A GUIDE TO FUEL PERFORMANCE

UNDERSTANDING HEATING OIL PROPERTIES,
POTENTIAL PROBLEMS, AND REMEDIES

The NORA Fuel Quality Technical Manual

Authored by Wai-Lin Litzke, Brookhaven National Laboratory
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Brookhaven National Laboratory Staff

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Roger McDonald
George Wei

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National Oilheat Research Alliance
Alexandria, VA 22314
www.nora-oilheat.org

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1. Introduction

Heating oil, as its name implies, is intended for end use heating consumption as its primary application. But its identity in reference name and actual chemical properties may vary based on a number of factors.

By name, heating oil is sometimes referred to as gas oil, diesel, No. 2 distillate (middle distillate), or light heating oil. Kerosene, also used as a burner fuel, is a No. 1 distillate.

Due to the higher heat content and competitive price in most markets, No. 2 heating oil is primarily used in modern, pressure-atomized burners. Using No. 1 oil for heating has the advantages of better cold-flow properties, lower emissions, and better storage properties. Because it is not nearly as abundant in supply, it is often markedly more expensive than No. 2 heating oil.

Given the advanced, low-firing rate burners in use today, the objective is for the fuel to be compatible and achieve combustion performance at the highest achievable efficiency of the heating systems — with minimal service requirements.

Among the Oilheat industry's top priorities are improving reliability and reducing service costs associated with fuel performance. Poor fuel quality, fuel degradation, and contamination can cause burner shut-downs resulting in "no-heat" calls. Many of these unscheduled service calls are preventable with routine inspection of the fuel and the tank.

This manual focuses on No. 2 heating oil — its performance, properties, sampling and testing. Its purpose is to provide the marketer, service manager and technician with the proper guidelines for inspecting the product, maintaining good fuel quality, and the best practices for proper storage. Up-to-date information is also provided on commercially available fuel additives, their appropriate use and limitations.

2. Overview of Heating Oil

When crude oil is distilled as a key part of the refining process, gasoline, heating oil, jet fuel, and numerous other products are produced which contain mostly carbon and hydrogen (hydrocarbons) which provide a lot of energy. Other compounds in petroleum products are sulfur, nitrogen, and oxygen. The heavier products, or fractions, may contain small amounts of metal and salts. Most of these impurities along with water are later removed in the refining process. Under mandates of the U.S. Environmental Protection Agency, the amount of sulfur in the fuel is being reduced.

Oil refining is the process of separating the vast mixture of hydrocarbons of different lengths (number of carbons) by their differences in boiling point. This distillation or straight-run process is only the beginning. Other processes are needed to convert longer chains into shorter ones, to remove impurities and to combine mixtures of different fractions to make the desired products. The desired products (including diesel and heating oil) are all defined by their specifications (Chapter 3). The specifications are established by the American Society of Testing and Materials (ASTM) and are uniformly respected by the petroleum industry.

In a modern refinery, the volume of high-value products that can be derived from a barrel of crude oil can be maximized by adding other processes. These processes take the distilled bottom products (the heaviest hydrocarbons with the highest boiling points) and convert them to lighter products. Thermal cracking, catalytic cracking, hydrocracking are some of conversion processes that break down the long-chain hydrocarbons.

Diesel fuel and heating oil coming out of distillation are similar products. It is the post distillation process and further treatment to reduce sulfur content that differentiates the use of one product for heating, the other for the transportation market. Both heating oil and diesel fuel are a blend of products from various process streams: straight-run product, light cycle oil, and hydrocracked stock. Some cracked products can vary and exhibit low quality and performance.

Figure 2-1 An oil refinery is a combination of all of these units [1].

In the U.S. about one third of the distillate fuel comes from hydrocracked stock (FCC and coker). These cracked components generally have high sulfur content and are inherently less stable than the straight-run products. To produce low-sulfur diesel, sulfur is further removed through additional hydrotreating and blending with lower sulfur blending streams. Light cycle oil is an intermediate product produced in a catalytic cracker and is commonly used as a blending component in diesel fuel and heating oil.

Figure 2-2 Flow-chart of how low-sulfur fuel is typically produced in the U.S. [2]

A major difference between diesel fuel used for vehicles (on-road or highway) and heating oil is its sulfur content. Highway diesel, defined as low-sulfur, must presently have a sulfur content at or below 0.05 wt % (500 parts per million, stated as 500 ppm). Beginning in 2006, the diesel fuel's sulfur content will be reduced to "ultra-low sulfur" level, such that it will be at a maximum of 0.0015 wt% or 15 ppm. This is being mandated by the U.S. Environmental Protection Agency (EPA) to reduce pollutant emissions from vehicles. Regulation of diesel for off-road vehicle use will follow; sulfur limits are being promulgated as this piece is being written. As sulfur content of diesel fuel is reduced to much lower levels as compared with heating oil, the amount of hydrocracked stock that can be blended into diesel fuel becomes more limited.

The EPA does not regulate heating oil used for residential appliances. It may be purchased as No. 2 (0.5 wt% sulfur max / 5000 ppm), or No. 2 Low Sulfur (0.05 wt% max/ 500 ppm), though recent experience shows that most residential heating oil consumed today falls below 2500 ppm. State and local environmental regulations often limit the maximum sulfur content allowable in burner fuels.

References:

[1] <http://science.howstuffworks.com/oil-refining4.htm>

This website offers additional information on the subject of oil refining and other reference sources such as American Petroleum Institute, Institute of Petroleum, Chevron Learning Center.

[2] Sutterfield, F. D., Olsen, D. K., "Technologies for Meeting Low-Sulfur Fuel Specifications in the United States, p. 411, Proceedings of the 7th International Conference on Stability and Handling of Liquid Fuels, January 2001.

A Note on Units:

To convert from weight percent (wt%) to parts per million (ppm), multiply by 10,000

Example: 0.05 wt% Sulfur = 500 ppm Sulfur

3. Purchasing Fuels

Specifications

The terms “heating oil” and “diesel fuel” describe the fuels that are used for home heating. They are very similar, although diesel is often cited when referring to vehicle fuels and heating oil when talking about burner fuels. In the U.S. Grade No. 2-D is the most common diesel fuel for trucks, with Grade No. 1-D and Grade No. 4-D also commercially available. The primary difference in the specifications is that diesel fuel has a cetane and a sulfur limit. Cetane is an important component for diesel engines and affects how smoothly the fuel burns, however, it is not relevant for burner fuels.

Burner fuels include No. 1 (kerosene), No. 2, and No. 6. These grade designations are established by the American Society for Testing and Materials (ASTM). The grades are numbered in order of increasing density and viscosity, with No. 1 the lightest and No. 6 the heaviest.

Fuel specifications and associated test methods are established by committees. They are developed by consensus among refiners, equipment manufacturers, and users in order to ensure that the fuel provides satisfactory performance and reliable operation. The ASTM Committee D-2 (Petroleum Products and Lubricants) is responsible for diesel and burner fuel specifications, ASTM D 975 and ASTM D-396 respectively. Refer to Table 1 for their properties.

In these specifications, there are requirements or limits for the values of fuel properties. Standard test methods that are used to measure the values of the properties are also listed. These properties and methods are described in Chapter 4.

What to buy

When purchasing bulk fuels it is always recommended that you ask for the specifications. Look to see that its properties are suitable for their intended use. For example, if you purchase low-sulfur heating oil, be sure that the specifications show the sulfur content is less than 0.05 percent by weight (wt%).

If you buy heating oil in the summer for use later during the heating season be sure to review the cloud and pour points of the fuel (Chapter 4 discusses these cold-flow properties in detail). In locations where the winter is very cold or there are occasional cold snaps, certain fuels may not be suitable for use as they could gel. Considerations must then be taken to either blend with cold-flow additives or kerosene as appropriate to counter gelling problems before they occur.

Some heating oil retailers periodically sample to verify the specifications of the fuel. Others rely on the sampling and testing of their suppliers. Chapter 6 explains how to sample fuels being received by barge or transporter trucks at the bulk terminals, or those fuels picked up by the delivery trucks at the rack. The sample of the fuel taken should represent an entire load or batch of fuel. A commercial lab specializing in petroleum testing will be needed to analyze the properties listed in Table 1 using the standard test methods. This is called “specifications testing” and it may take about a week for the lab to report the results. You need not test for all the properties every time. Randomly test the incoming fuels as a means of quality control.

A commercial lab specializing in petroleum testing will be required to analyze the properties listed in Table 1 using the standard test methods. You need not test for all the properties every time. You should determine how often you test based on the cost of testing and the reliability of your supplier. A list of commercial test labs can be found in the Appendix. Chapter 3 explains further what the properties mean.

If possible, it is always a good idea to do some basic inspection of the fuel for cleanliness and haze, which could indicate the presence of water or wax (in cold weather). Suspended water in fuel may result in water in your customers' tanks which will cause future problems. This should be done regularly with all bulk quantities of fuel before accepting it. The purpose of this visual inspection is to prevent picking up fuel that may contain contaminants or water. Chapter 6 gives more information on preventing contamination of bulk tanks, delivery trucks and customer tanks with a bad batch of incoming fuel.

Table 3-1 ASTM Fuel Specifications for Burner Fuels and Diesel

Property	Heating Oil ASTM D396	Diesel ASTM D975	ASTM Test Method
Flash Point °C, min	38	52	D 93
Water and sediment, % vol, max	0.05	0.05	D 2709
Distillation temperature °C			D 86
90% volume recovered, min	282	282	
90% volume recovered, max	338	338	
Kinematic viscosity at 40°C, mm²/s			D 445
min.	1.9	1.9	
max.	3.4	4.1	
Ramsbottom carbon residue % mass, max	0.35	0.35	D 524
Ash % mass, max	—	0.01	D 482
Sulfur, % mass, max Grade No. 2	0.50	0.50	D 129
Grade No. 2- Low Sulfur	0.05	0.05	D 2622
Copper strip corrosion rating, max.	No.3	No.3	D 130
Cetane number, min.	—	40	D 613
Density at 15°C, kg/m³, max.	876	—	D 1298
Pour Point °C, max*	-6	—	D 97
Cetane, index, min (Note 2) or	—	40	D 976
Aromaticity, % vol, max (Note 2)	—	35	D 1319
Cloud Point, °C max or	—	Depends on Location	D 2500
LTFT/CFPP, °C max	—	Depends on Location	D 4539/ D 6371
Red Dye	Note 1	Note 1	

Note 1. By federal regulation, these grades of heating oil and diesel sold for tax-exempt purposes are required to contain the red dye solvent (ref: 40 CFR Part 80 and 26 CFR Part 48).

Note 2. Applies to No. 2 low sulfur diesel.

4. Understanding Fuel Properties

Good heating system performance requires that the fuel supplying the burner should have specific characteristics that are important for its proper operation. The fuel properties can be interrelated or sometimes cause similar effects. When the properties are beyond its range, or out-of-specification, operating problems can occur.

Knowing what to look for is a first step in diagnosing and solving fuel-related operating problems. This section covers fuel properties in greater detail.

Fuel Properties and Performance

Heating oil is a mixture of different refinery process streams blended to meet the manufacturing specifications, such as ASTM D 396 or pipeline requirements. Its properties should be related to its performance as a burner fuel, and specific standard tests have been designed to measure these properties. Considerations for performance must also include storage properties — cleanliness, stability, and cold-flow characteristics, to ensure ease of handling and fuel delivery.

Factors that affect the fuel flow, filter clogging tendency, or nozzle clogging include:

- Low Temperature Operability or Cold Flow Properties
- Fuel stability
- Fuel cleanliness (water, dirt)
- Viscosity

Factor that affects efficiency, fouling of boilers, flue gas emissions:

- Sulfur content

Factors that affect clarity

- Red dye
- Fuel cleanliness
- Wax

How Properties are Defined

Ash (ASTM D 482) content may be defined as the carbonaceous residue that remains after combustion of the oil in air at a specified high temperature. It is determined by igniting a sample of fuel in a vessel and allowing it to burn until only ash remains. Ash in distillate fuel oil is usually negligible; however, during transportation from the refinery, ash contributors may be picked up. Water transportation, in particular, presents many opportunities for fuel oils to be contaminated with ash producers such as sea water, dirt, and scale rust.

Cetane number (ASTM D 613, D 976) is typically used in diesel fuel specification and determined with a test engine and is a measure of the ignition quality of the fuel (Method D 613). When a test engine is unavailable, cetane number is estimated by calculating the cetane index using a formula dependent on specific gravity and mid-point (50%) boiling temperature (D 976).

Cloud point (ASTM D 2500) is specified in ASTM specifications for diesel fuels, but not heating oil. It is the temperature at which a cloud or haze of wax crystals first appears in the fuel. At or below this temperature, the wax crystals (paraffinic constituents of the fuel) settle out and may clog filter systems. The temperature at which the precipitation occurs depends upon the origin, type, and boiling range of the fuel. The specification for diesel fuel states that satisfactory operation should be achieved, in most cases, if the cloud point is specified at 6°C above the tenth percentile minimum ambient temperature for the area in which the fuel will be used.

Copper strip corrosion test (ASTM D 130) is designed to assess the relative degree of corrosiveness of a petroleum product. Corrosion of various metals can occur, depending on the types of sulfur compounds in the fuel. Although most sulfur compounds in crude oil are removed during refining, heating oil has between 500 and 5000 ppm of sulfur. This qualitative test measures the possible problems with copper and brass or bronze parts of the fuel system.

Distillation range (ASTM D 86) indicates the vaporizing tendencies of the fuel, and generally characterizes liquid petroleum fuels. The procedure measures the amount of liquid vaporized and subsequently condensed as the temperature of the fuel in the distillation flask is raised at a prescribed rate. The 90% point is the temperature at which 90% of the liquid has evaporated. For atomizing burners, fuels must contain sufficient volatile components to ensure that ignition and fuel vaporization is accomplished consistently.

Flash point (ASTM D 93, D 56) is the lowest temperature at which the vapor above the fuel can be ignited with a flame. This point can be measured with a test flame under controlled specified conditions, such as by the Pensky-Martens Closed Tester (Method D 93) or by the Tag Closed Tester (Method D 56), which are normally used for fuel oils. Flash point is used in shipping and safety regulations to define "flammable" and "combustible" materials. Contamination with more volatile products, such as gasoline (1% or 2%), can substantially lower the flash point of the fuel.

Heating value (ASTM D 240) is a measure of the energy available from the fuel when it is burned completely. Heat content is determined using a bomb calorimeter under specified conditions and is usually expressed as British Thermal Unit (Btu)/lb. It may also be calculated with sufficient accuracy from other known data, such as specific gravity, sulfur content, and aniline point. Typically, the heat content is not quoted in most fuel oil specifications since it is not directly controllable during manufacture, and as kerosene is added for winter reasons the Btu value often falls.

Pour point (ASTM D 97) is the temperature at which the fuel gels under standard test conditions; below this temperature, the oil stops flowing. Pour-point limits should be considered, based on the anticipated storage conditions and fuel application.

Ramsbottom (ASTM D 524) carbon residue is the amount of carbon residue left after evaporating the oil under specified conditions. The value provides some indication of the relative coke-forming tendency of the oil. High-carbon residue appears to cause a rapid buildup of carbon and nozzle fouling in small heating units.

Relative density or specific gravity (ASTM D 1298) is the ratio of the mass of a given volume of liquid (fuel) to the mass of an equal volume of pure water, both at the same reference temperature (15°C or 60°F). API gravity is a different way of expressing specific gravity (sp gr at 60/60F reference temperature) and is calculated by:

$$\text{API gravity, deg} - (141.5 / \text{sp gr}) - 131.5$$

A fuel with a lower API gravity generally has a higher heating value. For example, kerosene (No. 1 oil) has a higher API gravity than No. 2 oil, and therefore, a lower heating value. The API gravity scale generally is used in the United States.

Stability of heating oil may be defined as a measure of a fuel's resistance to change. The composition of all fuels changes over time; however, in an unstable fuel the changes occur more rapidly in terms of color, formation of gummy or insoluble materials, and deposition of sludge on the bottom of storage tanks. The storage stability of fuel oils may be influenced by many factors including the origin of the crude oil, refinery treatment, and compatibility of fuels when blended. The mechanism of sludge formation is very complicated and not well understood. Although stability is not specified in D396 heating oil, methods have been developed to predict fuel oil stability to ensure satisfactory performance where applications are critical. A common test is ASTM Test for Stability of Distillate Fuel Oil (Accelerated Method, D 2274), which measures the stability of distillate fuel oils under accelerated oxidizing conditions. Another similar test often used by the industry is the Dupont/Octel F-21 (D 6468). As with any accelerated method, correlation between the test results may vary significantly with actual field conditions. Empirical methods are available to assess stability, but there is no universally accepted procedure for determining the tendency of fuel oils to deposit sludge while in storage.

Sulfur (ASTM D 129) content of the fuel affects corrosion and the formation of deposits on boiler tubes. The sulfur content of fuel oil can be determined by several methods. This ASTM Test for Sulfur in Petroleum Products (General Bomb Method) has long been established, but other more rapid techniques are available. Combustion of sulfur-containing fuels also produce sulfur oxides which contribute to atmospheric pollution. High-sulfur fuels also can accelerate the formation of gum and sediment in the fuel during storage.

Viscosity (ASTM D 445) determines the flow of the oil to the burner nozzle or atomizer. Fuel viscosity is very sensitive to temperature and is higher at lower temperatures. The accepted procedure for determining viscosity is kinematic, and is expressed in units of centistokes (cSt) or one millimeter squared per second (mm²/s).

Water and Sediment (ASTM D 2709) in the fuel can cause corrosion of equipment and plugging a system with tight spaces (such as burner nozzles and filters). A high content of water and sediment usually results from poor handling and storage of the fuel.

The following sections cover more fully those properties that have an important effect on product storage, stability and handling of liquid fuels. When fuel cleanliness (or tank cleanliness) becomes unacceptable, or cold-flow properties are out of range for normal operation, or the fuel becomes very unstable, problems with fuel flow, filter clogging and oil line plugging can occur.

Fuel Stability

The stability of heating oil depends a great deal on the crude oil sources from which it was derived, severity of processing, use of additives and any additional refinery treatment. Different refineries may produce distillate fuels that vary in composition and stability properties. Normally produced fuels have adequate stability properties to withstand normal storage and use. However, fuels that are stored for prolonged periods or subjected to high temperatures may form excessive amounts of sediment and gums that can overload filters or plug nozzles. It is therefore necessary to consider a fuel's storage and thermal stability.

The fuel's storage stability should be assessed at the time of manufacture. That is, the fuel should have some performance criteria in the purchase specification. Test Methods ASTM D 2274 and D 5304 are commonly used accelerated stability tests. It should be noted, however, that positive results from laboratory tests does not guarantee that there will be no operational problems in the field due to varying tank conditions and mixing of fuels. Nevertheless, adhering to some performance criteria assures some level of protection.

Fuels tend to degrade with time in storage, and its effects are only compounded with added handling and transport due to the potential for contamination. If you start off with an unstable fuel, it does not improve.

If the fuel fails a stability test, it does not mean that the fuel cannot be used. It is merely a warning that the fuel only has a limited shelf life before it forms excessive particulates.

Table 4.1 Stability Tests Commonly Used for Distillate Fuel

Test Method	Test Conditions	Acceptable Limits
ASTM D 5304	Oxygen overpressure (100 psig) at 90° C (194° F) for 16 hrs	1.5 mg/100ml (up to 2.5 mg/100ml) sediment
ASTM D 2274	Oxygen bubbled through fuel at 95° C (203° F)	2.5 mg/100ml sediment
ASTM D 6468	150° C (300° F) 90 min	80% reflectance (optical meter reading)

Cold Flow Properties of Heating Oil

Heating oils are typically refined so that its low temperature properties are fit for the area and time of year it is to be used. During brief periods of unseasonable cold weather, however, operational problems may be experienced during transport and storage of fuel oil. The following are some guidelines on how to determine the cold flow characteristics of the fuel oil, the suitability for its current use, and how to remedy operational problems by fuel blending or additive use.

Using standard industry methods there are at least several properties that can be measured to determine the cold flow characteristics of fuel oil. Those most commonly used for No. 2 heating oil (or diesel) include the following:

Figure 4-1 Cold Flow Temperatures

Cloud and Pour Points (CP, PP)

As the fuel is cooled a temperature will be reached at which the clear fuel begins to cloud. The cloudiness is caused by the formation of wax (paraffin) crystals in the fuel. The highest temperature at which this occurs is referred to as the cloud point. Below the cloud point these wax crystals might become large enough to plug the oil-line filter, pump strainer, and burner nozzle. As the temperature is lowered further, gelling of the fuel occurs. At or below the pour point temperature the fuel does not flow.

ASTM D 396 specification for heating oil limits the Pour Point at a maximum of 21°F (-6 °C).

Cold Filter Plugging Point (CFPP)

This test was designed to estimate or correlate with low temperature operability of vehicle fuel (diesel). Under defined laboratory test conditions, this test gives the temperature at which a test filter becomes clogged by wax as the fuel is cooled.

In Europe multiple tests are used to define acceptable low-temperature behavior. For example, in Germany the specification for heating oil (DIN 51603-1) considers both the CP and CFPP to define acceptable low temperature behavior.

Current Practices

Current practices used by the industry (i.e. pipeline companies) consider both cloud and pour points to denote the fluidity of the product based on time of year and location. A typical schedule in the mid-Atlantic region could be,

Pour Point:	August 1 st – March 14 th	Maximum: - 18°C (0°F)
Pour Point:	March 15 th – July 31 st	Maximum: -12 °C (+10°F)
Cloud Point:	August 1 st – March 14 th	Maximum: - 9°C (+15°F)
Cloud Point:	March 15 th – July 31 st	Maximum: - 7°C (+20°F)

Although ASTM D 396 does not specify a range for cloud point, it is recommended that both cloud and pour points be established and specified in all purchase specifications based on location. There is no guarantee that satisfactory operation will be achieved on a broad basis where local temperatures may be much lower than the above-specified temperatures, and so it is advisable to use a typical temperature chart as shown in Table 4-2.

Recommendation

No single laboratory test can adequately predict the cold flow performance in all fuels and in all storage systems. Storing fuel oil indoors, or providing insulation to storage tanks and piping minimizes problems associated with poor cold flow operation.

In general, satisfactory operation should be achieved in most cases if the Cloud Point is 6°C above the 10th percentile minimum ambient temperature for the area in which the fuel will be used. The 10th percentile temperature means that, on average, the ambient temperature is not expected to go below this value more than 3 days for a 30-day period. The temperatures are based on historical data and depend on the local climate. They are listed on the chart in the following pages by month and region during the winter.

For example, on Long Island, NY during December, the 10th percentile temperature is -14°C. (See table 4.2 on next page, re: New York, South 42 deg. lat.) Six degrees above that is -8°C, so for Long Island during December, the practical, maximum cloud point specified should be -8°C (18°F).

**Appropriate low temperature properties should be agreed upon between the fuel supplier and purchaser for the expected ambient temperatures.
See Table 4.2 on the next page.**

A Note on Units

To convert from degrees Celsius (C) to degrees Fahrenheit (° F), multiply by 1.8 and add 32.

Example 1

What is -15 °C?

$$(-15 \times 1.8) + 32 = 5 \text{ or } 5 \text{ deg. F}$$

To convert from deg. F to deg. C, subtract 32 then divide by 1.8

Example 2

What is 20 deg. F?

$$(20 - 32) / 1.8 = -7 \text{ or } -7 \text{ deg. C}$$

Table 4-2 10th Percentile Minimum Temperature °C (°F)

State		Oct.		Nov		Dec		Jan		Feb		Mar	
		°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
Alabama		4	39	-3	27	-6	21	-7	19	-3	27	-2	28
Alaska	North	-25	-13	-37	-35	-45	-49	-49	-56	-47	-53	-43	-45
	South	-11	12	-13	9	-18	0	-32	-26	-32	-26	-29	-20
	SE	-4	25	-11	12	-16	3	-19	-2	-13	9	-12	10
Arizona	N. 34° lat.	-4	25	-12	10	-14	7	-17	1	-16	3	-12	10
	S. 34° lat.	7	45	0	32	-2	28	-4	25	-3	27	-1	30
Arkansas		2	36	-4	25	-7	19	-11	12	-7	19	-3	27
California	N. Coast	3	37	0	32	-2	28	-2	28	-1	30	-1	30
	Interior	2	36	-3	27	-4	25	-7	19	-6	21	-6	21
	S. Coast	6	43	2	36	0	32	-1	30	0	32	2	36
	SE	1	34	-6	21	-8	18	-11	12	-7	19	-5	23
Colorado	E.105° long.	-2	28	-12	10	-14	7	-19	-2	-15	5	-12	10
	W.105° long.	-8	18	-18	0	-25	-13	-30	-22	-24	-11	-16	3
Connecticut		-1	30	-7	19	-16	3	-17	1	-16	3	-9	16
Delaware		2	36	-3	27	-10	14	-11	12	-10	14	-6	21
Florida	N. 29° lat.	7	45	1	34	-2	28	-3	27	-1	30	2	36
	S. 29° lat.	14	57	7	45	3	37	3	37	5	41	7	45
Georgia		3	37	-2	28	-6	21	-7	19	-6	21	-2	28
Idaho		-4	25	-13	9	-18	0	-21	-6	-18	0	-13	9
Illinois	N. 40° lat.	-1	30	-9	16	-19	-2	-21	-6	-18	0	-11	12
	S. 40° lat.	1	34	-7	19	-16	3	-17	1	-15	5	-8	18
Indiana		-1	30	-7	19	-16	3	-18	0	-16	3	-9	16
Iowa		-2	28	-13	9	-23	-9	-26	-15	-22	-8	-16	3
Kansas		-2	28	-11	12	-15	5	-19	-2	-14	7	-13	9
Kentucky		1	34	-6	21	-13	9	-14	7	-11	12	-6	21
Louisiana		5	41	-1	30	-3	27	-4	25	-2	28	1	34
Maine		-3	27	-10	14	-23	-9	-26	-15	-26	-15	-18	0
Maryland		2	36	-3	27	-10	14	-12	10	-10	14	-4	25
Massachusetts		-2	28	-7	19	-16	3	-18	0	-17	1	-10	14
Michigan		-2	28	-11	12	-20	-4	-23	-9	-23	-9	-18	0
Minnesota		-4	25	-18	0	-30	-22	-34	-29	-31	-24	-24	-11
Mississippi		3	37	-3	27	-6	21	-6	21	-4	25	-1	30
Missouri		1	34	-7	19	-14	7	-16	3	-13	9	-8	18
Montana		-7	19	-18	0	-24	-11	-30	-22	-24	-11	-21	-6
Nebraska		-3	27	-13	9	-18	0	-22	-8	-19	-2	-13	9
Nevada	N. 38° lat.	-7	19	-14	7	-18	0	-22	-8	-18	0	-13	9
	S. 38° lat.	8	46	0	32	-3	27	-4	25	-2	28	1	34
New Hampshire		-3	27	-8	18	-18	0	-21	-6	-21	-6	-12	10
New Jersey		2	36	-3	27	-11	12	-12	10	-11	12	-6	21
New Mexico	N. 34° lat.	-2	28	-11	12	-14	7	-17	1	-14	7	-11	12
	S. 34° lat.	4	39	-4	25	-8	18	-11	12	-7	19	-3	27
New York	N. 42° lat.	-3	27	-8	18	-21	-6	-24	-11	-24	-11	-16	3
	S. 42° lat.	-1	30	-5	23	-14	7	-16	3	-15	5	-9	16
North Carolina		-1	30	-7	19	-10	14	-11	12	-9	16	-5	23
North Dakota		-4	25	-20	-4	-27	-17	-31	-24	-29	-20	-22	-8
Ohio		-1	30	-7	19	-16	3	-17	1	-15	5	-9	16
Oklahoma		1	34	-8	18	-12	10	-13	9	-8	18	-7	19
Oregon	E.122° long.	-6	21	-11	12	-14	7	-19	-2	-14	7	-9	16
	W.122° long.	0	32	-4	25	-5	23	-7	19	-4	25	-3	27
Pennsylvania	N. 41° lat.	-3	27	-8	18	-19	-2	-20	-4	-21	-6	-15	5
	S. 41° la.	0	32	-6	21	-13	9	-14	7	-14	7	-8	18
Rhode Island		1	34	-3	27	-12	10	-13	9	-13	9	-7	19
South Carolina		5	41	-1	30	-5	23	-5	23	-3	27	-2	28
South Dakota		-4	25	-14	7	-24	-11	-27	-17	-24	-11	-18	0
Tennessee		1	34	-5	23	-9	16	-11	12	-9	16	-4	25
Texas	N. 31° lat.	3	37	-6	21	-9	16	-13	9	-9	16	-7	19
	S. 31° lat.	9	48	2	36	-2	28	-3	27	-1	30	2	36
Utah		-2	28	-11	12	-14	7	-18	0	-14	7	-8	18
Vermont		-3	27	-8	18	-20	-4	-23	-9	-24	-11	-15	5
Virginia		2	36	-3	27	-9	16	-11	12	-9	16	-4	25
Washington	E.122° long.	-2	28	-8	18	-11	12	-18	0	-11	12	-8	18
	W.122° long.	0	32	-3	27	-3	27	-7	19	-4	25	-3	27
West Virginia		-3	27	-8	18	-15	5	-16	3	-14	7	-9	16
Wisconsin		-3	27	-14	7	-24	-11	-28	-18	-24	-11	-18	0
Wyoming		-4	25	-15	5	-18	0	-26	-15	-19	-2	-16	3

Using Additives for Improved Storage and Handling

Additives that lower the fuel's pour point and the temperature at which the fuel could cause a filter to plug are called flow improvers. Flow improvers are of polymer-type compounds. They do not reduce the fuel's wax content, but limit the size of wax crystals to reduce the potential for filter plugging. Flow-improvers are used in small concentrations and can lower the CFPP by several degrees. Cold-flow additives can effectively depress pour point, but will not change the fuel's cloud point.

Additives may be expensive and therefore they must be shown to be effective by careful evaluation before and during their use. Additives may offer a range of effects on different heating fuels. The following chart provides an example of the effects of three commercial cold-flow additives on depressing pour point temperatures. The effects are compared to the base fuels, which do not contain additives. Data is provided for two different heating fuel samples that have been treated with the additives at the same treat rate.

Figure 4-2 Additive response to pour point temperatures

It is important to test your additive against the base fuel you use to find the most effective additive to depress pour points.

Blending with Kerosene

Blending heating oil with substances containing lower wax content, such as kerosene, could effectively lower the cold-temperature operability limits, including both cloud and pour points. Kerosene is a solvent that dissolves wax by changing its solubility in the fuel. How much kerosene or flow improvers used must be judged on the base fuel and the additive that you may be using. Careful analysis based on testing is the most effective method of determining the most cost effective approach. You will have to analyze whether blending with kerosene or with additives is more economical based on the costs of those two products and their effectiveness. (See Figures 4-3 and 4-4 on the next page.)

The following charts provide an example of the effects of kerosene blending on two different heating fuel samples. The base fuels were blended at 30, 50, and 70% by volume of kerosene. Reported here is how much the pour point was reduced by adding kerosene as compared to the base heating oil sample (without kerosene). This is called the pour point depression and will be different for different fuel samples.

Figure 4-3 How kerosene affects pour point temperatures

Example: If the Temperature Depression is -20°F , with a blend of 50% kerosene, this means that if the base fuel had an initial pour point of $+5^{\circ}\text{F}$ the blend will now have a pour point of -15°F . At this point the fuel can't flow.

Figure 4-4 How kerosene affects cloud point temperatures

Note: This chart gives temperature depression, or temperature reduction, for cloud point. This is a comparison of the different blends when compared to the base fuel (no kerosene).

How to Evaluate Cold-Flow Additives

Cold-flow additives may be referred to by many different terms, the more commonly used within the industry include:

- Cold Filter Plugging Point (CFPP) additives
- Pour point depressants
- Cold Flow Improvers (CFI) — generally a CFPP and pour point additive combination
- Low Temperature Flow Test (LTFT) additives
- Nucleators
- Wax modifiers
- Wax dispersants – Wax suspension agents
- Cloud point depressants

The following lists some of the more common performance tests used to evaluate the fuel's response to cold-flow additives.

Performance Test	Method
<i>Cloud Point</i>	<i>ASTM D2500 This test indicates the temperature when wax becomes visible in the fuel. Operability problems may occur when ambient temperatures fall below the fuel's cloud point (CP) temperature.</i>
<i>Pour Point</i>	<i>ASTM D97 This test measures the gel (or freezing) point of the fuel. To prevent blockage of the fuel line the operability temperature limit is always higher than the pour point (PP).</i>
<i>Cold Filter Plugging Point CFPP</i>	<i>ASTM D6371, IP 309, CEN 116 This test was developed to find the lowest temperature that a diesel fueled vehicle could start and operate. This is the industry standard for vehicular fuel in Europe and is commonly used in the U.S. In Germany, the specification for heating oil (DIN 51603-1) considers both the CP and CFPP to define acceptable low temperature behavior.</i>

Additives should be used only when needed to prevent or solve a problem. When comparing additives consider the following:

- The fuel response to a given additive must be measured to determine the amount of additive needed.
- Additives are fuel specific (varies with crude type) and may perform well in one fuel and poorly in another. It is therefore recommended to test several different batches of fuel.
- In order to make an informed decision, comparison tests should be done where all conditions are controlled and the only variable is the additive. This requires laboratory analyses in order to measure effectiveness at various additive concentrations. The costs can be compared with the various options to improve cold flow.
- A comparison of additive response may be made with kerosene blending to achieve the same response.

Mixing

Additives will not fix the product in tanks that have already formed wax crystals. For a cold-flow improver to work it must be mixed thoroughly with the fuel so there must be no undissolved wax present. It should be added to a tank before the fuel is put in so that mixing takes place. When adding a cold-flow improver the fuel must be at least 5 to 10°C above its cloud point. Pouring it in the top of a tank in which the wax has dropped out of the fuel is a waste of time and money. This is not true for kerosene which can help to dissolve the wax.

Application

Where there is a potential problem with gelling in fuel lines, such as with outdoor tanks or exposed piping, the cold-flow additives are effective to prevent fuel delivery problems. It is important to know whether these additives are already present in the fuel as received from the supplier. The first increment of additive is most effective, and if the fuel marketer is planning to use the same type, additional amounts may produce little or no improvement.

Commercially available cold-flow improvers are often combined with detergents and other additives sold as fuel conditioners. If such additives are used in bulk tanks the detergent in the additive can strip rust and dirt from tanks, which may then lead to reduced filter life. It is recommended to remove water and loose dirt from tanks before dosing with the product or check for detergency effects on a few small tanks.

Cost Analysis of Fuel Additive Treatment vs. Kerosene Blending

The cost of additive treatment will vary depending on the performance required. A comparison can be made to the cost of kerosene blending for the same performance. A cost analysis will help the fuel marketer make an informed decision on the most cost effective way to ensure adequate winter operability performance.

Fuel additive treat costs should be compared on a cost per gallon basis. Typical costs for an additized "winter" fuel will be between 1 to 5 cents per gallon. The actual cost depends on the level of additive needed. The fuel marketer or consumer should get enough supporting data from the additive supplier to assure that they are receiving adequate improvements at the specific additive treat rate and cost.

To compare the costs of blending with kerosene and treating with a cold-flow additive use the following example:

Additive Treatment or Blending with Kerosene?

STEPS to CALCULATE COSTS

- (1)** Determine the cost of kerosene and No. 2 heating oil (\$/gallon)

Let's say we will be treating 42,000 gallons of fuel (or 1000 barrels of oil).

Assume that kerosene costs \$0.08 per gallon more than No. 2 oil.

- (2)** Determine the kerosene blend ratio needed based on your fuel properties and cold-flow requirements. (i.e. 50/50, 70/30, etc.)

Let's say that we wish to blend at a ratio 50/50 to reduce the pour point by up to -23°F .

(Note: You will need to know the pour point of the fuel you wish to treat. You can get this from the specifications provided with the fuel or else send a sample to an analytical lab to determine this value.)

- (3)** Determine the amount of kerosene needed (gallons) and its cost.

The 50/50 blend costs: $21,000 \text{ gallons} \times \$0.08 = \$1680$.

- (4)** Determine the treat rate and cost of additive (\$).

Given our sample data on pgs 23-24, "Additive B" will do the job at a treat rate of 1000 ppm or 300 pounds/1000 barrels.

Assume additive treat cost to be \$2.00 per pound,

300 pounds to treat 42,000 gallons of No. 2 oil $\times \$2.00 = \600 .

- (5)** Calculate the cost differential (kerosene cost - additive cost)

The cost difference is \$1080. per 42,000 gallons of fuel.

The result is a net savings of \$0.025 per gallon using a cold-flow improver instead of the 50/50 kerosene blend. A higher kerosene blend (i.e. 70/30), if needed, would cost even more, thus making the additive treatment the better option.

5. Common Fuel Problems

Fuel Cleanliness

The most common heating oil burners in the U.S. and Europe are the high-pressure atomizing gun burners. The nozzles in these burners are designed to spray fine droplets of oil at pressures 100-175 psi for good combustion. The nozzle also meters the oil at specific firing rates; generally these burners operated at or above 0.5 gallon per hour. Because the passages are small the tendency for particulate contamination is greater at low firing rates. As new technologies emerge with highly efficient boilers and furnaces, fuel cleanliness and proper filtration become more important to allow for the lower firing rates.

Clean fuels will also reduce the tendency for oil line and filter prematurely clogging. Filters are used to prevent fine particles from getting to the pump, clogging strainers and the nozzle.

Water

Water and dirt can lead to filter plugging and tank corrosion. The water in the fuel can promote the growth of bacteria, yeast, and fungi (also known as microbes).

One of the most effective ways to keep the fuel clean is to minimize the water that accumulates in the tank. There are several pathways that water can get into the tank:

- Broken or loose fittings on the tank;
- Moisture from the air can condense on the walls of the tank;
- Water in the fuel itself (dissolved and free water);
- Rain water or snow entering the tank during fill-up

By far the most common entryway, especially for outdoor tanks, is through the fittings. Finding the right location and proper installation are the keys to reducing water accumulation in this way. Stick the tank with water-indicating paste at every service interval to get an estimate of how much is at the bottom of the tank. This can quickly tell you if this is the cause for burner shutdowns. You may need to stick the tank in more than one location to assess the problem. For tanks with a top-feed oil line from the tank it may be necessary to remove the line and stick the tank from this bung. In a tank that may be sloped slightly, you may find that the water has collected at the intake of the suction line. Pumping out the tank or replacing it are the only solutions.

How much water do we collect from condensation in tanks?

Condensation of moisture in the air can occur on the interior walls of the tank when it is empty or partly filled. The space above the fuel level is filled with air that can move in and out of the vent pipe due to differences in temperature or pressure. Free water that collects on the walls runs down the side of the tank and settles to the bottom.

A small-scale test was setup to estimate the amount of water that can accumulate in tank bottoms that is associated with condensation of moist ambient air and natural tank breathing. A "greenhouse" was setup to simulate broad-range conditions that might be experienced during hot and humid summers by day and night. Electric heaters, and humidifiers provided air temperatures of about 90°F (day) and 68°F (night), and relative humidity about 85% - 90%. Lights were installed to provide additional radiant energy during the day.

Individual 5-gallon cans were filled with heating oil to different levels from 10% to 90% of total volume. Smaller fuel samples filled pint-sized glass jars for observations. Open "vents" were installed on the fill openings to allow for natural air movement as we cycled between day and night time temperatures. This test was conducted over 4-month storage period.

Figure 5-1 Condensation Test in Small Tanks

Samples in 500 ml glass jars.

Figure 5-2 Condensation In Partially Filled Tanks.

These photos show the internal walls of the 5-gallon cans that were 10% and 90% full. In the partly filled tank at 10% full, there is some surface corrosion where water condensation occurred.

Surface corrosion above fuel level

Tank bottom

During this test period small amounts of water were found in some of the small glass jars particularly those that were partly filled. The photos below show a comparison between the 10% and 90% full jars. The nearly full jar had little water.

The amount of condensation collected was small during this test period and amounted to about 0.1% of the total volume of the container (1-pint jar). **Assuming similar conditions for an empty 275-gallon home tank located outdoors, you may collect about 1 quart of condensed water in this type of hot and humid environment over 4 months.**

Where there are lower humidity levels, generally in the Northeast of the country, this amount of condensation could take longer to accumulate (i.e. over 2 or 3 summers).

Figure 5-3 Water condensation test over 4 months

Keeping outdoor tanks full will help to minimize water condensation in tanks.

Products of Fuel Degradation

Certain fuel components are reactive and will oxidize to form other components that are not soluble in the fuel. Varnish or gums are oxidation products that can coat piping, fuel pumps, and burner nozzles. The term sludge usually refers to the heavy, dark-colored deposits that settle to the bottom of the tank. The rate of decomposition of fuel through various degradation processes is related to its stability.

Over time gum, dirt, water, and rust will accumulate at the bottom of the tank, and this is commonly referred to as Bottom Sediment and Water (BS&W). This mixed layer of sludge can lead to plugging of fuel lines and filters.

The nature of the sludge components could be identified by infrared analyses (FTIR). Representative samples collected from various home tanks were analyzed in this manner.

The most significant components of sludge are heavy fuel components (such as gum) caused by the oxidation and degradation of fuel, water, traces of dirt and rust. These components foul tanks, filters, and piping.

What to do about clogged fuel lines?

Taking a tank bottom sample is the best way to find out how much sludge has accumulated in your tank and if this is what is causing your burner to shut down. Refer to Chapter 6 and the section on How to Sample Home Tanks. If the oil intake is located near the sludge build-up then all this sediment can easily be drawn into the oil supply line. If these contaminants are stirred up after a recent fill-up of the tank the burner can also shut down.

The following photos show the condition of a fuel supply line found in a test home that had problems with repeated burner shutdowns. The tank is about 25 years old and is set up as a single-pipe system with fuel drawn from tank bottom outlet. There is a history of line clogging problems at this site.

Figure 5-4 Clogged copper fuel line in a 1-pipe system

This is a bottom-draw oil supply from the tank that is intended to minimize sludge accumulation within the tank. The water and contaminants however tend to get sucked into the oil lines and deposit inside the lines. Over time this would prevent oil from getting to the burner.

The next page contains recommendations for clearing clogged lines.

Recommendations for clearing clogged lines.

- Clear the lines by using a hand-pump to draw out the sludge away from the tank as opposed to blowing the line back into the tank with compressed air or CO₂ cartridges.
- Pushing the contaminants back into the tank will only allow it to get drawn back into the oil line; this then becomes a chronic problem.
- Replace all fuel lines when replacing an old tank. Both 1-pipe and 2-pipe systems are susceptible to clogging.
- A coarse filter with a water separator near the tank would help to keep water and sediment out of the lines.

Keep fuel oils stable by keeping the fuels clean and maintaining the tanks:

- Ensure that the fuels you are supplying to your customers are clean and free of water.
- Inspect your fuel supply. Check for water and sediment in your bulk storage tanks. Check the cleanliness of your delivery trucks.
- Check home tank bottoms by sticking for water or taking sample.
- Pump out tanks that have sludge build-up.
- Locate tanks away from direct exposure to the sun to minimize high temperatures and degradation of fuel.

Microbial Contamination

Heavy microbial contamination can lead to costly service problems and is a concern for the petroleum industry from crude oil production, through product transfer, storage, and finally consumer use (Figure 5-6). The potential losses include not only equipment failure and downtime for repairs, but also customer satisfaction.

Throughout the distribution system there are many possible routes where water can enter the system and be transported along with the fuel. Microbes may be introduced into fuels as products cool in refinery tanks. Bacteria and fungi (microbes) carried on dust particles and water droplets could enter tanks through tank vents. Barges often use sea water as ballast, and this can contaminate stored product if compartments are not adequately emptied before refilling. Water can enter tanks through broken fittings and improper installation.

The costs for decontaminating facilities or tank cleaning are high. Prevention of problems by good housekeeping and regular monitoring is more cost effective than the treatment of microbial problems after they occur.

Figure 5-5 Blue arrows show sites where water and microbes tend to accumulate.

Wherever water tends to accumulate, even in small amounts, microbes (such as bacteria, yeast and fungi) can grow. There is often enough water in the bottom of large storage tanks, fuel tanks on trucks and consumer tanks for some microbial growth to occur. The microbes tend to be most active between the water and fuel layers, and also on internal tank and fuel delivery system surfaces. When the tank contents are disturbed, for example when the tank is refilled, the microbes become suspended in the bulk fuel where they cause fouling and may be passed on down the distribution chain to contaminate facilities downstream. In a homeowner's tank these microbes can clog fuel lines, filters and nozzles causing burner shutdowns.

It is recommended that fuel supplies be checked for suspended water before being accepted and transferred into a bulk storage plant. The barge operator should not only sound the tank to

verify the amount of fuel to be delivered, he should also verify whether or not there is any water at the bottom, and also be able to provide you with a tank bottom sample. These procedures are quick to do and would provide the retailer an indication of the cleanliness of the fuel when it is received. If contamination exists filtration and separation of water from the fuel by settling may be necessary to prevent transferring any contamination to your delivery trucks or customers' tanks downstream. Chapter 6 gives guidelines on how to sample fuels from a barge, bulk storage tank and truck, and how to diagnose problems.

Microbial Effects on Tanks and Fuels

Microbes need water and a source of food. The fuel itself serves as a source of carbon, hydrogen, oxygen, nitrogen, sulfur, and phosphorus; other elements found in fuel storage systems such as calcium, sodium, iron, nickel, copper, and other metals feed the microbes.

Biological material, which appears as a slimy mass, can get trapped in the fuel delivery system and clog the filter restricting the flow to the burner.

Figure 5-6 Microbial growth observed in container previously storing fuel oil.

Most bacterial growth takes place at the boundary between the fuel and water. This usually occurs at the tank bottom, although microbes also can stick to tank walls. They can produce a slimy layer called a biofilm that adds to the bottom sludge and sediment. The byproducts of microbial activity, or wastes, cause the fuel to degrade and physical damage to the fuel delivery system. Under the right conditions, usually hot and humid conditions, their uncontrolled growth leads to problems such as filter clogging and fuel lines plugging.

Microbes can cause corrosion of metals including steel, iron, copper, nickel, aluminum, and their alloys. They can even affect the integrity of nonmetals such as plastics and composites. Microbially induced corrosion, or MIC, of metals is caused by various direct and indirect mechanisms. The best known, direct mechanism involves the action of sulfate reducing bacteria (SRB) that grows in water and sludge in the bottoms of tanks. SRB can cause pitting corrosion in steel tanks. In this process SRB uses the sulfates found in the fuel to develop an electrochemical corrosion cell, altering the condition on the metal surface and enhancing corrosion that would not occur in the absence of these microbes. This usually occurs along the bottom centerline of the tank where water tends to accumulate.

Microbes can affect the integrity of the fuel storage system by leaving behind waste products of its activity. Byproducts containing organic acids accelerate corrosion through indirect mechanisms that chemically etch the metal. Certain bacteria produce hydrogen sulfide, usually detectable as a foul odor that sours the fuel and affects its stability. Other wastes called surfactants produced by microbes can promote the suspension of water in the bulk fuel causing it to become hazy, and making it difficult for fuel-water separators to work properly. This results in increased water content in the fuel and potentially causing further corrosion problems in pumps downstream.

Identifying Microbial Corrosion

Microbially induced corrosion on steel surfaces can be identified based on three types of evidence:

- Surface appearance of the corrosion damage. SRB causes slope-walled pits within pits.
- Biological cell counts of SRB, and general bacterial population.
- Chemical identification of corrosion products and other deposits. This usually includes soft, black corrosion products rich in iron sulfides overlying severe pitting.

Refer to Chapter 6 for guidelines on how to use field test kits to determine microbial contamination.

6. How to Diagnose Fuel Problems

Monitoring the fuel is an essential part of maintaining good fuel quality. The following are guidelines for evaluating and accepting fresh fuels, and monitoring of stored fuels. Stored fuels will age over time and form sediment that contributes to sludge at the bottom of the tank. There are basically two ways by which fuel quality can degrade: (1) by contaminants introduced during fuel delivery and storage, and (2) sediment formation from unstable fuels.

The only way to identify if there is a fuel quality problem that could lead to service problems downstream is to know the condition of the product. Sampling and analyses should be done to quality control the fuel oil as it is received from the supplier, while it is stored at your bulk terminal, and during transport in the delivery trucks. Once the product is delivered to the customer and stored in his tank, all service problems should begin with a diagnosis of the fuel in the home tank, the condition of storage and fuel delivery system (oil supply lines to the burner, fuel pump/ strainer, filter, nozzle).

The types of contamination that could occur during distribution and storage:

- Other products — gasoline
- Water, dirt (leading to filter plugging and tank corrosion)
- Off-specification fuel (high cloud, pour points)
- Trace metals – copper, zinc (accelerates oil degradation)
- Microbes/ microbial growth (filter plugging, corrosion of metal tanks)

Contamination with other petroleum products can affect flash point (with gasoline), or viscosity and boiling range (with heavy oils).

It is important to continuously monitor the condition of the tank so that any accumulation of water and sediment at the bottom is removed periodically. Inspection and water draining should be done at least annually. Water promotes corrosion and bacterial growth at the fuel-water interface.

Simple Tests to Quickly Evaluate Fuel

Clear and Bright Test (ASTM Method D 4176)

This is a quick and easy test that allows you to visually inspect the fuel supply you are buying in the field. You can determine if there is suspended free water (haze) and contamination with solid particles.

You need: 1-quart clear glass jar, 4-oz. bottles

Bar chart and haze rating photos (Example shown on the following 2 pages)

Method:

- Take a sample of the fuel from the tank or truck and fill about 90% of the jar.
- Place the bar chart behind the jar. Compare the appearance of the bar chart through the sample with the standard photos. Look at the comparison of the lines and how they fade gradually. Ignore the color differences. However, if the fuel is too heavily dyed or the fuel is too dark to allow you to see through the jar, pour a smaller amount of fuel into the 4 oz. bottle.
- Record the number on the photo that the sample resembles most. This is the rating.
- Hold the sample up to the light and check for haze or clarity. Swirl the sample to produce a vortex and examine the bottom of the vortex for particles.
- Record the following observations:
 - Was it clear and bright? Or not?
 - Were there particles?
- Record the outdoor temperature or the fuel sample temperature if different.
- Record your observations if the fuel appears darker than usual.

The fuel should have no water or particles, and this is considered “clean and bright.” When compared to your observations of typical fuels, the haze rating could give you an indication of an unusual batch of contaminated or off-specification fuel.

If a sample is taken when the outdoor temperature is cold, small amounts of wax particles may settle out and cloud the fuel; this should not be confused with a water haze. These wax crystals will clog filter systems in your fuel delivery system. Check for the Cloud Point (ASTM D 2500) and Pour Point (ASTM D 97) temperatures of the fuel. The fuels you store and use should have cloud and pour points well below the outdoor temperatures in your geographic region. If they are not, you can expect cold-weather operability problems. Refer to the previous section on Cold Flow Properties of Heating Oil.

Figure 6-1 Bar Chart for Clear and Bright Test

Copies may be obtained from:

American Society for Testing and Materials

100 Barr Harbor Drive

West Conshohocken, PA 19428-2959

ASTM Designation: D4176

PCN: 12-44176012

Figure 6-2 Haze Rating Standard for Clear and Bright Test

EXAMPLE ONLY

ASTM
American Society for Testing and Materials
1910 Avenue of the Americas
Philadelphia, PA 19103
610-855-7800
www.astm.org

How can you do a visual inspection of heating oil with the dye?

The Clear and Bright Test method for "Free Water and Particulate Contamination in Distillate Fuels," ASTM D 4176, is a very quick and easy tool to estimate the presence of water and contaminants by visual inspection. This is an accepted method for "clear" fuels (amber) like diesel fuel. Using a 1-quart, clear glass jar all one needs to do is to examine the fuel for clarity. The procedure comes with a chart and haze (water) rating photos for comparison.

In heating oil, the dye, which can appear dark in some fuels, makes this visual test hard to do. However, if a smaller sample is used and placed in a 4 oz. bottle, some water, haze, or contaminants may be more easily observed. For low levels of contamination it may still be difficult to detect. Nevertheless, it is highly recommended that the quality of your fuel supply be inspected on a consistent basis.

Figure 6-3 Checking heating fuel for clarity.

If you see a haze, there is something wrong with the fuel. There is either water in the fuel or wax settling out of the fuel if the outdoor temperature is below its cloud point.

Fuel Sampling

The integrity of a fuel sample is critical to getting useful information from the fuel's analysis. If the sample is not properly taken and stored, the results you get may not be representative of the actual condition of the bulk fuel or give the correct indication of a potential problem. Detailed procedures for proper sampling can be found in the procedure, ASTM D 4057 – Standard Practice for Manual Sampling of Petroleum and Petroleum Products.

The basic principle of this procedure is to obtain a sample or a mixture of several samples that represent the material in a truck or storage tank. Depending on where you are sampling from and for what purpose, there are several different types of devices that can be used to collect a fuel sample. Guidelines for manually obtaining spot samples of fuel oil are described in detail in the following sections.

Sampling Tips

- Use clean sampling devices and new sample containers.
- Check to make sure how much total volume of sample is needed to conduct all the tests before a sample is taken. A 1-to-5 gallon total sample size may be necessary, depending on the number of tests. Determine the appropriate type of sample containers needed. A 1-gallon epoxy-lined can would be ideal for most tests on bulk samples; a 1-quart plastic (Nalgene) bottle for bottom samples will do for sediment tests.
- Sample containers should be filled to minimize headspace, but no more than 95% full to allow for expansion.
- Use the appropriate device for pulling bottom samples. The devices should be cleaned after each sample has been taken to prevent contaminating each successive sample. A little rubbing alcohol will do.

How to Sample Incoming Fuels from Barge

The following describes a procedure for checking the quality of the product delivered. The most common and cheapest way of obtaining a representative fuel sample is by using a drip-type sampler. This sampling procedure is often done on a bunker offshore for fuels brought in by ship or barge. It would also be applicable for onshore terminal tanks. The best location to install the sampler is at the end of the delivery hose at the manifold to the tank.

The figures below show samplers that are commercially available. This is an example of how to position the sampler with the minimum working clearance required. The fuel is collected in a cubitainer. This plastic container, with a capacity of about 1 gallon, is attached to the needle valve of the sampler.

Figure 6-4 Drip Sampler Located Between the Manifold and Delivery (Kittiwake)

Figure 6-5 Examples of Manual Drip Samplers (Kittiwake or DNV)

Operating Drip Sampler

The tube within the sampler and sample valve should always be cleaned before use. This can be done by removing the tube, simply flushing it with a clean distillate fuel (such as kerosene) and allowing it to drain thoroughly before installing. The tube should always be installed with the holes facing the direction of the incoming fuel.

When fuel transfer starts, place a container under the sampler, open the sampler valve fully and flush the sampler with fuel. Close the valve and attach a cubitainer onto the valve as shown. If the sample is required only for testing on site, then it is possible to substitute a single sample bottle in place of the cubitainer.

Adjust the needle valve to give a slow and steady drip. Time the fill rate to estimate that it will provide for sufficient sample over the expected delivery period. Place an empty cubitainer on the sampler and continue to draw a sample. On completion of the bunkering, remove and seal the cubitainer, fully open the sampler valve and allow the sampler to drain.

Always close the sampler valve before blowing through the fuel lines on completion of bunkering.

Close the sampler valve if pumping stops, to prevent the sample being drawn back, under vacuum, into the fuel line.

Always get the barge operator to witness removal and sealing of the cubitainer. If this request is refused, or if no witness is provided, then note this in the delivery log.

Specification Testing

Section 3 on purchasing fuels lists the fuel properties and tests that should be done for these samples. Private testing laboratories that specialize in analyzing petroleum samples can perform tests for fuel properties specified in ASTM D 396 for burner fuels. ASTM International maintains a Directory of Testing Labs on-line with full text search for services and locations of testing laboratories. The information on the types of tests performed, specific tests performed, materials analyzed, or other services offered has been provided by the laboratories. Refer to this most useful website,

<http://astm.365media.com/astm/labs/index.html>

How to Sample Bulk Storage Tanks

For large distributors sampling the fuels in the bulk tanks at your terminal gives you an idea of the condition of the fuels as stored, and what is being delivered to your customers. If you have already checked the quality of the incoming fuels, be aware that any potential contaminants existing in your storage tank can affect the overall quality of the fuel supply.

Bulk Samples

To look at the condition of the fuels in the bulk tanks, take samples from a variety of levels in the tank, including a bottom sample. Access to the fuel in the bulk tank may be from a hatch at the top. To get a representative sample of the bulk fuel from a tank, take samples from different levels (i.e. top sample, middle, lower) and combine them into one sample. This will give information on the general quality of the product. Taking a sample from the tank's bottom allows you to determine how much contaminants (water, sediment, sludge) may be accumulating. It will also give an indication of potential problems with the tank. For example, rust could indicate corrosion of the internal tank surface.

Figure 6-6 Sample locations in a bulk tank.

Figure 6-7 Sampling from a bulk storage tank

**Bottle cage to
be used with
Boston Round
Bottle**

Zone Samplers made of clear acrylic tube or stainless steel

These bulk samples give valuable information on the general condition of the fuel. A moderate to large sample size is required dependant upon the test matrix. Analyses of these samples should be done when you suspect contamination in the tank, contamination with other products, or cold flow properties are off-specification.

Samples can be obtained by bottle sampling using a bottle cage with a glass, Boston round bottle (16 or 32 oz.). Brown glass bottles protect the sample from light, which may affect results.

Zone samplers (shown above) are also simple to use and versatile for sampling product from stationary tanks, tank vehicles, and tank ships. This sampler can take all level samples of liquid products. This type of "fuel thief" is typically 1 in. diameter or larger, and varies in length. A check valve or a ball valve at the bottom of the thief remains open as the sampler is lowered. When the sampler is held stationary near the bottom of the tank, the check valve closes, effectively containing a column of fuel.

Line Samples

A line sample is another way to sample a tank if accessing the tank interior is difficult. Clean sample containers can be filled directly from a pipe or spout. For samples taken during loading (such as into the bulk tank and at the rack) allow for about 300 gallons of fuel to be dispensed before filling sample container. Fill container to within 1/2 inch of the top then cap immediately.

Figure 6-8 Line sample from bulk tank collected in epoxy-lined can.

Bottom Sample for Water and Sediment

Check tank bottoms for settled water, sludge or microbes (bacteria, yeast, fungi) taking a sample with a Fuel Thief, or Bacon Bomb sampler. Only a small sample size is required. This consists of a stainless steel cylinder tapered at both ends and fitted with an internal, plunger type valve. The valve opens automatically when the sampler strikes the bottom of a tank and closes when lifted.

**Figure 6-9 Bacon Bomb with extension rods to sample from tank bottoms.
The (4 oz.) 1" diameter one is also referred to as the Pencil Bomb.**

This is preferable to using the water indicating paste on a stick, as a sample can more easily be inspected visually. Unless there is more than about 1/2-1" depth of water, it is hard to detect it on the stick. An emulsion at the bottom (water and sludge mixture) can also displace the water from the paste, which may appear as spots on the paste. This does not mean there is an insignificant amount of water, as it does not take much to cause corrosion or support bacterial and fungal growth. A sample may give evidence of rust flakes or a slimy type of microbial growth.

How to Sample Transport Trucks

If there is suspected contamination of fuel during transport, a bulk sample and/or bottom sample from a large transporter truck or small delivery truck may help to diagnose the source of the problem. The same types of manual samplers used for bulk tanks will be useful here.

Figure 6-10 Sampling a delivery truck with Bottle Cage Sampler.

How to Sample Home Tanks

Sampling from small residential tanks requires an accessible bung with an opening of 2" diameter minimum. A bottom sample is most useful to assess the cleanliness of the tank. For customer accounts that have repeat calls, there may be problems with heavy sludge accumulating at the bottom of the tank. Take a sample with a fuel thief or a hand pump to look at the condition of the tank bottom. This will tell you how much water, sediment, or rust there is.

Figure 6-11 Bottom sample taken with a Pencil Bomb or Fuel Thief.

Check the level and pitch of the tank. Pull a bottom sample from the low end of the tank if possible. You may wish to take additional samples near the fuel supply line or from the fill-pipe. Tanks are sometimes installed with a slight tilt to allow water to collect in one end. Take note that when a sample is drawn from a port not located at the low end of the tank, sludge or water may not be detected. For large tanks it is recommended that samples be taken from more than one location to ensure that water and any contaminants are detected.

Testing for Microbial Contamination

Tank bottom samples are best used for evaluating microbial contamination. These may either be tested by a laboratory or in the field for biological activity. This section covers how to use field test kits to assess microbial contamination.

Water in the tank bottom promotes microbial growth and it is expected that slight infestation is typical. However, under conditions when there is heavy growth, thick mats of materials that form could lead to filter plugging problems and tank corrosion.

Estimating the amount of microbial growth can be conveniently done with the use of field test kits available on the market. Several suppliers use solid test media on dip-slides and liquid media in pre-measured vials. They contain sample bottles, the nutrient, and an indicator (dye or chart), and results can take 2 to 5 days depending on the type of kit.

While laboratory testing for biological growth can give more precise results in terms of cell counts (i.e. organisms/ml), they are usually more expensive. In addition, unless the samples are very carefully packed in cold storage, the results may be misleading because of the time lag between taking the sample and getting it to the laboratory.

These kits are much less expensive than laboratory analyses. Although they are not as accurate, they require very small samples (about an ounce) and can effectively tell you if you have slight, moderate, or heavy infestation of microbes. Essentially this is all you need to know to determine your next step of action. Some commercially available field test kits include:

Products:

1. Hum-Bug Detector® Kit. (Hammonds Companies)
2. Liqui-Cult Microbial Test Kit (Metalworking Chemicals & Equipment Co.)
3. Microb Monitor 2 (ECHA Microbiology, Ltd.)
4. EasiCult (Orion Group)

Use your observations (color, odor, clarity) in addition to the microbial tests to help you to identify microbial problems.

- Check for microbial mats or slime.
- A blend of brown to red, or black material in the fuel or water layer indicates the presence of microbes.
- Hydrogen sulfide has a rancid odor and indicates heavy microbial contamination.

Figure 6-12 Obtaining 5cc of bottom sample for microbial field test (left); injecting sample into aqueous broth for detecting bacterial and fungal growth (right).

Figure 6-13 Example of fuel oil sample in a test vial at the start of the test.

Figure 6-14 Examples of fuel oils after an incubation period of 30-hours (Liqui-Cult, MCE). Color change in the broth medium (bottom layer) from clear to pink indicates bacterial growth.

Take note of your results...

Slight or no growth: Low levels of microbial growth won't affect your fuel delivery system and will have little effect on fuel clarity.

Moderate growth: This could potentially be a problem site if materials can be drawn into the fuel line.

Heavy growth: If you are getting repeated no-heat calls, burner shutdowns due to filter and line clogging, then its time for mechanical cleaning and/or chemical treatment, or as a last resort tank replacement.

Prevention and Control

Microbial control requires a strategy with consideration for tank system design, appropriate sampling and analysis protocols, monitoring, and remedial treatment.

The approach to prevention of corrosion in storage tanks is the following:

- Good tank system design and operation to minimize water entry. Proper installation and tank location, having adequate inspection port for sampling, water removal, and cleaning when necessary.
- Remedial treatment includes fuel filtration, biocide treatment when needed, tank cleaning and disposal of contaminated fuel.
- Tank materials selection includes non-metallic materials to avoid corrosion, or coatings to isolate the steel surface from water. Cathodic protection (CP) can prevent corrosion, including microbially induced corrosion. It should be noted that CP is generally applied to external surfaces; protecting inside surfaces requires CP to be applied inside of tanks.

References:

1. ASTM D 6469 Standard Guide for Microbial Contamination in Fuels and Fuel Systems
2. ASM (The Materials Information Society) Handbook, Volume 11, Thomas R. Jack, Biological Corrosion Failures

7. Assessing "Problem" Home Tanks

Many "problem" tanks share common causes, which are identified below. These problems greatly affect fuel quality and the reliability of heating system performance. Recommendations on how to solve these problems are included.

Water and Sludge Accumulation in Tanks

- The primary entryway for water in outdoor tanks is through loose and broken fittings. Check for these types of leaks and where possible consider installing new tanks indoors or in a sheltered location.
- Consider where you locate a new tank, especially for outdoor tanks. Check that you do not install under the edge of the roof where rainwater or snow can fall directly onto the top of the tank. The rainwater tends to seep through loose-threaded fittings; using pipe dope and making sure that fittings are secure helps to minimize these problems.
- Condensation of hot, humid, air in the tanks can slowly add to the water collecting at the bottom of the tank. This occurs as a tank "breathes" through the vent during the filling operation, drawing of fuel from the tank, and temperature changes experienced in outdoor tanks. Without periodic water removal, the amount of water that could accumulate after many years could be appreciable. Using a long measuring stick and water-indicating paste will help you to monitor the tank for water.

Figure 7-1 Detecting water using stick and water-indicating paste

Color change showing
presence of water

- Be aware that water can be introduced into tanks from other ways; water can be delivered along with the fuel if it was already contaminated. Periodically check for water and cleanliness of the fuels received from your supplier. Sample to check that your tanker truck and/or bulk storage tanks are clean and dry.
- Sludge is a mixture of water, gum formed from the aging of fuels, rust, and microbes (bacteria and fungus). Repeat service calls due to sludge build-up requires special attention. Sampling the tank bottom using a fuel thief allows you to assess its condition and how much build-up there is.
- Collect the bottom sample in a clear, glass jar and take note of what it looks like.

Does the sample taken from the bottom of the tank look like any of these samples?

Figure 7-2 By the sample drawn above, this tank has a problem with excessive water accumulation. You can also detect this much water with water-indicating paste on a stick.

Figure 7-3 This sample contains heavy amounts of degraded fuel products and water.

- With many years of accumulation, the only effective means of removing sludge is through mechanical cleaning.
- Physical cleaning or replacement of heavily contaminated tanks, and replacement of clogged fuel supply lines, are the only effective means to solve these types of service problems.
- A floating suction device used on the fuel supply line may help to reduce the amount of sediment that gets picked up into the fuel delivery system. When a floating suction is used it is essential to monitor and remove the water as it accumulates. This should be done to prevent internal corrosion of steel tanks and to minimize microbial growth.

Fuels Degrading in Storage

- The most important factors affecting storage stability of the fuel are the condition of the tank, the amount of existing sludge, water or microbial growth.
- Most of the incoming heating fuels from major suppliers appear to have acceptable stability. Pipeline sources of fuel tend to be more stable; barged fuels tend to be slightly less stable possibly due to the added handling and transport, longer storage times, and potential contamination.
- Generally, older tanks that have more overall accumulation of sludge show an increased likelihood of service problems. When replacing a tank, do not transfer old fuel into the new tank.
- Newer tanks with little water or sludge have fewer problems with microbial growth and provided better fuel storage stability.
- High sludge content (measured as Bottoms Sediment and Water or BS&W, of 10% or more) results in more clogging problems of the fuel line and filter. You can detect large amounts of contamination at the tank bottom simply by sticking the tank and using water-indicator paste. If the paste color appears spotty, you likely have a mixture of water and heavy components of fuel (an emulsion).
- Tanks with existing sludge problems do not improve with fuel stabilizing additives. Stabilizers are typically designed for use with freshly refined, clean fuels to slow down oxidation and natural aging of fuels.
- Some dispersant-type fuel additives show reduced sludge on filters and may help to maintain cleaner fuel delivery system (supply line, filter, nozzle).
- To minimize fuel degradation during storage, keep outdoor tanks away from direct sun; high temperatures during the summer can accelerate the fuel aging process. Where possible install tanks in shaded areas, or on the north side of homes.

What does a tank bottom sample tell you about its constituents?

A sample taken from the bottom of the tank can tell you how much overall sludge there is and the nature of the problem. Using a method to determine Bottom Sediment & Water (BS&W), such as ASTM D2709, the components of a sample can be separated by density using a centrifuge. This is done with specialized equipment-glass containers and a centrifuge. If you don't own such equipment you can send a sample to a commercial laboratory that does petrochemical analyses. They should also be able to make a determination of the components.

The photos above show examples of fuel bottom samples with different layers of contaminants. The heaviest layers usually consist of sediment and water. The fuel is usually at the top of the sample container, below which there exists an emulsion (fuel by-products of ageing and water mixture). Having some information about the sludge contents allows you to focus your effort on how to solve the problem.

In the above samples, Sample 1 shows water and contaminants as related to fuel-breakdown (an unstable fuel). A pump-out of the contaminants along with improved practices for minimizing water build-up would help to improve the cleanliness and stability of the fuel. Sample 2 shows more evidence of non-fuel contaminants, which indicates that debris may be getting into the tank during filling.

What To Do If the Fuel is Deficient

Fuel is off-specification

Periodically taking a sample of the bulk fuel and testing for its specified properties can give you an indication of the overall quality of the fuel from your supplier. If there is a problem with a fresh batch of fuel, then there are two options. The fuel should not be accepted from the supplier if it is contaminated with water or debris. If there are acceptable ways to bring the fuel back into specifications then the following methods may be considered.

Dilution and Blending. In some cases, when a fuel is off-specification, dilution with another batch of fresh fuel can effectively bring the entire batch within acceptable limits. For example, blending can lower a high cloud point or raise the flash point. Blending should always be done with small test samples and analyzed before attempting mixing the entire stock.

Fuels that are contaminated with microbes, debris, or water should not be blended.

Contaminants in Tanks

Excessive no-heat calls are likely to occur with large amounts of sludge in the tank. Field experience shows that chronic problems occur in tanks having about 1/2" or more water/sludge using the stick and paste indicator, or about 10% BS&W by analysis. Pumping out these most-contaminated tanks and clearing out the oil line would eliminate these service calls.

Fuel lines that are piped from the bottom of the tank are more susceptible to line clogging if there is no filter/water separator at the tank. Where there is no filter at the tank, any sludge or water drawn from the tank would become trapped in the lines.

If water is the major constituent, then you will need to determine where the water is coming from. There may be a broken or poorly threaded pipe, loose fill cap, or a crack in the tank. Keep tanks filled during the summer to minimize the air space above the fuel. This reduces the amount of water accumulation in the tank that comes from condensation.

8. How to Prevent Fuel Problems

A preventative maintenance program should be based on need, resources, and common sense. A successful fuel quality surveillance program must include the following items: (1) specifications when purchasing fuels; (2) sampling, testing and record keeping; and (3) good housekeeping.

Each company should have a set of procedures for the sampling and testing of their fuel supply and bulk storage tanks, where applicable. For home tanks, checking for water should become a routine part of heating systems maintenance. Documentation should be set up so that these efforts can be reviewed at any time. The information on home tanks is valuable for tracking problem areas and for assessing whether or not changes in procedures really worked. This will save money in the long run when you can quickly identify and solve problems.

Good housekeeping requires minimizing dirt and water entering a tank. Water promotes the growth of microbes, which use the fuel as a food source, and accelerates internal corrosion of the tank. Water can enter a tank through cracked or leaking fill pipes and vents, and therefore, these should be checked when water contamination is suspected. The change in air temperatures can cause condensation within the tank. Dirt and debris are generally introduced into the fuel through careless handling.

Technicians who maintain the heating systems and the delivery personnel should be trained on how to identify possible fuel quality problems. Fuels should be checked from the receipt of fuel, through delivery and storage.

Cleaning tanks that are less than 10 years old is not necessary as part of a preventative maintenance program, but there could be circumstances that would make cleaning necessary or desirable, such as a severe accumulation of sludge.

Monitoring Home Tanks

Install Suction Gauge on Filter Housing

A suction gauge can be installed on the filter housing to monitor the condition of the filter insert. A high vacuum indicates when this becomes clogged. For every system the suction gauge reading may be different from the start, when the filter is clean. You need to note the gauge reading when the burner is "off" and when it is "on." Note this on the service tag on the equipment.

When the filter fills with sediment the gauge will read higher vacuum (in-Hg). This should be read when the burner is "on." Comparing the readings of a system with previously recorded readings can guide you as to when you need to replace filters.

Count Your Service Calls

Start with your current service accounts. This is your baseline of information. Count the total number of unscheduled service calls – No heat, no hot water (or not enough), and odor. Note how many customers and how much volume is delivered to these customers. You don't want to count preventative maintenance inspections, new equipment installations, and plumbing or duct problems.

Monitor the service calls each day (24-hr. period) for Jan-Feb when you may have the most calls of the season. Use either:

- Number of service calls per customer, or
- Number of service calls per volume delivered

Put this information on a chart. The number of calls will vary throughout the year with more calls during the heating season. You can compare these numbers on a monthly basis (for example Jan-Feb) from year to year to assess how you are doing with changes to your fuel maintenance program.

How to Store Fuel Oil

Tank Considerations

- An accessible bung should be provided at the top of the tank to allow for periodic inspection for water and sludge. Any accumulation at the tank bottom should be removed on a routine basis so that it will not clog filters or burner nozzles.
- If tank pump-out or replacement is needed, then try to draw down as much of the oil as possible by consuming it, then properly dispose of the bottom fuel. Do not transfer the old fuel to a new tank. Accumulated water, sludge and bacteria will cause your new tank to quickly corrode. Flush out or replace fuel lines to the burner.
- To avoid internal corrosion use non-corrodible tanks (plastic, fiberglass). Interior coatings or linings used in steel tanks that are not completely sealed or bonded can make worse corrosion in exposed areas or surface pitting.
- Do not bury bare steel tanks or piping underground without corrosion protection or leak detection.
- Locate outdoor tanks in cool, shaded areas if possible. This minimizes the exposure of the fuel to high temperatures from direct sun.

Piping Considerations

- Metals such as galvanized steel, zinc, and copper accelerate the breakdown (or oxidation) of oil. Avoid long routings of copper lines between the tank and burner.
- With an outdoor tank all piping should be well insulated from the cold weather. Under extremely cold conditions, untreated No. 2 oil could gel and lead to burner shutdown.
- A floating suction at the fuel intake may help to reduce the amount of sediment drawn into the supply line. Improve the cleanliness and stability of the fuel along with improved practices

9. About Fuel Oil Additives

Fuel oil marketers often use chemical additives to improve handling and storage of fuel. These additives are blended into the oil at the bulk plant storage tanks, in the trucks at the loading rack, or directly into the consumer tanks. Numerous types of additives are available for distillate fuels and, therefore, it is necessary to look closely at the needs and to match them to the product. Described below are categories of additives that perform various functions most relevant to heating oil applications.

Additives should be used only when needed to prevent or solve a problem. Because of their cost, additives must be shown to be effective by careful evaluation before and during their use. Additive evaluation depends on a measurable change in fuel properties and performance. Also discussed below is a generalized approach for evaluation by laboratory analyses.

Additives are fuel specific, which means that they may perform well in one fuel and poorly in another. If an additive is used to modify fuel properties, then specific laboratory test methods should be used to measure the fuel's response to a given additive at the prescribed treatment dosage. An evaluation may require sampling of a series of fuels to represent the range of fuel properties under actual operating conditions, and over a specific time period.

The key to effective additive treatment is to understand the following points:

- **What the additive is used for,**
- **Treatment rate and effectiveness,**
- **Its limitations,**
- **Its costs,**
- **Hazards and safety precautions,**
- **Regulations on the usage, storage, and disposal**

Types of Additives and How to Test for Their Effectiveness

The types of additives an oil marketer will typically encounter are classified as aftermarket fuel additives. These are commercial products that are marketed for use with fully formulated fuels (such as No. 2 heating oil and diesel). Additives should be purchased from reliable sources to ensure that the products effectively meet the claimed benefits.

Multifunctional fuel additive packages classified as fuel stabilizers may contain a mixture of the following compounds:

- oxygen inhibitor (antioxidant)
- dispersant
- corrosion inhibitor
- metal deactivator
- biocide

Multifunctional additives are generally more effective than individual additives in that they can potentially resolve multiple fuel issues that exist with problem fuels.

A series of "screening test requirements" may be developed for aftermarket fuel additives. The requirements should be derived from data obtained through standardized laboratory tests, which enable objective assessments on whether the advertised claims of improved performance can be partially or fully verified, and whether any adverse side effects will occur with use of the additive due to incompatibility with other additives already present in the formulated fuel. All additives should meet such requirements on compatibility, stability, filterability, minimum handling temperature, and/or biocide activity to be qualified for use in a home heating system.

The components of an additive are usually proprietary and, therefore, it is essential to understand how they function and how to measure their performance. The following table summarizes the most common additive types used in No. 2 heating oil and their specific functions.

Stabilizers address the following fuel problems:

- **Control of color darkening**
- **Minimize deposit buildup or sludge during storage of fuel**
- **Improve resistance to fuel oxidation**

Stabilizers cannot reverse the effects of fuel degradation such as color that has changed or sludge that has been formed. It is important to recognize their limitations and therefore stabilizers should be considered only as preventative measures to reduced fuel problems. They are most appropriately applied with fresh fuels. Additives will not clean tanks that contain existing water and sludge. In general, fuel supplies that are already clean and stable do not require additives.

Additive Type Function

Cold Flow Improvers- Polymers	Depress cold temperature operability limit, reduces filter plugging from wax crystals
Detergent/ Dispersants	Prevent settling or separation
Antioxidants/ Stabilizers	Designed to prevent fuel degradation reactions that form gums
Corrosion Inhibitors	Prevents rust on metal surfaces due to moisture and acids
Metal Deactivators	Reduce fuel degradation reactions that are catalyzed by fuel soluble compounds of metals such as copper
Biocides	Kills slime-producing bacteria/ fungi

How to Select an Additive

The following are general guidelines and questions for the oil marketer to keep in mind when selecting an additive:

- Define the problem and the type of performance needed.
- Make sure that the fuel sample being tested represents the fuel to be treated.
- Will the additive be used once, or is continuous treatment required?
- Does the additive perform more than one function?
- Does the additive have the correct usage approvals for the intended use?
- Does the additive have a comprehensive data package supporting its suitability? (Refer to the appropriate Performance Tests for the different additive categories described in the following sections.)
- Does the additive supplier have technical support if there are questions or problems?
- Can the supplier provide a way to determine effectiveness in specific cases?
- What are the safety and handling requirements?
 - Are there instructions on labels?
 - Do Material Safety Data Sheets (MSDS) accompany the product?
 - How do you properly dispose of the additive containers?
 - Know the local laws concerning disposal of sludge or water bottoms from storage tanks.

Antioxidants and Metal Deactivators

Function: Fuel degradation caused by oxidation or aging leads to gum deposits. This process can be slowed down by antioxidant additives and is best applied during the manufacturing of heating oil. Dissolved metals, such as copper, can enhance degradation by accelerating aging and producing mercaptide (sulfur-containing compounds) gels. To minimize these effects, metal deactivators can be introduced into the fuel to combine with the metals and render them inactive. In general, copper and copper-containing alloys should be avoided.

Common Names: Stabilizers, Gum Inhibitors

Types of chemicals to look for:

Compounds in the category of hindered phenols: 2,6-ditertiarybutyl phenol

Phenylenediamine compounds: N,N'-disalicylidene-1,2 propanediamine, and

N,N'-disalicylidene-1,2- cyclohexanediamine are common metal deactivators;

Tertiary-alkyl primary amines: 1,1,7,7-tetramethyloctylamine

Performance Tests:

1. Accelerated Thermal Stability (ASTM D 6468)
2. Oxidation Stability Accelerated Method (ASTM D 2274)
3. Fuel Storage Stability –13 week test, 43 °C (ASTM D 4625)

Dispersants

Function: Dispersants are used to maintain insoluble residues suspended in the oil. Typically, dispersants are used in multifunctional additives with other stabilizing and antioxidizing additives. Dispersants are most effectively used before the fuel degrades. Once the gummy deposits form and are amassed with dirt, biological organisms, and other debris, this sludge becomes much more difficult to disperse.

A secondary function of dispersants is its corrosion-inhibiting effect. Some stabilizer dispersants can form a thin film on metal surfaces of fuel systems to protect its surfaces.

Common Names: Detergent

Performance Tests: No standards exist for heating oil application.

Possible Side Effects:

Initial use of dispersant may cause fuel filter plugging problems as existing deposits, sludge, and scale are picked up from the fuel storage system.

Corrosion Inhibitors

Function: Tank surfaces that come in contact with the fuel may rust due to water that accumulates or acids that could form in the fuel. Corrosion inhibitors can be used to prevent the formation of rust.

Common Names: Anti-rust, Anti-erosion

Performance Tests:

1. Detection of Copper Corrosion by Copper Strip Tarnish Test (ASTM D 130)
2. Steel Corrosion (ASTM D 665)

Possible Side Effects: Some corrosion inhibitors can interact with the fuel and other lubricant additives to form gums and sludge deposits. Suppliers should be able to demonstrate no-harm performance (compatibility) when these additives come into contact with the fuel and other additives.

Biocides

Function: Water accumulation at the bottom of oil tanks and fuel handling systems is a common problem throughout the fuel industry. Water in combination with hydrocarbon fuel can support microbial growth. Certain species of microbes can survive at the fuel-water interface of the storage tank where there is no free oxygen. Some bacteria use the oxygen bound in fuel sulfur compounds, and the hydrocarbon fuel as the nutrition source. By-products of microbial activity such as hydrogen sulfide and organic acids can lead to storage problems such as corrosion; the sheer amount of cell growth can lead to operational problems.

Microbiological organisms in fuel are commonly classified as bacteria, molds, or yeast. Certain strains are frequently used to evaluate the effectiveness of additives, such as *Pseudomonas aeruginosa* (bacteria), *Cladosporium resinae*, (mold), and *Candida tropicalis* (yeast).

A variety of biocides are commercially available to help control microbial contamination in water. Biocide additives are regulated under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), and the product must be registered with the federal Environmental Protection Agency (EPA) for specific applications. For example, a biocide that is registered for treating fuel oil storage tank water bottoms cannot be used for treating gasoline storage tank water bottoms. Check that the product you are using has an EPA registration number, which is usually indicated

on the container's label as REG. NO. (6-digit number). A marketed product must perform as claimed and be labeled with information, including product use, treatment rate, and human exposure and hazards.

Common Names: Water-phase, Fuel-phase biocides

Types of Chemicals To Look For: Some common compounds that are approved as fuel-water biocides include the following [Peyton]:

Biocide	Bacterial Activity	Typical Dosage*	Stability
Glutaraldehyde	Typically effective in 3-8 hours against all bacteria	100 ppm for a 50% solution	Stable under temperature and pH fluctuations; degraded by hydrogen sulfide
Methylene-bis-thiocyanate	May take up to 12 hours to react; not generally effective against sulfate reducing bacteria	200 ppm of a 10% solution	Degrades slowly with increasing temperature and pH
Sodium dimethyl dithiocarbamate/ disodium ethylene-bis-dithiocarbamate	Moderate effectiveness in 3-8 hours against most bacteria	200 ppm of a 15% solution	Stable under temperature and pH fluctuations; reacts with dissolved iron to form a precipitate
Isothiazoline type	Typically effective in 4-12 hours against all bacteria	100-400 ppm of a 1-2% solution used as needed	Degrades slowly under temperature and pH fluctuations
Dibrominated proprionamide	Typically effective in 15 minutes to 2 hours against all bacteria	100 ppm of a 20% solution	Degrades readily in high-temperature, high-pH conditions
Hexahydro-1,3,5-triethyl-S-triazine	Typically effective in 3-8 hours against all bacteria	100 ppm of a 95% solution	At pH values < 6.5, activity increases but lifetime diminishes

*Actual treat rate and frequency of application depends on the level of contamination and the storage condition (i.e., fuel:water ratio, turnover of the fuel, etc.). Contact the manufacturer for specific recommendations.

Heavily contaminated systems need to be physically cleaned to remove debris.

Performance Tests:

1. To be effective according to U.S. Military Specifications, MIL-S-53021, the biocide must kill or inhibit the growth of the three organisms, listed above, based on concentration.
2. Common field test kits. Some commercially available ones- Liquid-Cult Fuel Test Kit (MCE Inc.), EasiCult (Orion Corp.), Hum-Bug Detector Kit (Hammonds Co.)

Possible Side Effects: Interaction with other additives, fuel filter plugging due to mass of deteriorating microbes.

References: Peyton, Kim B., Ondeo/ Nalco Fuel Field Manual, McGraw-Hill Professional Engineering series, 2002.

Cold Flow Improvers

Function: Flow improvers are designed to lower the cold temperature operability limit of diesel and heating fuels, and to avoid wax formation in cold weather. Once wax has formed in the fuel, an additive will not change the waxes already present. Although, if the temperature falls lower, an additive will interact with, and modify, newly separating waxes.

To dissolve wax, a solvent such as kerosene must be used. Unfortunately, kerosene cuts can be expensive and of limited availability, and can reduce heat content.

Commercial cold-flow improvers or pour-point depressants effectively depress pour-point temperatures. Its effects depend on the characteristics of the fuel as well as on the additive. Different fuels exhibit different behaviors, even though they are all classified as heating oil. Some additives are more effective than others at the same concentrations. Much less chemical additive is needed to reduce pour point temperature compared to the volume of kerosene required for the same effect.

Common names: Cold Filter Plugging Point (CFPP) additives, Pour Point Depressants, Low Temperature Flow Test (LTFT) additives, Nucleators, Wax modifiers, Wax dispersants/ Wax suspension agents, Cloud Point Depressants

Performance Tests:

1. Pour Point (ASTM D 97) – This test predicts the gel point in the fuel lines and fuel tanks. The operability limit is always higher than the pour point.
2. Cloud Point (ASTM D 2500) This test indicates the temperature when wax becomes visible in the fuel. The recommended cloud point temperature depends on the time of year and the location of operation. These are specified in ASTM D 975.

Possible Side Effects: Adding too much cold-flow improver can thicken the fuel and reduce CFPP response.

Appendices

A. Commercial Testing Labs for Petroleum Products

B. Petroleum Testing Equipment Suppliers

APPENDIX A

SOME COMMERCIAL TESTING LABS FOR PETROLEUM REFINED PRODUCTS, PETROCHEMICALS, LUBRICANTS

Arizona

Amalgatech
Analyze, Inc.
Clinical Technologies, Inc.

California

Anachem Laboratories
Analysts, Inc.
DL Labs/ Calcoast
Herguth Laboratories, Inc.
Inter-City Testing & Consulting Corp.
Micro Photonics Inc.
RADCO Inc.
Ramtech Laboratories
SGS Control Services
Zymax Environtechonology

Colorado

Trace Laboratories

Connecticut

Specialized Technology Resources

Delaware

Lewis Research, Inc.

Florida

Constellation Technology Corp
Inter-City Testing & Consulting
King Laboratories
PRI Asphalt Technologies, Inc.
Quantachrome Corp.

Georgia

Materials Analytical Services, Inc.

Illinois

Advanced Materials Center, Inc.
Falex Testing Laboratory
Intertek Testing Services
Micro Measurement Laboratories
Phoenix Chemical Laboratory
SGS Control Services, Inc.

Louisiana

ANA-LAB Corp.
Intertek Testing Services
Lubriport Laboratories, Inc.
Saybolt Inc.
SGS Control Services, Inc.
Sherry Laboratories
SPL, Inc.

Maryland

ANA-LAB Baltimore-DC
Customs Science Services
Martel Laboratories, JDS, Inc.
Penniman & Browne, Inc.
SGS Control Services, Inc.
Trace Laboratories

Massachusetts

Kidde-Fenwal, Inc.
Shuster Laboratories
Michigan
Biosan Laboratories, Inc.
Bodycote Met-Chem, Inc.
Ghesquiere Plastic Testing, Inc.
Greening Testing Laboratories
RTI Laboratories, Inc.

Minnesota

Aspen Research Corp.
DDL, Inc.

Missouri

Engineered Lubricants Co.

New Hampshire

VHG Labs, Inc.

New Jersey

ABIC International Consultants
ANA Laboratories, Inc.
Atlantic Product Services, Inc.
ATS RheoSystems
Bennett Testing Service, Inc.
Camin Cargo Control, Inc.
EMSL Analytical, Inc.
Gibraltar Laboratories, inc.
Hydrocarbon Technologies, Inc.
Intertek Testing Services
Laboratory Service, Inc.

New Jersey (continued)

Oiltest, Inc.
Saybolt LP
SGS Control Services, Inc.
Sor Testing Labs
Spectrum Laboratories, Inc.

New Mexico

International Lubrication and Fuel Consultants, Inc.

New York

Advanced Plastic & Material Testing
Buck Analytical and Testing Labs
Edison Analytical Laboratories, Inc.
Inter-City Testing & Consulting Corp.
Ithaca Materials Research & Testing
Koehler Petroleum Testing Lab
The M&P Lab
Volumetric Techniques, Ltd.
VTEC Laboratories, Inc.

North Carolina

PAR Laboratories, Inc.

Ohio

Akron Rubber Development Lab, Inc.
American Electric Power
American Testing Company, Inc.
Ashland Inc.
ATC Laboratories
Bowser-Morner, Inc.
Momentum Technologies, Inc.
S. D. Myers, Inc.
Smithers Scientific Services, Inc.

Oklahoma

ANA-LAB Corp.
Sherry Laboratories
TRW Petroleum Technologies

Pennsylvania

Anter Laboratories, Inc.
C D S Laboratories, Inc.
Cannon Instrument Co.
Graphic Arts Technical Foundation

Tennessee

Galbraith Laboratories, Inc.
SGS Control Services, Inc.
United Power Services, Inc.

Texas

A & B Labs
ANA-LAB Corp.
Core Laboratories
Dixie Services, Inc.
Harris Testing Laboratories, Inc.
InterCorr International, Inc.
Intertek Testing Services
Lab Consultants and Marine Surveyors, LLC
Perkin Elmer Automotive Research
Polyhedron Laboratories, Inc.
Saybolt, Inc – Petrochemical Div.
SGS Control Services, Inc.
Southwest Research Institute
SPL, Inc.

Virginia

Hampton Roads Testing Labs, Inc.

Washington

Bio Research Laboratories, Inc.

Wisconsin

Fluid Power Institute
Structural Research, Inc.
Thomas A. Edison Technical Center

APPENDIX B

TESTING EQUIPMENT SUPPLIERS

The following is a list of American companies that may be able to provide the testing equipment required in various reference methods. This listing was derived from the Thomas Register on the Internet, a database consisting of American manufacturers classified under various products and services. A search through this database for "Petroleum Testing Equipment" and "Instruments: Petroleum Testing" resulted in the following:

Petroleum Testing Equipment

CDS Analytical, Inc.	Oxford, PA
ERDCO Engineering Corp.	Evanston, IL
Falex Corp.	Sugar Grove, IL
Humboldt Mfg., Co.	Norridge, IL
Koehler Instrument Co., Inc.	Edison, NJ
Lawler Manufacturing Corp., Inc.	Bohemia, NY
Varlen Instruments Inc.	Bellwood, IL

Instruments: Petroleum Testing

Alpha Resources, Inc.	Stevensville, MI
Anton PAAR USA	Ashland, VA
Asoma Instruments, Inc.	Austin, TX
Atlantic Analytical Laboratory, Inc.	Whitehouse, NJ
Automation Products, Inc.	Houston, TX
Cannon Instrument Company	State College, PA
Chandler Engineering Co., L.L.C.	Tulsa, OK
Chase Instrument Co.	College Point, NY
Cosa Instrument Corp., West Coast Div.	Houston, TX
Costa Instrument Corp.	Norwood, NJ
CSC Scientific Co., Inc.	Fairfax, VA
Datalive Corp.	Baltimore, MD
Devere & Lau Co.	Anaheim, CA
Dewes-Gumb Die Co., Inc.	Long Island City, NY
Dj Scientific/Dickey-john	Auburn, IL
Dual Manufacturing Co., Inc.	Chicago, IL
ERDCO Engineering Corp.	Evanston, IL
Falex Corp.	Sugar Grove, IL
First International Inc.	Gaithersburg, MD
Future Impex Corp.	Granada Hills, CA
Gardner, Paul N., Co., Inc.	Pompano Beach, FL

Instruments: Petroleum Testing (continued)

Gilson Company, Inc.	Worthington, OH
Greer's Ferry Glass Works	Quitman, AR
GTE Corp. Communications Systems Div.	Taunton, MA
Haake	Paramus, NJ
HB Instrument Co.	Collegeville Trappe, PA
Humboldt Mfg. Co.	Norridge, IL
Inventive Systems Inc.	Lexington Park, MD
Kessler Instruments, Inc.	Westbury, NY
King Refrigeration, Inc.	Freeland, MI
Koehler Instrument Co., Inc.	Bohemia, NY
Lancer USA, Inc.	Longwood, FL
LaPine Scientific Co.	Blue Island, IL
Lawler Manufacturing Corp.	Edison, NJ
Metorex, Inc.	Bend, OR
Metorex, Inc.	Hayward, CA
Orbeco Analytical Systems, Inc.	Farmingdale, NY
Paar Physica USA	Edison, NJ
Petrolab Company	Latham, NY
Photographic Analysis Co.	Wayne, NJ
Ruska Instrument Corp.	Houston, TX
Scientific International, Inc.	Bloomfield, NJ
Sensidyne, Inc.	Clearwater, FL
Southeastern Liquid Analyzers, Inc.	York, SC
Teledyne Brown Engineering /Environmental Services	Westwood, NJ
UVP Inc	Upland, CA
Wedgewood Technology, Inc.	San Carlos, CA
Weksler Instruments, An Operating Unit of Dresser Instrument Div.	Freeport, NY
WilkensAnderson Co.	Chicago, IL

The above is only a partial listing of what is available under these product headings. To search for other product headings or obtain future updated listings this database can be accessed through their electronic address:

<http://www.thomasregister.com>

It should be noted that reference to any specific manufacturer here does not constitute or imply its endorsement or recommendation. This listing has been published for convenience to the reader and was obtained from publicly accessible information.