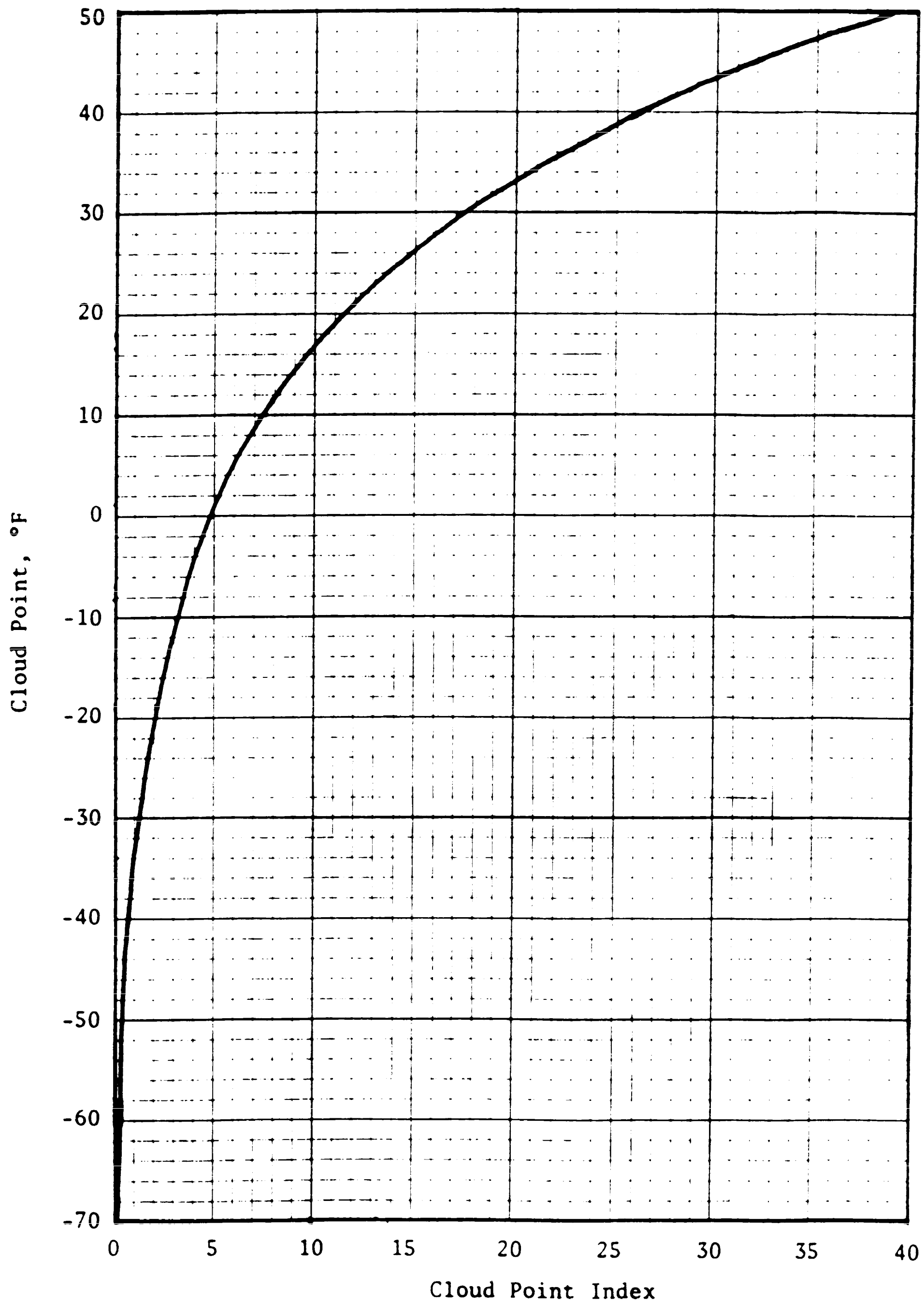

Figure 4-1
Graph of Cloud Point Index for Blend Calculations

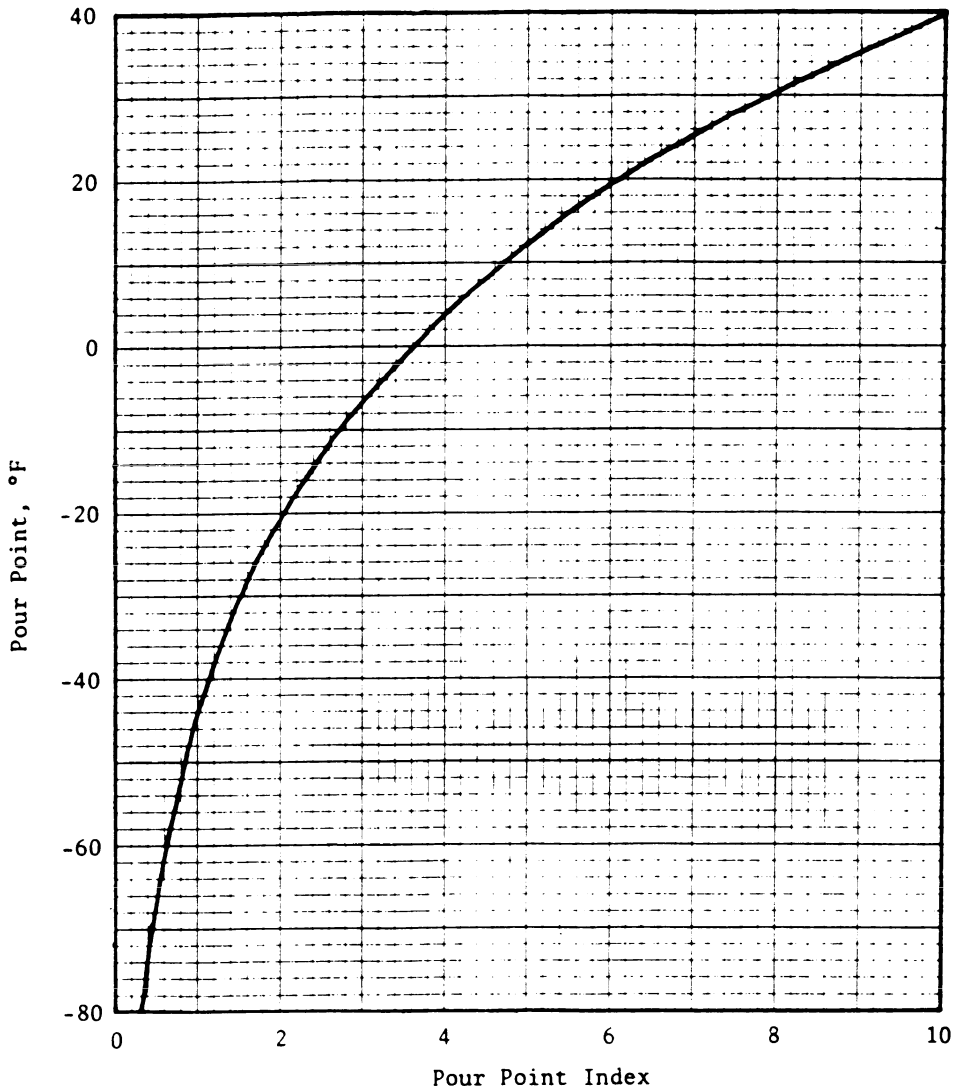

Figure 4-2
Graph of Pour Point Index for Blend Calculations

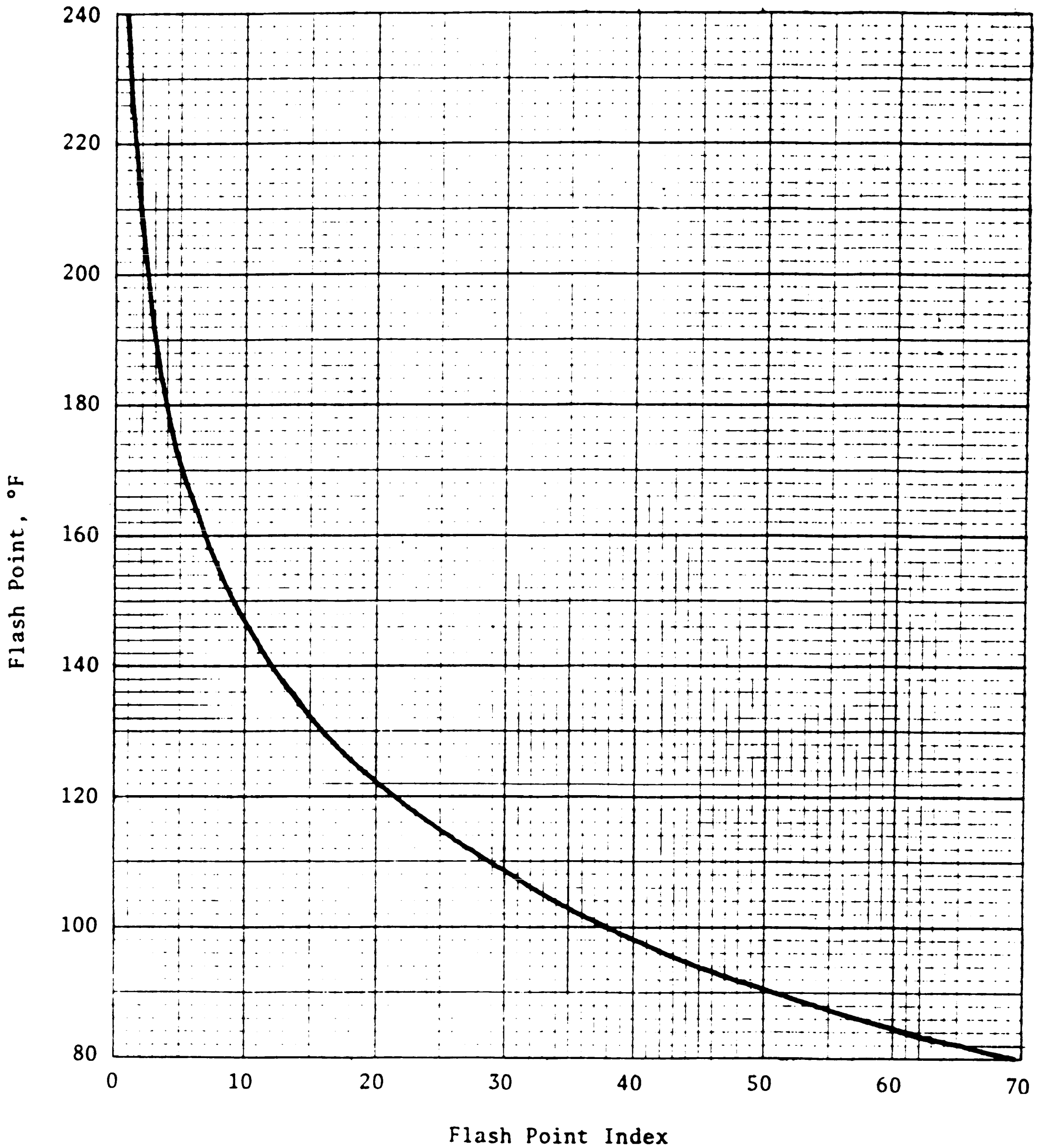

Figure 4-3
Graph of Flash Point Index for Blend Calculations

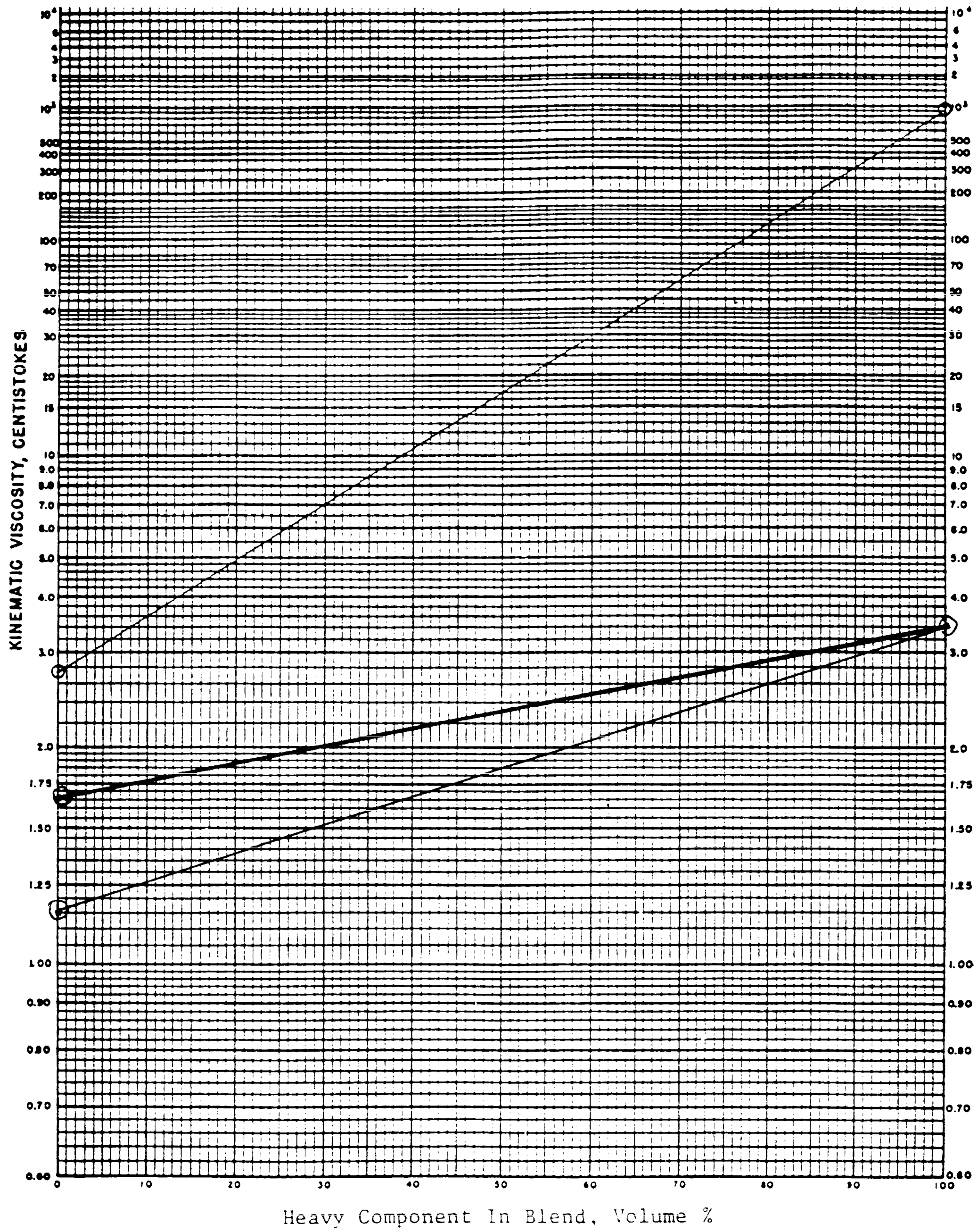

Figure 4-4
Kinematic Viscosity Blending

4.2.4 Other Fuel Blends

Note: DF-2 is an equivalent designation for 2-D commercial fuel

JP-5, JP-8, Jet A, or Jet A-1 (as Kerosenes) have been considered a blend stock to winterize No. 2-D fuel. According to a report, “Emergency Fuels Technology,” (Defense Technical Information Center No. AD A125275, published in 1982), JP-5, JP-8, Jet A, and Jet A-1 fuels could be expected to perform adequately as substitute fuels in diesel engines which require DF-2 as a primary fuel. Cetane number and kinematic viscosity at 104°F (40°C) are tests that are not required for JP-5 aircraft turbine fuel, or for other kerosene-type jet fuels including JP-8, commercial Jet A and Jet A-L JP-8 is essentially Jet A-1 plus required additives. JP-5 is essentially a high flash point (140°F (60°C), minimum) Jet A-1 fuel plus required additives. In order to evaluate these and other properties considered to be important for compression-ignition engine operation, requests were made for refiners to submit samples of their jet fuel products. The U.S. Navy had instituted a policy by which DF-2 would no longer be supplied to the Marine Corps for operation of vehicles with compression ignition engines. Instead, JP-5 would be used in these engines. Request for samples were made by DFSC to those companies currently under contract to supply JP-5 for U.S. Navy, and a second request for samples of kerosene-type jet fuel was made to petroleum companies, domestic and foreign, known to be supplying these types of fuel. These requests resulted in the receipt of 23 samples identified as JP-5, 35 samples of Jet A, and 9 identified as Jet A-1. The range of values and averages obtained for properties of interest to compression-ignition engine operation have been summarized in Tables 4.3, 4.4, and 4.5 for the JP-5, Jet A, and Jet A-1 fuels, respectively. The data for the JP-5 fuels in Table 4.6 indicate that all of these fuels are within a narrow range of properties. Four samples had cetane numbers below 40, the minimum value for DF-1, the lowest value being 34.8 cetane number.

An SAE paper number 892070, “Jet Kerosene Fuels for Military Diesel Application,” analyzed a larger number of JP-5 and JP-8 fuels. Many of the JP-5 fuels were produced in the U. S., and therefore represent a good source of blend stock for winterization of diesel. Many of the California JP-5 fuels had cetane numbers below 40, whereas none of the Texas, Louisiana, or Washington state JP-5 cetane numbers were below 40. All of the JP-8 samples including Texas and Louisiana, had cetane numbers higher than 40 except for a 39.6 CN from Castellon, Spain, and one sample from West Germany with a 39.0 CN.

While the low viscosity of kerosene-type jet fuels makes them less attractive as blend stocks for lowering the cloud point of 2-D diesel fuel, the freezing point maximum requirement of -52.6°F (-47°C), for all but Jet A which is

Table 4.3
Averages and Range of Values for Properties of 23 JP-5 Samples

Properties	JP-5 Samples			DF-2 Requirements	
	Average	High	Low	CONUS	OCONUS
Gravity, API	40.7	44.1	36.3	NR*	NR
Density at 15°C, kg/L	0.8213	0.8428	0.8054	NR	0.815 to 0.860
Flash Point, °C	65	73	65	52, min	56, min
Viscosity, cSt @ 40°C @ 20°C	1.5	1.7	1.3	1.9 to 4.1	1.8 to 9.5
Cetane Number	42.0	47.5	34.8	40 min	45 min
Cetane Index	41.7	47.2	36.5	(43 min**)	NR
Distillation, D 86, °C 10% Recovered 50% Recovered 90% Recovered	196 214 241	204 223 267	188 204 226	NR Report 338 max	NR Report 357 max
Aromatics, FIA, vol%	20.8	25.0	15.0	NR	NR
Cloud point,°C	-	-45	-60	+	+
Freezing point, °C	-	-46	-74	NR	NR
Hydrogen, mass%	13.59	13.84	13.34	NR	NR
Neat heat of combus-tion, MJ/L	35.40	36.10	34.71	36.43+++	NR

*NR = No Requirement.
**If cetane index is used in lieu of cetane number, it is 43.
+At or below anticipated ambient temperature at location of use. (See Appendix A of VV-F-800D for guidance.)
++As specified by the procuring activity based on Table 2.2 Diesel fuel DF-2 for Europe and S. Korea shall have a maximum limit of -13°C.
+++Typical value for a reference diesel fuel.

Table 4.4
Averages and Range of Values for Properties of 35 Jet A Samples

Properties	Jet A Samples			DF-2 Requirements	
	Average	High	Low	CONUS	OCONUS
Gravity, API	42.9	48.4	37.9	NR*	NR
Density at 15°C, kg/L	0.8110	0.8349	0.7862	NR	0.815 to 0.860
Flash Point, °C	55	68	43	52, min	56, min
Viscosity, cSt @ 40°C @ 20°C	1.5	1.7	1.1	1.9 to 4.1	1.8 to 9.5
Cetane Number	45.2	51.9	36.3	40 min	45 min
Cetane Index	44.2	49.5	35.8	(43 min**)	NR
Distillation, D 86, °C 10% Recovered 50% Recovered 90% Recovered	189 211 242	200 226 259	172 193 199	NR Report 338 max	NR Report 357 max
Aromatics, FIA, vol%	18.5	21.9	12.0	NR	NR
Cloud point,°C	-	-35	<-60	+	+
Freezing point, °C	-	-42	-59	NR	NR
Hydrogen, mass%	13.82	14.82	13.36	NR	NR
Neat heat of combus-tion, MJ/L	35.04	35.85	34.12	36.43+++	NR

*NR = No Requirement.
**If cetane index is used in lieu of cetane number, it is 43.
+At or below anticipated ambient temperature at location of use. (See Appendix A of VV-F-800D for guidance.)
++As specified by the procuring activity based on Table 2.2 Diesel fuel DF-2 for Europe and S. Korea shall have a maximum limit of -13°C.
+++Typical value for a reference diesel fuel.

Table 4.5
Averages and Range of Values for Properties of 35 Jet A Samples

Properties	Jet A -1 Samples			DF-2 Requirements	
	Average	High	Low	CONUS	OCONUS
Gravity, API	44.9	49.3	41.3	NR*	NR
Density at 15°C, kg/L	0.8018	0.8185	0.7823	NR	0.815 to 0.860
Flash Point, °C	43	51	1.0	52, min	56, min
Viscosity, cSt @ 40°C @ 20°C	1.3	1.4	1.0	1.9 to 4.1	1.8 to 9.5
Cetane Number	42.6	48.1	34.7	40 min	45 min
Cetane Index	43.4	47.0	38.2	(43 min**)	NR
Distillation, D 86, °C 10% Recovered 50% Recovered 90% Recovered	 174 199 233	 183 213 242	 166 181 202	 NR Report 338 max	 NR Report 357 max
Aromatics, FIA, vol%	19.4	21.0	18.1	NR	NR
Cloud point,°C	-	-45	-60	+	+
Freezing point, °C	-	-49	-61	NR	NR
Hydrogen, mass%	13.84	14.12	13.62	NR	NR
Neat heat of combustion, MJ/L	34.65	35.20	33.92	36.43+++	NR

*NR = No Requirement.
**If cetane index is used in lieu of cetane number, it is 43.
+At or below anticipated ambient temperature at location of use. (See Appendix A of VV-F-800D for guidance.)
++As specified by the procuring activity based on Table 2.2 Diesel fuel DF-2 for Europe and S. Korea shall have a maximum limit of -13°C.
+++Typical value for a reference diesel fuel.

TABLE 4.6 - Blend Properties Calculated for a No. 2-D Diesel Blended with a Low-Cetane-Number Jet A Fuel from Torrance, Louisiana

Requirement	Fuel		
	Jet A, Torrance, LA	No. 2-D Diesel	Blend
Composition, vol % Jet A No. 2-D	 100 0	 0 100	 40 60
Gravity, API	37.9	38.3	38.2
Specific gravity, 60°F	0.8349	0.8333	0.8339
Density, lb/gal, 60°F	6.953	6.940	6.945
Flash point, °C (°F)	63 (145)	64 (148)	64 (147)
Cloud point, °C (°F)	-60(-76)	-11 (+12)	-18 (-1)
Pour Point, °C (°F)	-59(-74)	-21 (-5)	-29 (-21)
Sulfur, wt%	0.01	0.130	0.082
Carbon residue on 10% bottoms, wt%	0.05	0.044	0.050
Cetane number	36.3	47.0	42.7*
Cetane index	35.8	49.0	44.3
Distillation, °C (°F) IBP 0% 50% 90% EP	 193 (379) 199 (390) 212 (414) 234 453) 253 (487)	 189 (372) 212 (414) 250 (483) 309 (588) 333 (632)	 * * 235 (455) * *
Viscosity @ 40°C, cSt	1.6	3.4	2.45
Gross Heat of Combustion, Btu/gal	NA	136,580	NA

*Laboratory measurement is required.
N A = Not Available

-40°F(-40°C),” and their availability make them ideal as blend stocks. Minimized use of kerosene-type fuel blend stocks can protect important property values specific for 2-D fuel.

5.0 Achieving Cloud and Pour Point Requirements in Long-Term Storage

In long-term strategic storage, it is common practice to store No. 2 Diesel with a sufficiently low cloud point such that the fuel can be used whenever it is needed independent of the time of the year. As can be seen for VV-F-800D requirements for OCONUS DF-2 in Tables 4.3 to 4.6, the cloud point is specified at -13°C, maximum, for fuel destined for use in Europe and S. Korea. Looking at the requirements in Table 2.2, this is sufficiently low to cover all the countries except for S. Korea, Norway, and Turkey during the two coldest months of December and January. For these cases and cases where the actual 6-hour diurnal low temperature is below the -13°C, field blending of DF-2 with jet turbine fuel is the common and accepted practice for the U.S. military.

Vehicle engine and fuel system design can be critical in accomplishing cold weather operability. Under identical operating conditions, different engine types can perform differently with the same type of fuel. For example, during a cold weather exercise (approximately 3°C below the cloud point for the diesel fuel) an M-1 tank (a gas-turbine powered tank) was inoperable while the M-60 tank (a diesel engine powered tank) was fully operable. Turbine engine fuel nozzles are directly fed from the fuel cells and do not recirculate the fuel for cooling of injectors/injector pumps as does the diesel engine. It is not uncommon for fuel used in diesel engine vehicles to reach 86°F (30°C) above ambient temperature during operation. A gas turbine fuel system for cold weather operation would require heat tracing for exposed fuel lines and filters and installation of an in-line fuel heater.

Low temperature operation in cold states such as Maine and Minnesota using diesel fuel originally procured in a warmer state or meeting “pipeline” quality for another region, may not function satisfactorily during winter months. While Canadian Provinces will have similar fuel property requirements to neighboring states, colder weather is regional in much of Canada, requiring appropriate planning considerations. Fuel blended for use in warmer climates (e.g. Mexico) could cause problems during unexpected cold weather.

In strategic storage, replenishment of a partially full storage tank should follow the same specification requirements for cloud point as were used for filling the tank initially. Partial filling, or topping off of tanks, should not be done using fuel having a cloud point reduced by additives or cold weather blend stock not used in the initial filling. Blend calculations can be made to estimate the effect of a high-cloud fuel addition to a partially full tank, assuming the tank is small enough that the fuel will be adequately mixed. This also assumes that the fuel in storage is sufficiently below the required cloud point maximum for the fuel system or the specification requirements are such that they meet year-round requirements.

For No. 2 diesel at or near the minimum flash point, use of jet turbine fuel or kerosene having a much lower flash point as a blend stock is not practiced in long-term storage, since the resulting flash point would not meet DF-2 minimum flash point requirements.

6.0 Recommendations

Diesel in storage for emergency stand-by generators should have properties that meet year-round operational requirements. Replenishment diesel should meet system cold weather operational requirements. If part of the fuel is stored at higher than ground temperatures or outside in ambient temperature conditions, and sufficiently low cloud point fuel is not available year-round, then it is recommended to either store a sufficiently large supply to avoid replenishment during the summer or provide heating to the outdoor storage facility to accommodate higher cloud point fuel and to meet minimum operational temperature requirements.

The blending of jet turbine fuel and kerosene with available DF-2 to reduce cloud point to outdoor ambient temperatures is not recommended for emergency diesel generator fuel supply systems. However, if required for tank topping, blending of jet turbine fuel and kerosene into DF-2 to be delivered to the tank can be tolerated to the point that the resulting fuel mixture has properties required for the system and engine to operate at normally encountered temperatures. For most standby diesel engines, this would be room temperature and higher. Both viscosity and flash point should also be considered. Blend calculations can be used for both the new diesel with kerosene and the bulk fuel in storage. In practice, it can be assumed that the new diesel/kerosene blend will blend as a single component with the diesel in storage. However, if it is not completely mixed in the storage tank, the lowest viscosity and flash point would still be available in the tank for any stratified fuel. Use of the blend calculations provided in this note will help to reduce the quantity of kerosene used in blending as it is a better approach than the more common approach of simply making 50% blends of kerosene in diesel. These calculations can also cut down on the cost of testing blends at various concentrations by minimizing the need for as many analyses of blends.

The use of additives to reduce cloud point and/or pour point of stored DF-2 is not a straight forward solution to high cloud point fuel. For replenishment of a DF-2 storage tank, additive laden fuel can be more problematic than kerosene blending and is not recommended as a measure to improve low temperature characteristic of a substantial quantity of fuel. The additive will not be effective at the diluted concentrations which can be experienced after the added fuel mixes with the bulk of the fuel in the storage tank. Adding sufficient quantities of additive to treat a large storage tank and assuring proper mixing is not worth the cost or the uncertainty regarding long-term storage properties.

Blending of fuels as a stopgap measure to assure continued operability is possible within limits. It was shown in section 4 that mixing No. 2-D and 1-D or certain kerosene-type fuels can be done with reasonable assurance that the fuel will perform satisfactorily. However, there are concerns over certain properties that these fiels may not meet and possibly violate the definition No. 2-D diesel fuel. Such items as cetane number or index, viscosity, flash point, and lubricity must be considered when these blends are used to meet cloud point requirements.

It is preferable to procure and use fuel specified for its desired purpose. However, as in the winter of 1993-94, many users may not find diesel fuel available to meet the cold weather performance characteristics required because of low temperatures and may need to blend fuels in order to meet fuel operability requirements for colder than expected weather.

In the face of a continuing attention to operations and maintenance costs at nuclear power plants, the future of the industry depends largely upon increasing plant availability and improving operating efficiency. The success in achieving these objectives is dependent upon the success of each plant's equipment maintenance program.

NMAC'S goal

The goal of the Nuclear Maintenance Applications Center (NMAC), operated by EPRI, is to provide member utilities with practical, proven maintenance practices and expertise which will assist power plant personnel in effectively managing their planned and emergent maintenance requirements; and, to facilitate the transfer of maintenance-related technology at a working level within the nuclear power industry.

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