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NOTES ON

HEAVY FUEL OIL

1984

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SECTION 1 **Introduction**

1 Diesel Power Plants and Fuels

Shipowners and operators, with increasing frequency, are seeing their vessels bunkered with fuels which, as a minimum, have significantly increased the crews' fuel handling and treatment workload; and, in the extreme, have caused catastrophic diesel engine failures. These problems are not limited to specific diesel engine types nor are they restricted to a narrow range of fuel grades. It is becoming apparent that no operator is immune. It also is evident that the future holds little prospect for improved quality. The increasing use of some poorer grades of crude oil as feed stock and more intensive refining practices have produced continued degradation in the quality of residual oils and blends, as well as some contamination of previously clean marine diesel oils (MDO).

Concurrent with continued fuel quality degradation, diesel engine designers have been increasing the Mean Effective Pressures (M.E.P.) of engines in a never-ending search for higher power outputs (per cylinder) and lower fuel consumption rates. The higher M.E.P.'s result in higher piston ring/liner loadings which can accelerate bore wear rates when poor quality heavy fuel oils are burned.

Because of its very small market share, the marine industry has little influence on world petroleum prices and refinery practices. Consequently, the ship operator must equip his ships with the necessary tools to cope with the escalating problem of degraded fuel quality.

The diesel's capability to burn worldwide commercial grades of marine fuel oils is dependent upon the range of significant fuel characteristics and the level of contaminants in the fuel oil. As fuel grade and quality decrease, the impact on diesel engine operating reliability and economy will be strongly influenced by the ability of shipboard fuel systems to provide properly treated fuel.

To adequately assess the influence of fuel quality on the operation of diesel engines and their support systems, such as the fuel storage, transfer, and service systems, a basic working knowledge of fuel characteristics and their impact on the performance of diesel engines and shipboard fuel handling and treatment systems is required. It is the intent of this document to provide the reader with this necessary overview including:

i) The influence of crude oil sources and various refining procedures on the ultimate quality of marine fuels as bunkered

ii) The impact of marine fuel characteristic properties and contaminants on diesel engine and support system operation

iii) Fuel sampling and analysis techniques and laboratory and onboard test procedures for various marine fuel properties

iv) A review and functional description of storage, treatment, transfer and service systems for diesel engines operated on marine diesel, and heavy marine fuels

v) Typical components and/or subsystems available for the onboard treatment of various fuel properties which exceed specified levels

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SECTION **2**   **Marine Fuel Oil Origins and the Influence of Refinery Processes**

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SECTION **2   Marine Fuel Oil Origins and the Influence of Refinery Processes**

1   Crude Oil Sources

Petroleum products, in general, whether diesel oil, lubricating oil, light fuel oil or heavy fuel oil, are essentially composed of two major elements, carbon and hydrogen. The combination of these two elements is called a hydrocarbon. Its ultimate source is crude oil as found in its natural states in various geological formations throughout the world.

Crude oil consists of a very broad spectrum of hydrocarbons ranging from very light, volatile gases to heavy residues. Residual fuels are, in effect, the heavy residues resulting from the refining process. The more desired hydrocarbons and some less desirable ones are extracted from crude oil by the refining process. Similar processes are also used to reconstruct the less desirable hydrocarbon residues into forms that can meet current market demand. The hydrocarbons mostly found in marine fuel oils fall into four (4) main classes − paraffinic, aromatic, naphthenic and olefinic. These basic compound types are further categorized below.

Paraffinic hydrocarbons ($C_N H_{(2N+2)}$) are lower in specific gravity than aromatic hydrocarbons of the same boiling point, while naphthenic and olefinic compounds are intermediate in density. Their resistance to chemical change or oxidation is very good. These hydrocarbons are clean burning, and thus are desirable in distillates such as gas oil or diesel oil.

Aromatic hydrocarbons ($C_N H_{(2N-6)}$) possess a much higher specific gravity than the other three classes. Aromatics are very stable under heat and are chemically active to a moderate degree. The aromatic compounds contain a higher proportion of carbon than the other hydrocarbon types. Due to this characteristic, they have a tendency to smoke, which somewhat limits their use in diesel engines.

Naphthenic hydrocarbons ($C_N H_{2N}$-ring type) are extremely stable, cyclo-ring compounds and in many cases have more stability than the paraffins. These hydrocarbons are more commonly found in heavy marine fuel oils rather than distillate oils.

Olefinic hydrocarbons ($C_N H_2$-straight chain) are more chemically active than the other three classes of hydrocarbons. Olefins are subject to oxidation or polymerization, forming gums. Olefins are not present in large amounts in straight-run distillates, but are found in large quantities in cracked marine fuel oils.

While crude oil is the source of the various hydrocarbon compounds in marine fuels from which thermal energy is produced during combustion in a diesel engine, it also is the source of many undesirable properties and characteristics which are carried over in the refining process to the resultant petroleum product. Section 2, Table 1 lists the principal contaminants which are related to the source of the crude oil. These contaminants will be concentrated in heavy fuel oils which have been subjected to intensive refining.

TABLE 1
Crude Source Related Properties and Characteristics

i)	Sulfur
ii)	Vanadium, Nickel, etc.
iii)	Pour point
iv)	Ash content

In addition to the contaminants, pour point (a property) is directly related to the source of the crude oil.

Normally, the level of a particular property can be utilized to trace the geographical source of a crude oil from which a given product is refined. As an example, Venezuelan crude is noted for its high (oil soluble) ash (vanadium, nickel, silica, etc.) content, whereas crude oils from the Middle East Region are generally noted as being low in sulfur content. Section 2, Table 2 presents a breakdown of some typical sources of crude oil by geographical location while identifying product yield levels and various other properties. The influence of these source-related characteristics as they appear in refined products on marine diesel engine operation will be discussed in detail in Section 3.

3   Refinery Processes

Ultimately, marine fuel oil quality is influenced by the worldwide refinery mix, the variation in crude oil quality available, and the demand patterns for middle distillate and residual fuels. Section 2, Table 3 gives a number of the properties and characteristics associated with marine fuels which are strongly influenced by the refinery processes utilized.

The four (4) most common types of refining methods currently utilized, a brief description of the resultant product characteristics, and a discussion of the influence of fuel quality on refinery-based blending of heavier and lighter products to produce various grades of intermediate fuel oils are presented in the following paragraphs.

3.1   Atmospheric Distillation

This is the oldest and most common refining process and consists of boiling crude oil at atmospheric pressure in a fractionating tower up to temperatures not exceeding 371 degrees Centigrade. Beyond this temperature, heavy hydrocarbons begin to crack and materials form which are not desired at this point in the process. As the various constituents of the crude oil vaporize at different rates, the lighter, more volatile gases rise high in the tower before condensing and being collected. The heavier, less volatile gases condense and are collected lower in the fractionating tower. Section 2, Figure 1 presents a simplified schematic of the atmospheric distillation process.

Straight-run residual fuels obtained from atmospheric distillation were the primary heavy fuels used in marine diesels in the 1950's, '60's and early '70's. They provided clean combustion, ease of fuel handling and treatment, storage stability and compatibility. Also, since specific gravities were usually well below 0.980, the separation of water and sediment was well within the capability of installed shipboard fuel oil purification systems.

TABLE 2
Effect of Crude Source on Various Product Yields and Characteristics

	High Gravity Sweet Crude (North Sea Light)	Low Gravity Sweet Crude (North Sea Medium)	Medium Sulfur Crude Oil Light Murban	Medium Sulfur Crude Oil Heavy (North Slope)	High Sulfur Crude Oil Light (Arabian)	High Sulfur Crude Oil Heavy (Venezuelan)
Crude Oil						
Gravity($^\circ$API)	37.6	26.0	39.4	26.8	33.4	16.8
Sulfur(Wt%)	0.13	0.23	0.74	1.0	1.80	2.40
Pour Point($^\circ$F)	5	<-5	+5	-5	-30	-10
Sulfur Range(Wt%)	0-0.5	0-0.5	0.51-1.0	0.51-1.0	1.0+	1.0+
C_4 and Lighter Yield	2.2	0.7	1.8	1.8	1.7	0.4
Light Naphtha(C_5-200°F)						
Yield(Vol%)	6.4	2.1	6.78	5.8	9.0	2.5
Gravity($^\circ$API)	79.9	79.2	82.2	68.3	78.5	65.0
Sulfur(Wt%)	0.0002	0.001	0.012	0.01	0.024	---
Naphthenes(Vol%)	21.5	24	---	30.0	10.4	51.9
Aromatics(Vol%)	1.5	3	---	---	2.4	4.7
Paraffins(Vol%)	77.0	73	---	48.8	87.2	43.4
Octane No.(RON Clear)	78	80	69	65	54.7	---
Heavy Naphtha(200-400°F)						
Yield(Vol%)	22.0	8.7	21.2	12.6	8.4	6.0
Gravity($^\circ$API)	53.6	50.1	56.9	49.7	59.6	49.0
Sulfur(Wt%)	0.003	0.01	0.013	0.02	0.027	---
Naphthenes(Vol%)	55	58.5	20	56.4	18.2	58.5
Aromatics(Vol%)	11	14.0	17	---	12.3	13.9
Paraffins(Vol%)	34	27.5	63	43.6	69.5	27.6
Kerosene(400-5--$^\circ$F)						
Yield(Vol%)	15.4	14.7	16.14	12.3	15.0	5.0
Gravity($^\circ$API)	40.2	34.4	45.4	37.4	38.5	36.4
Sulfur(Wt%)	0.03	0.063	0.058	0.20	0.094	0.48
Pour Point($^\circ$F)	-70	<-70	---	---	---	-80
Distillate(500-650°F)						
Yield(Vol%)	23.2	29.7	10.4	12.1	19.8	15.5
Gravity($^\circ$API)	33.2	27.5	37.8	31.3	37.1	---
Sulfur(Wt%)	0.13	0.18	0.47	0.56	1.05	0.99
Cetane No.	51	40.0	54	47	---	---
Pour Point ($^\circ$F)	20	-15	0	---	0	---
Viscosity(@100°F)	40.3 SUS	44.6 SUS	4.2 cSt	---	3.28 cSt	---
Heavy Gas Oil						
Yield(Vol%)	23.1	31.3	9.24	14.7	*	*
Gravity($^\circ$API)	25.4	19.7	33.6	25.8		
Sulfur(Wt%)	0.21	0.31	1.06	0.90		
Pour Point($^\circ$F)	105	80	41	55		
Viscosity (@210°F)	48.1 SUS	53.1 SUS	---	77 SUS 100°F		
Residual Oil						
Yield(Vol%)	7.7	12.8	34.5	40.7	46.1	70.6
Gravity($^\circ$API)	11.8	10.1	22.6	13.0	17.6	---
Sulfur(Wt%)	0.39	0.48	1.49	1.74	3.08	3.0
Pour Point($^\circ$F)	---	---	85	475	40	60
Viscosity(@210°F)	2,030 SUS	3,690 SUS	---	391 SUS	21 cSt	---
Total (%)	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 3
Refining Process Related Characteristics and Properties

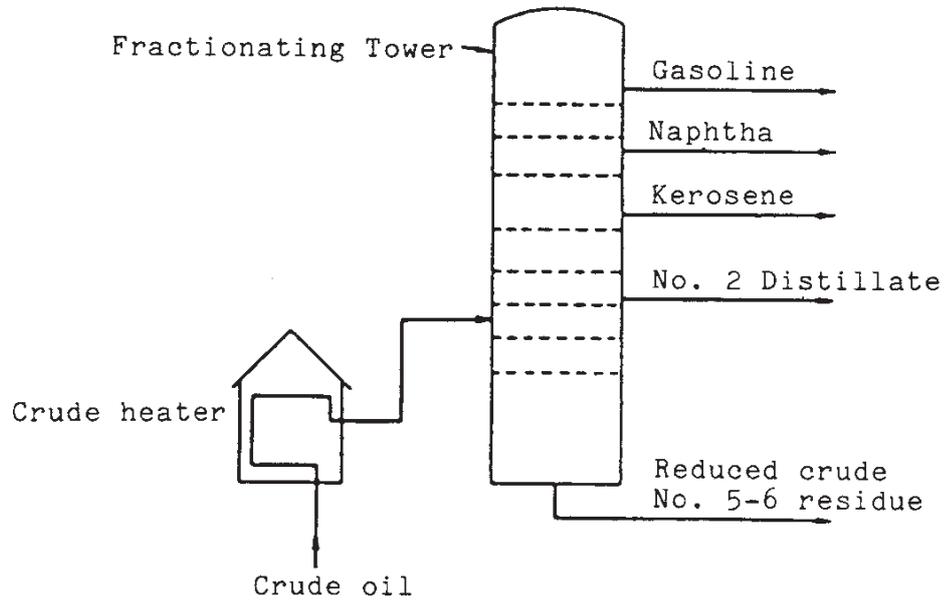|	
i)	Specific Gravity
ii)	Viscosity
iii)	Conradson Carbon Residue-(CCR)/Asphaltenes
iv)	Sediment
v)	Water
vi)	Flash point
vii)	Compatibility
viii)	Sodium

3.3   Vacuum Distillation

This process is essentially a modified version of the straight-run method of distillation. Very simply, when the pressure in the distillation/condensation tower is reduced below atmospheric (partial vacuum), the residual fuel from an atmospheric process will yield additional heavy distillates and will further concentrate impurities and carbon in its residual oil or vacuum bottoms. Vacuum distillers produce residual oils that are feed stocks for other refinery processes. They are not generally available in the marine fuel marketplace due to their very high viscosity. As shown in Section 2, Figure 2, vacuum distillation bottoms can be further refined by the use of a secondary process such as viscosity breaking. In this procedure, the feed stock, vacuum bottoms, is heated to a higher temperature and pressure for cracking, although not as high as in the thermal cracking process (described later). Simplistically, the high viscosity feed stock is broken down to a residuum which is considerably lower in viscosity than the original feed stock. While this product can be utilized as a heavy marine fuel with little or no blending back with a lighter distillate, it has increased specific gravity, and less desirable characteristics, such as high Conradson carbon and high asphaltenes. It is usually less stable and less compatible with other residuals than the original feed stock. These characteristics can present problems for marine diesel power plant and fuel treatment system operation.
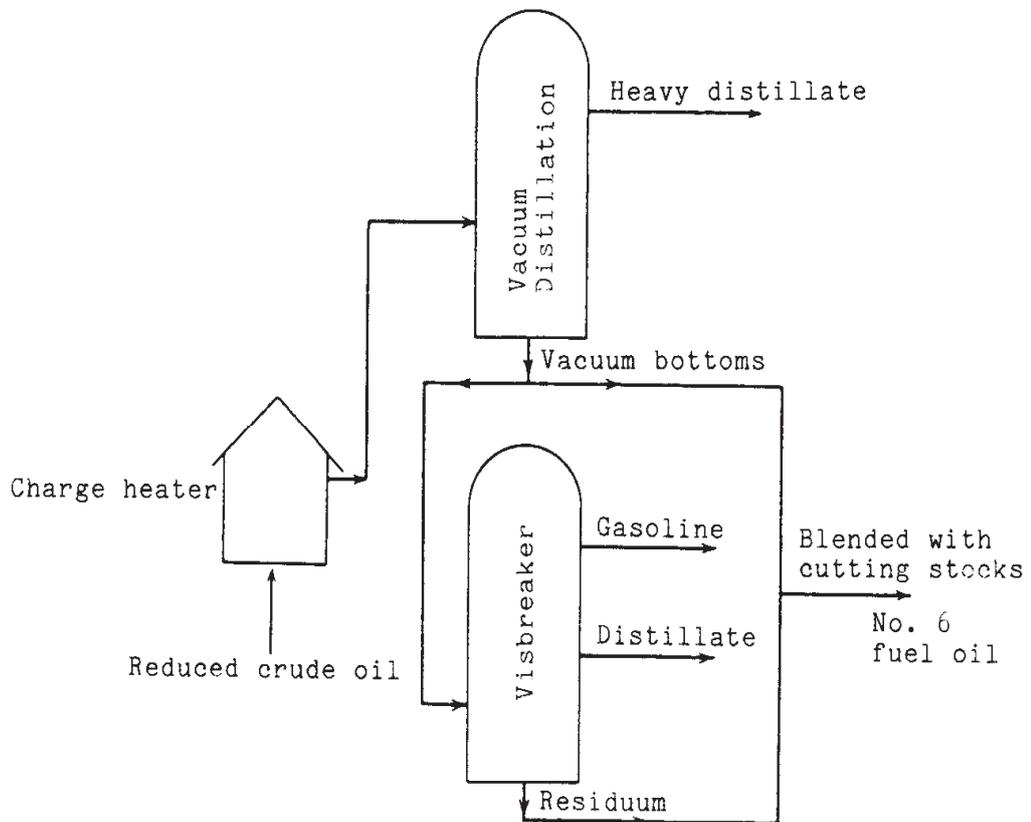
3.5   Thermal Cracking

This procedure is shown in Section 2, Figure 3. In this process, the feed stock, straight-run residual, is heated to high pressure and temperature in the reaction chamber. The heavy, large, long chain oil molecules of the residual fuel are cracked or broken, producing both short chain and additional long chain molecules. These cracked products are then vaporized in the flash chamber and flow to the fractionating tower where they are condensed at different levels to the products shown in Section 2, Figure 3.

Thermal cracking increases the yield of high quality distillate fuels from crude oil, and reduces the yield of residual fuel. Like vis-breaking, this process also yields residual fuels with a high specific gravity and a high sulfur, vanadium, Conradson carbon/asphaltenes content together with poorer stability and compatibility. The impact of this process is to produce a cracked residual fuel which is more difficult to burn, and has a lower calorific value (on weight basis), and a higher sludge and impurities content, all of which can result in increased engine downtime, maintenance, and repair costs.

FIGURE 1
Atmospheric or Straight-Run Method of Crude Oil Distillation
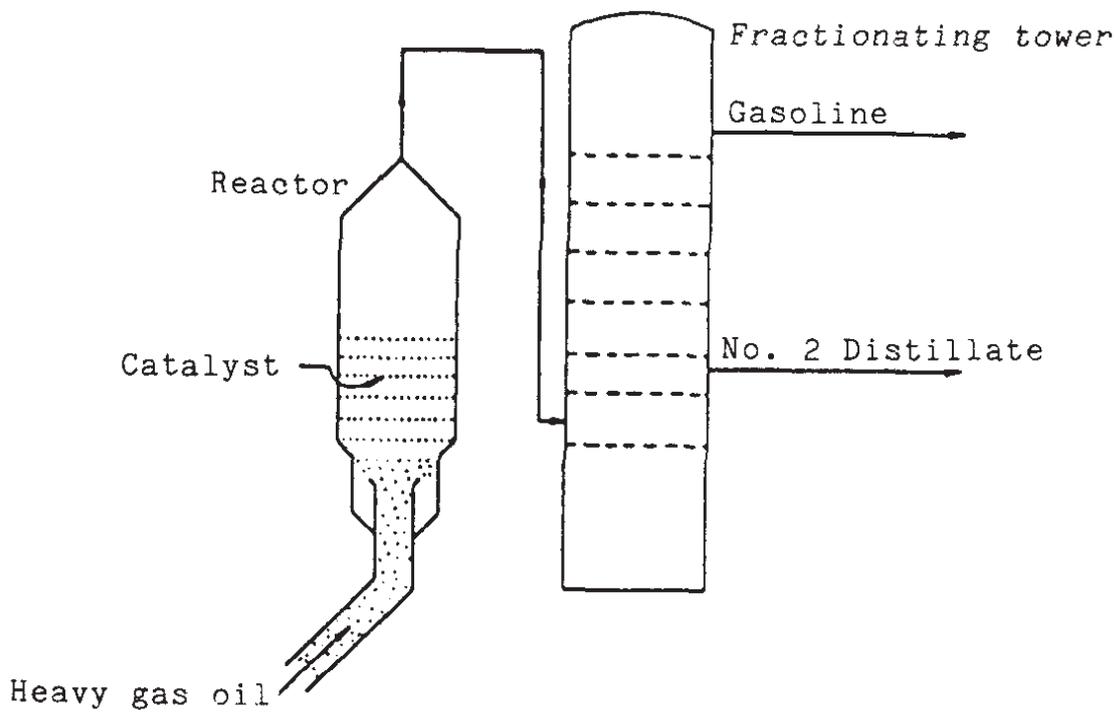

FIGURE 2
Vacuum Distillation and Vis-breaking Processes

FIGURE 3
Thermal Cracking Process

Fractionating tower

Gasoline

No. 2 Oil

Charge heater

Reaction chamber

Flash chamber

Residuum
No. 5-6 fuel oil

Reduced crude

FIGURE.4
Catalytic Cracking Process

Fractionating tower

Gasoline

Reactor

No. 2 Distillate

Catalyst

Heavy gas oil
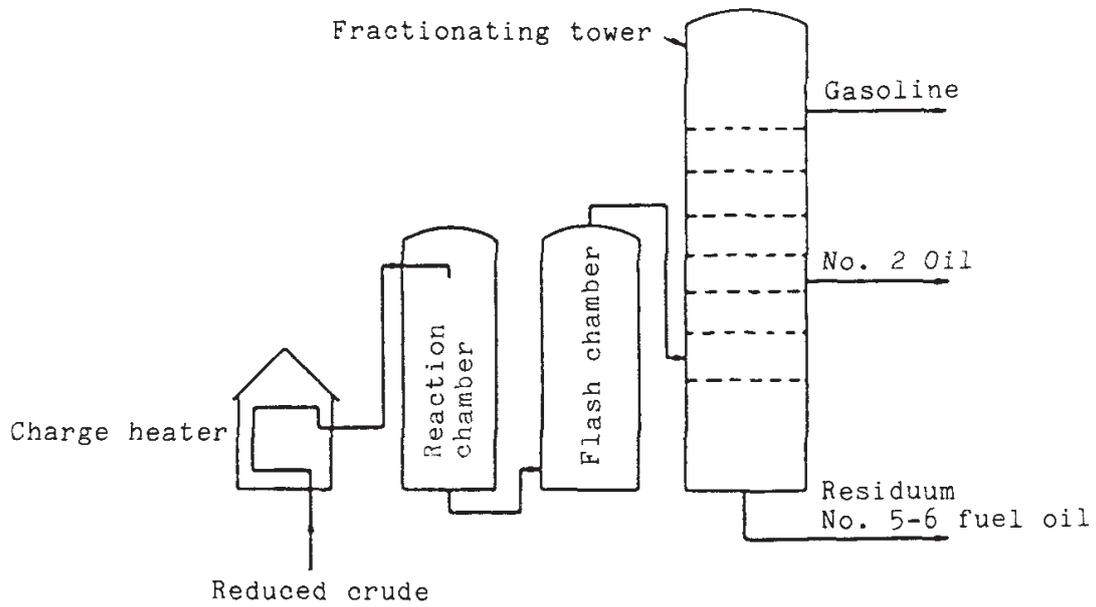
3.7   Catalytic Cracking

This process is a variation of thermal cracking. It is shown diagrammatically in Section 2, Figure 4. Catalytic cracking, including fluidic catalytic cracking, (F.C.C.), are processes in which a chemical catalyst is used to increase the yield of the thermal cracking process. The presence of a powdered catalyst added to the feed stock stream allows the breakdown of long chain molecules into lighter, short chain hydrocarbon molecules at lower pressures and temperatures. In addition, the fine, powdered catalyst used with the charge stock can carry over into the resultant cracked residuum. This powdered catalyst, sometimes referred to as "catalyst fines" or "cat cracker catalyst", is very hard and extremely abrasive. It is not unlike fine sand, and can rapidly increase the wear of injection pumps, fuel valves, injectors, piston rings, piston ring grooves, liners, stuffing box seals, and turbocharger blading. Whenever a straight-run residual oil has been processed through an F.C.C. unit to produce a cracked residuum, there is a very high probability that some of these abrasive catalyst particles, comprised of aluminum oxide and/or silicon dioxide, will be carried over and find their way into even the lightest blends of intermediate marine fuels derived from the contaminated cracked residuum.

3.9   Refinery Blending and Storage

While not part of the actual refining process, on-site refinery fuel blending, handling and storage can have a significant impact on fuel quality as bunkered. By blending, less desirable cracked residual oil can be made more attractive as fuel oil. This is accomplished by adding to a given quantity of residual oil a small amount of lighter distillate or cutter stock. It is not uncommon for these fuels to have been produced in different refinery units and even from different crude stocks. Thus, the potential for incompatibility problems to occur, such as sludge formation or stratification, exists.

Currently marine fuels bunkered as residual oils are in fact blends of deep cracked residuum and lighter distillate cutter stock. These have, as a result of increasing refinery yield demands on crude supplies, all but replaced the straight-run residual fuels obtained from atmospheric distillation, which characterized marine residual fuels of the past.

While the most significant portion of fuel contamination by water and debris normally occurs during barge transport, pipeline transport and tank farm storage at the refinery also can increase contaminant levels prior to transport for shipboard use.

5   Market Influences on Marine Fuel Quality

Current trends translate into heavier, higher sulfur crudes for worldwide refiners. This fact, combined with refinery upgradings to the more complex cracking process to produce higher per unit crude distillate yields, will have a significant impact on the quality of cracked residuals and blended fuels available to the marine industry.

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SECTION 3 Marine Fuel Oil Properties and Characteristics and Their Impact on the Diesel Engine

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SECTION **3 Marine Fuel Oil Properties and Characteristics and Their Impact on the Diesel Engine**

Marine fuel quality can significantly affect the performance, operation and maintenance of the diesel engine. To better understand the important effect of diesel fuels on the engine itself, it is important to have a basic understanding of fuel characteristics, properties and contaminants which impact the operation of a diesel engine and its fuel handling and fuel treatment systems.

Whereas the marine diesel engine is a very efficient power plant, it does have a higher degree of sensitivity to specific fuel properties and contaminants than does the steam boiler. For the purposes of this document, a fuel property is considered to be a characteristic occurring in the fuel carried over from its crude source or which is the result of the refining processes by which it was produced. A contaminant is considered as foreign matter introduced into a fuel as a result of refining, transport or storage. This section will address the following properties and contaminants and their influence on diesel engine operation.

Characteristic Properties	*Contaminants*
Viscosity	Water
Specific Gravity	Sodium
Carbon	Sediment
Residue/Asphaltenes	Alumina/Silica (Catalytic Fines)
Ash	
Vanadium	Sludge
Compatibility	Fibers
Cetane	Oxidation Products (Gums, Varnish)
Flash Point	
Pour Point	
Heating Value	

1 Marine Fuel Oil Characteristic Properties

1.1 Viscosity

Heavy fuel oils are normally purchased on the basis of a limiting viscosity due to storage, handling, or engine-related restrictions. Viscosity does not, however, carry a quality implication, regardless of the fact that many purchasers of marine fuel oils believe this to be the case. A false sense of quality assurance has developed through the procurement, on the basis of viscosity only, of straight-run fuel oils. As heavy fuel oils are produced in the future by more and more intensive secondary processing, the relationship between fuel oil viscosity and fuel oil quality becomes less and less meaningful. Today, as well as in the future, viscosity is an inadequate yardstick by which to judge heavy fuel oil quality.

Viscosity is a measure of a fuel's resistance to flow. When expressed in seconds of Redwood 1 (SR1) at 100 degrees Fahrenheit, it is the time it takes for a fixed amount of fuel to pass through an orifice of fixed size at 100 degrees Fahrenheit. The higher the viscosity, generally the higher the specific gravity.

The viscosity of any petroleum oil increases when the oil is cooled and decreases when it is heated. For this reason, the viscosity value of an oil must always be accompanied by the temperature at which the viscosity was determined. The viscosity value by itself is meaningless.

The two most common methods of testing the viscosity of a petroleum oil are the Saybolt and Kinematic (cSt). Of these, the Saybolt (ASTM D-88) is the method more frequently encountered in conjunction with lubricating oil. Today, the Kinematic method (ASTM D-4235) is normally used for fuel oil and is considered to be more precise. There are also the Redwood, mentioned above, and the Engler methods which are widely used in Europe, but only to a limited extent in the United States.

Viscosity is used principally to give information about the handling, treatment and atomization of the fuel. However, it also is a rough indicator of its carbon and asphalt content. The lower the viscosity, the easier it is to settle or to separate entrained water and solid particles. Although high viscosity fuels require proper preheating for good separator operation and heating before injection for good atomization, this characteristic usually can be handled without any problems.

By preheating fuel, separation in a centrifuge is improved, but a temperature of 98 degrees Centigrade should not be exceeded because flashing of water in the separator may occur with resultant loss of the centrifuge water seal.

Caution must be exercised when heating prior to injection to temperatures above 135 degrees Centigrade because cracking may occur, gases may be given off, and water may vaporize forming steam pockets in the fuel line. Insufficiently heated fuel, on the other hand, can result in poor atomization and delayed burning, which may lead to higher thermal loading, scuffing problems, possible piston and piston ring failure, and to an increase in fuel consumption.

In addition to heating prior to injection, an increase in fuel injection pressure may also be necessary to maintain design atomization spray patterns depending on fuel used. Where high viscosity fuels are concerned, an increase in primary fuel pump pressure may be necessary to prevent vaporization of a fuel's more volatile components due to the heating prior to injection.

In October, 1977, the world's marine fuel suppliers agreed to replace the Redwood 1 (SR1) at 100 degrees Fahrenheit system with the Kinematic (cSt) system of viscosity at 50 degrees Centigrade. In the future, European suppliers are expected to quote Kinematic viscosities at 8 degrees Centigrade (instead of 50 degrees Centigrade) in line with CIMAC and ESI recommendations.

For convenience, Section 3, Table 1 is provided with equivalents between the two systems, while Section 3, Figures 1 and 2 provide temperature/viscosity relationships for the two systems.

TABLE 1
Kinematic/Redwood Viscosity Equivalents of Typical Marine Fuels

cSt @ 50°C	SR1 @ 100°F	cSt @ 50°C	SR1 @ 100°F
30	200	180	1500
40	278	240	2400
60	439	280	2500
80	610	320	3000
100	780	380	3550
120	950	420	4000
150	1250	460	4480

FIGURE 1
Relationship between Redwood and SI Viscosity Systems
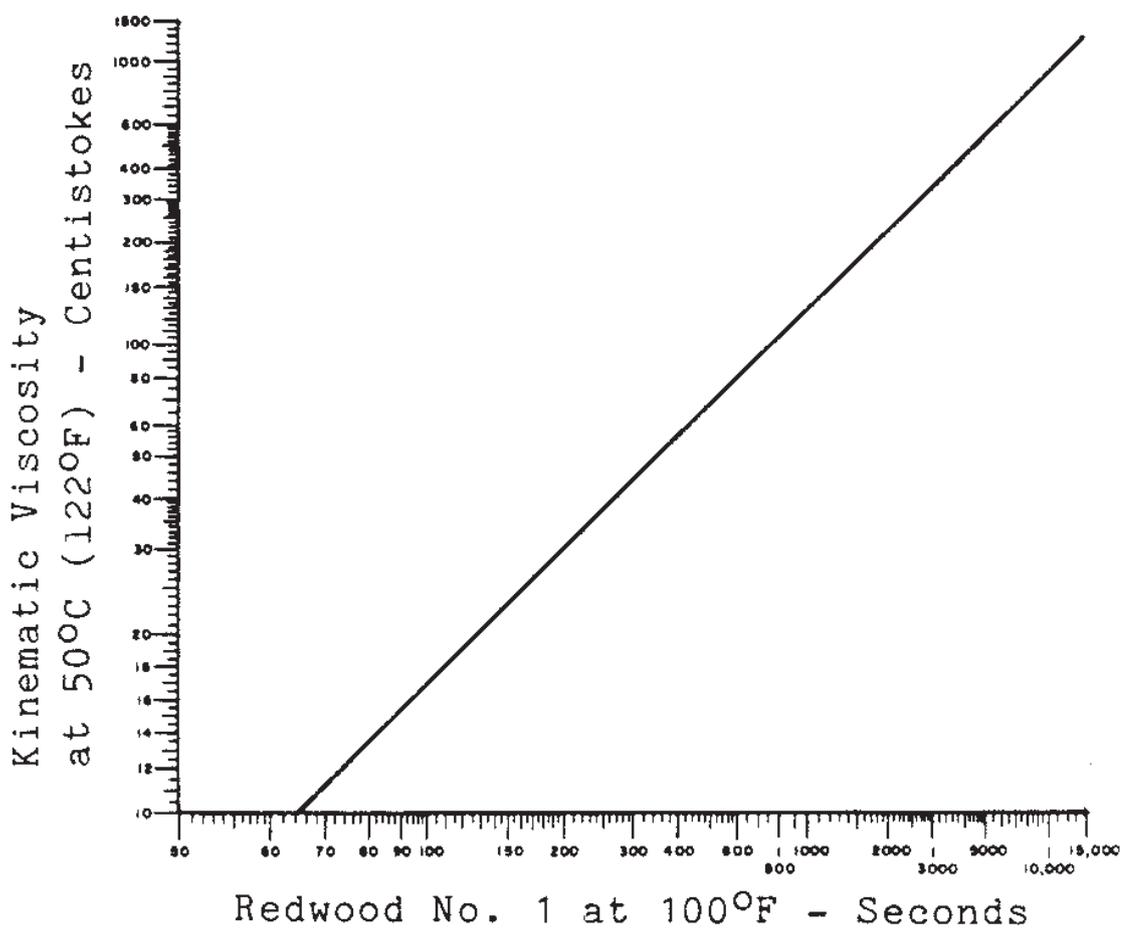
FIGURE 2
Relationship between Temperature and Viscosity for Marine Fuels
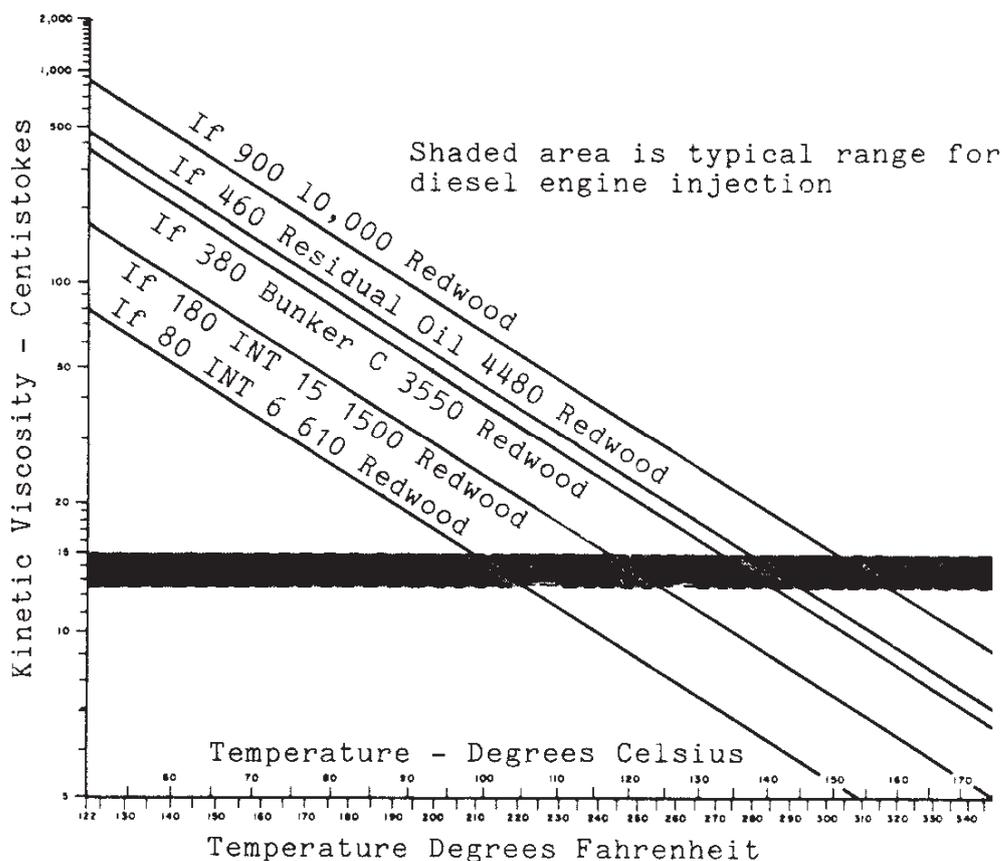
1.3   Specific Gravity

Specific gravity is defined as the ratio of the weight of a given volume of the product at 15 degrees Centigrade to the weight of an equal volume of water at the same temperature.

Specific gravity is determined by floating a hydrometer in the liquid and noting the point at which the liquid level intersects the hydrometer scale. Corrections must then be made in accordance with the temperature of the sample at the time of test. The ASTM D-287 standard provides details on the method.

The importance of specific gravity relative to diesel engine operation lies in the fact that today's standard fuel/water separating techniques are based upon the difference in density between the two substances. Therefore, as the specific gravity of fuel approaches 1.0, centrifuging becomes less effective. Since diesel engine fuels should be free of water and the salts normally dissolved therein, extra centrifuging capacity will be required for high gravity fuel. High specific gravity indicates a heavily cracked, aromatic fuel oil with poor combustion qualities, which can cause abnormal liner wear. This effect is most pronounced in smaller, higher speed diesels.

Heating the fuel prior to centrifuging assists in the separation process because the density of fuel oil changes more rapidly with temperature than does the density of water. A viscosity decrease also helps centrifuging. A maximum specific gravity of 0.991 (at 15 degrees Centigrade) can be handled satisfactorily. Above this value the centrifugal purifier cannot repeatedly and successfully operate, due to loss of its water seal. This 0.991 limit can vary under special circumstances. (See 5/7.7 "High Specific Gravity").

Specific gravity for future fuels is expected to rise to about 0.995. The major significance of this increase in specific gravity will be greater difficulty relative to water removal in settling tanks and centrifuges. This trend toward higher specific gravity will mean also lower hydrogen-carbon ratios, which will increase the difficulty of achieving clean combustion or, conversely, will foster increases in carbonaceous deposits and debris. This trend toward higher specific gravities has been due primarily to the more extensive use of secondary processing (vis-breaking and thermal or catalytic cracking) of heavier crude oils.

1.5   Carbon Residue/Asphaltenes

Conradson Carbon Residue (CCR) is a measure of the tendency of a fuel to form carbon deposits during combustion and indicates the relative coke forming tendencies of a heavy oil. Carbon-rich fuels are more difficult to burn and have combustion characteristics which lead to the formation of soot and carbon deposits. Since carbon deposits are a major source of abrasive wear, the CCR value is an important parameter for a diesel engine. The type of carbon also can affect abrasive wear.

Carbon residue is the percent of coked material remaining after a sample of fuel oil has been exposed to high temperatures under ASTM Method D-189 (Conradson) or D-524 (Ramsbottom).

Asphaltenes are those components of asphalt that are insoluble in petroleum naphtha and hot heptane but are soluble in carbon disulfide and hot benzene. They can be hard and brittle and made up of large macromolecules of high molecular weight, consisting of polynuclear hydrocarbon derivatives containing carbon, hydrogen, sulfur, nitrogen, oxygen and, usually, the three heavy metals − nickel, iron and vanadium.

A high CCR/asphaltene level denotes a high residue level after combustion and may lead to ignition delay as well as after-burning of carbon deposits leading to engine fouling and abrasive wear. Poor engine performance caused by slow burning, high boiling point constituents results in higher thermal loading and changes in the rate of heat release in the cylinder.

Normally, most if not all of a heavy fuel oil injection should burn between top dead center (TDC) and 90 degrees after TDC, with the expansion of generated gases acting on the piston to complete the power stroke. After-burning is of particular concern because the increased time needed for combustion exposes a greater area of cylinder liner to flame than would normally occur and subjects the cylinder lubricant to higher pressure and temperature stresses resulting in hot spots, severe radiation, and burning of the lube oil film. The latter leads to scuffing, cylinder wear and engine deposits.

CCR is expressed as a percent of the whole fuel. Fuels with high CCR values have an increasing tendency to form carbon deposits on injection nozzles, pistons, and in the ports of two-stroke engines. This causes reduction in the efficiency and performance of those components and increased wear. The maximum permissible CCR value depends on engine speed. The higher the speed, the shorter the time for combustion and the more residue deposited; hence, acceptable CCR values should decrease as engine speed increases.

While two-cycle, slow speed engines are less affected by a high CCR than four-cycle engines, it does contribute to increased fouling of gas ways and turbochargers, especially during low power operation or at idle. Idling should be limited to five to ten hours and be followed by running at full load to clear gas ways whenever possible. Continued operation at reduced output can also load up gas ways with unburned heavy fuel oils and lube oil. Here also, full load operation can help to clear gas ways.

As the Conradson Carbon increases, typically the asphaltene content of a heavy fuel oil also will increase. The combination of higher Conradson Carbon content and higher asphaltene content can increase the centrifuge sludge and fine filter burdens. This can require more frequent centrifuge desludging and filter element cleaning/replacement. Higher Conradson Carbon content also lowers the gross and net heating values (on weight basis) of a heavy fuel oil.

Asphaltene content is particularly important in 4-cycle engines due to their higher operating speeds, smaller bore sizes, and reduced combustion time. Concentrations of ten percent (10%) or greater can cause difficulties in combustion when present in conjunction with other high boiling fractions in the fuel. Some engine manufacturers permit limits above ten percent (10%); however, combustion difficulties will increase above this level, especially at reduced output.

A higher Conradson Carbon content/asphaltene content in heavy fuel oils is to be expected in the future. The increased content will result from refining more viscous, heavier crude oils and from additional, secondary processing, such as catalytic cracking and vis-breaking. These conditions will further concentrate more carbon in the bottoms that are blended or vis-broken to produce marine heavy fuel oils.

1.7   Sulfur

In varying forms and concentrations, sulfur occurs in all crude oils. When the crude is distilled, sulfur derivatives tend to concentrate in the heavier fractions, leaving the lighter fractions with relatively low sulfur contents. The extent to which various concentrations of sulfur can be tolerated depends on the type of engine and the operating power level of that engine.

This characteristic of fuel oil is responsible for "low temperature" corrosion which attacks cylinder liners and piston rings, leading to an increase in cylinder liner wear. The oxides in sulfur combine with condensing water vapor in the combustion chamber to form highly corrosive sulfuric acid. Some of this water is present in the fuel already, while another source of moisture may be in the intake and scavenging air.

Ignition lag and poor combustion quality of high sulfur fuels cause ignition to occur later than normal in the power stroke, requiring a large volume of fuel to be burned in a shorter time. The subsequent pressure rise is greater than that normally experienced and places a severe strain on the cylinder lubricating oil film. This oil film also is subjected to the combustion flame farther down the cylinder liner where the oil film may be thinner. Sulfur has a tendency to combine with the water mist precipitated by the lower inlet air temperatures, and the formation of sulfuric acid on cylinder liners takes place. Careful control of the cooling water temperature in the inlet air coolers and/or installation of a water mist separator after the air coolers should remedy the problem of condensing moisture in the intake air.

When operating an engine on a fuel with a high sulfur content, care must be taken to avoid reaching the acid dew point temperature within the cylinder. One way of controlling this is to adjust the cooling water temperature at the cylinder wall. As the M.E.P. of the diesel increases, the acid dew point temperature increases as well. Since sulfur is oil soluble, it cannot be removed from the fuel by centrifuging. It can, however, be neutralized by the use of proper alkaline additives in the cylinder and/or engine lubricating oils.

It should be noted that although the sulfur content of a fuel can be neutralized by the use of cylinder lubricating oils of proper alkalinity (TBN – Total Base Number), over-treatment for sulfur (low sulfur fuel oil) can be just as harmful as under-treatment. Over-treatment for sulfur leaves an excess of alkaline additive material free to form hard, abrasive deposits during combustion, with resultant increased abrasive wear of cylinder liners and piston rings. Therefore, when burning low sulfur fuel oil, the lube oil TBN should be lowered.

As the sulfur content rises above three percent (3%) by weight, the problem of condensation of corrosive acids becomes increasingly troublesome. This is especially important in trunk-type engines which are characteristic of 4-cycle diesel engines. In trunk-type engines the cylinder lube oil is scraped into the crankcase by oil control rings on the pistons. This oil has been contaminated by the sulfur in the fuel. Upon entering the crankcase, the sulfur is free to combine with moisture which may collect there. The TBN of the lubricating oil is eventually lowered to a point where it is rendered ineffective in controlling the sulfur content of the fuel.

For 2-cycle engines, an increase in the sulfur content leads to slower and less complete combustion with resultant formation of more corrosive acids, more unburned carbon, and an increase in wear rates. This is a very important consideration for slow-speed, crosshead type engines. The cylinder of a crosshead engine is more difficult to lubricate due to its greater surface area and the longer stroke.

When estimating the heating value of a fuel, the calorific value should be reduced by approximately 126 BTU/lb for each one percent (1%) by weight of sulfur in the oil.

In the future, increased sulfur levels in marine fuels can be expected from refining higher sulfur, heavier crude oils, and additional secondary processing, such as catalytic cracking, which concentrates more sulfur in the cracked residuum which is blended to produce heavy marine fuel oils.

1.9   Ash/Sediment

The ash contained in heavy fuel oil includes the (inorganic) metallic content, other non-combustibles and solid contamination. The ash content after combustion of a fuel oil takes into account solid foreign material (sand, rust, catalyst particles) and dispersed and dissolved inorganic materials, such as vanadium, nickel, iron, sodium, potassium or calcium.

Ash deposits can cause localized overheating of metal surfaces to which they adhere and lead to the corrosion of the exhaust valves. Excessive ash may also result in abrasive wear of cylinder liners, piston rings, valve seats and injection pumps, and deposits which can clog fuel nozzles and injectors.

In heavy fuel oil, soluble and dispersed metal compounds cannot be removed by centrifuging. They can form hard deposits on piston crowns, cylinder heads around exhaust valves, valve faces and valve seats and in turbocharger gas sides.

High temperature corrosion caused by the metallic ash content can be minimized by taking these engine design factors into consideration; (1) hardened atomizers to minimize erosion and corrosion and (2) reduction of valve seat temperatures by better cooling.

1.11   Vanadium

Vanadium is a metallic element that chemically combines with sodium to produce very aggressive low melting point compounds responsible for accelerated deposit formation and high temperature corrosion of engine components.

Vanadium itself is responsible for forming slag on exhaust valves and seats on 4-cycle engines, and piston crowns on both 2- and 4-cycle engines, causing localized hot spots leading eventually to burning away of exhaust valves, seats and piston crowns. When combined with sodium, this occurs at lower temperatures and reduces exhaust valve life. As the vanadium content (ppm) increases, so does the relative corrosion rate.

Vanadium is oil soluble. It can be neutralized during combustion by the use of chemical inhibitors (such as magnesium or silicon). Cooling exhaust valves and/or exhaust valve seats will extend valve and seat life. Raising fuel/air ratios also prolongs component life. Other measures which can be used to extend component life are the use of heat resistant material, rotating exhaust valves, and the provisions of sufficient cooling for the high temperature parts.

Vanadium content varies widely in heavy fuel oils depending on the crude oil source or crude oil mixes used by the refinery.

The vanadium levels of future heavy fuel oils generally will be higher than today's. This is particularly true of fuel oils produced from Venezuelan and Mexican crude. Vanadium cannot presently be economically reduced or removed by the refinery or the ship's systems. The burden of coping with high vanadium levels will continue to remain with engine builders and ship operators. This tolerance must be achieved through advances in materials and cooling techniques and through the use of onboard treatment methods such as chemical additives.

1.13   Compatibility

Residual fuel can be considered to be a colloidal dispersion of high molecular weight substances held in chemical and/or physical equilibrium in heavy fuel oil. When the equilibrium forces are disturbed, the high molecular weight components (typically asphaltenes) are thrown out of solution or precipitated to form a sludge or sediment. Compatibility problems occur when heavy fuel oils with a high asphaltene content are mixed with lighter fractions with a predominance of aliphatic hydrocarbons. The mixing can cause precipitation of the asphaltenes. It occurs when fuel oil suppliers blend in order to reduce final fuel oil viscosity, specific gravity, or other fuel property.

Incompatible fuel oils result in rapid strainer and separator plugging with excessive sludge. In the diesel engine, incompatible fuel oils can cause injection pump sticking, injector deposits, exhaust valve deposits, and turbocharger turbine deposits. Once an incompatible fuel oil is lifted or blended onboard, little can be done to undo the resultant problems except to continue to desludge, clean out, and maintain the engine(s) round-the-clock until the incompatible fuel oil is consumed. If another bunker supply is available onboard, switching to a compatible fuel oil will eliminate the handling and engine problems, but will probably result in a significant build-up of sludge in the bottom of all tanks containing the incompatible oil. Removal of the incompatible oil from affected tanks can be a very time consuming operation.

To predict a potential incompatibility problem, and to avoid its troublesome consequences, every cutter stock and residual fuel oil considered for blending should be subjected to a compatibility test. Most major oil suppliers will provide this screening before the blends are made. The simplest test is the ASTM D-278l spot test, which can be conducted quickly, inexpensively and without expensive test equipment or without highly trained technicians. There are several other test methods used by others, but these methods are more detailed, more costly and more time consuming.

It is very important to segregate bunkers. Frequently, compatibility problems are caused onboard by the indiscriminate mixing of different bunkers. Bunker segregation practices should be applied to storage, settling, and service tanks. As crude oils are subjected to more intense refining, compatibility problems can be expected to become more common because the secondary processes used tend to produce more unstable and incompatible marine fuel oils.

1.15   Cetane

Ignition quality is indicated by cetane number. The lower the cetane number of a fuel, the greater the ignition delay, and the longer the period of time between fuel injection and the beginning of the rapid pressure rise associated with fuel ignition and combustion. The cetane number of a fuel is dependent on the nature of the hydrocarbon from which the fuel is refined and the extent of refinery processing on the crude oil. As crude oils are refined more intensely, the fuel oils possess a greater aromaticity, which can increase the ignition delay, and can result in hard knocking or noisy engine running, which is undesirable over long periods of time. The result could be poor fuel economy, loss of power and, possibly, even engine damage. If the fuel oil requires blending for viscosity reduction, the lower viscosity cutter stock will have to contain a higher aromaticity to prevent incompatibility problems after blending. This higher aromaticity in the cutter stock can result in a similar increase in ignition delay, similar hard engine operation and similar end results. This can cause serious operational limitations in medium- and high-speed diesel engines, which are sensitive to the ignition quality of the fuel provided. Diesels operating at speeds of less than 400 rpm are much less sensitive to fuel ignition quality.

Difficulties in diesel fuel oil combustion are largely related to the time required to burn the fuel. This time includes ignition delay, or the time required to start combustion, and the complete combustion or burning period. Basically, ignition delay and burning duration increase with increased viscosity and aromatic content of the fuel and such fuels contain a higher percentage of high boiling point hydrocarbons. Both factors tend to lower the cetane number. Physical factors which influence ignition and burning time are the speed with which fuel droplets are atomized, vaporized and thermally

cracked to form a combustible mixture. Ignition and burning time can be improved by decreasing fuel droplet size and/or increasing swirl. Experience also has indicated that raising inlet air temperature can reduce the cetane sensitivity of higher speed diesel engines.

Cetane number is normally quoted for distillate fuels only. A number of methods exist for approximating the cetane number for residual fuels. However, there has not been a consensus of opinion on a single preferred test method.

1.17 Flash Point

The flash point of a fuel is the temperature at which fuel vapors can be ignited when exposed to a flame. All petroleum products will burn. However, in order for this to occur, the ratio of fuel vapor to air must be within certain limits.

When heavy fuel oil at a given temperature is exposed to air, some of it will vaporize, causing a vapor/air mixture of some degree near its surface. As the temperature of the fuel is raised, more and more will vaporize until, eventually, a temperature is reached at which the vapor/air ratio is high enough to support combustion if a source of ignition is present. This temperature is the flash point of the product.

For heavy fuel oils, the flash point usually is determined by a closed cup method, in which the product is heated in a covered container. This procedure most closely approximates the conditions under which the products are handled in actual service.

Two closed cup methods for determining flash point are widely used. They differ primarily in details of the equipment and in the specific fields of application. However, the tests are basically similar and may be grouped together for the purpose of description. They are:

> ASTM D-56   Flash Point by Means of the Tag Closed Tester
>
> ASTM D-93   Flash Point by Means of the Pensky-Martens Closed Tester

The former test (Tag) is used for most fuels and solvents, including lacquer solvents and dilutants with low flash points. The latter test (Pensky-Martens) is ordinarily used for heavy fuel oils, but can also be used for cutback asphalts and other viscous materials and suspensions of solids.

Flash point is important from a handling and storage consideration, but is of little value in determining combustion characteristics of a fuel. Maintain 10 degrees Centigrade below flash point in all storage, settling or service tanks.

The accepted, safe, minimum flash point for fuel oils established by most regulatory bodies is 60 degrees Centigrade. The primary purpose of reporting flash point is for safety during storage, heating and handling of liquid marine fuels. A high viscosity fuel with high specific gravity and a low flash point would be difficult to handle, because preheating above its flash point might be required for pumping and storage. As a practical matter, flash points of typical diesel fuels have little influence on the operation, performance and maintenance of main propulsion or auxiliary diesel engines. Care must be taken not to heat any fuel oil tank to the flash point of the fuel, oil. It is recommended to heat to within 10 degrees Centigrade of the flash point only.

1.19 Pour Point

For pumping and handling purposes, it is often necessary to know the minimum temperature at which a particular fuel oil loses its fluid characteristics. This information can be of considerable importance, because wide variations in pour point exist between different oils – even between oils of comparable viscosity.

The origin of the crude oil can have a large effect upon the pour point of the fuel oil. Traditionally, the Libyan and Nigerian (Lagos) crude oils tend to have higher pour points and can require more attention

to storage and heating. Also, straight-run residuals tend to have higher pour points than the corresponding cracked residuals would possess.

The behavior of an oil at low temperature depends upon the type of crude from which it is refined, the method of refining and the presence, if any, of additives. Paraffinic base stocks contain waxy components which remain in solution at warmer temperatures. When the temperature is decreased, these waxy components begin to crystallize. They become fully crystallized at a temperature slightly below the pour point. At this temperature, the undisturbed oil generally will not flow under the influence of gravity.

Crystallization of the waxy components does not mean that the oil as a whole is solidified – flow simply is prevented by the crystalline wax structure. This structure can be ruptured by agitation and the oil will proceed to flow, even though its temperature remains somewhat below the pour point.

An oil that is predominantly naphthenic, on the other hand, reacts in a somewhat different manner. Even with a comparatively low wax content, a naphthenic oil as a whole thickens more than a paraffinic oil of comparable viscosity when it is cooled. For this reason, at its pour point the entire body of oil is congealed. Agitation has little effect upon fluidity, unless it raises the temperature.

The pour point of a fuel takes on importance from the handling and storage aspects. If a fuel has a high pour point (that is to say, it ceases to flow at a relatively high temperature), then sufficient tank heating is required to maintain fuel temperature at least l2-28 degrees Centigrade above its pour point for satisfactory pumping. Additional facilities may be required to purge fuel lines, especially those exposed to temperatures lower than the pour point of all fuel once the pumping operation is completed.

Ideally, the pour point limit should not exceed 40 degrees Centigrade. However, 27 degrees is becoming a more practical, working pour point with today's fuels. Care must be taken not to allow the fuel to reach its pour point while in storage, because a high pour point may indicate the presence of paraffin crystals which, once formed, will prevent pumping even at 6-12 degrees Centigrade above the pour point.

1.21   Heating Value

When buying marine fuel oil, the heating values are of primary interest. More owner and charterer attention should focus on this important fuel oil property, to ensure the greatest value for the moneys spent.

Changes in diesel engine performance relative to the use of heavy fuel oil result primarily from the reduction in heat contained in and released during the combustion of higher gravity, higher sulfur, higher water content marine bunkers. this change can be quantified and observed as changes in brake specific fuel consumption (a term most frequently used as a performance indicator by operators) and overall engine efficiency (a more theoretically-oriented performance indicator). Diesel engine performance normally is based on the lower heating value of the fuel being burned which is derived from the higher (gross) heating value by subtraction of the latent heat of the water vapor produced during combustion.

The specific gravity of a fuel oil is a reflection of its heating value. The heating value is determined primarily by the carbon/hydrogen ratio; as the carbon/hydrogen ratio increases, the specific gravity will increase and the heating value will decrease. Section 3, Figure 3 will give some idea of the effect of the carbon/hydrogen ratio and the various hydrocarbon components on the heating value. The heating value is also decreased by the presence of sulfur.

The heat contained in a fuel, or its heating value (BTU/lb), is primarily affected by changes in a specific (or API) gravity and its sulfur content in percent by weight. As the gravity of the oil increases, the ratio of carbon to hydrogen increases, as well as the sulfur content. The result is that there is less hydrogen with its high heating value available per pound, and a consequent decrease in heat released during combustion. From a performance viewpoint, this change in heat content is

indicated by an increased brake specific fuel rate in pounds per brake horsepower-hour and, to a very slight degree, by a decrease in overall engine efficiency, as more fuel with a lower heat content must be burned for a fixed power output.

Operationally, at a fixed power, these changes usually can be correlated with such parameters as increased cylinder exhaust temperatures and increased firing pressures when burning a higher gravity/sulfur content fuel. Generally, at constant load, the changes in engine performance due to operation on higher gravity, lower heat content fuels are relatively small. It is in the area of engine condition and related factors such as the amount and frequency of required maintenance that operation with higher gravity and sulfur content fuels will have its greatest impact.

Section 3, Figure 4 presents a graphic relationship of higher and lower heating value sulfur content and API and specific gravities for marine fuels.

FIGURE 3
Relationship between Carbon/Hydrogen Ratio and Gross Heating Value and Carbon Atoms
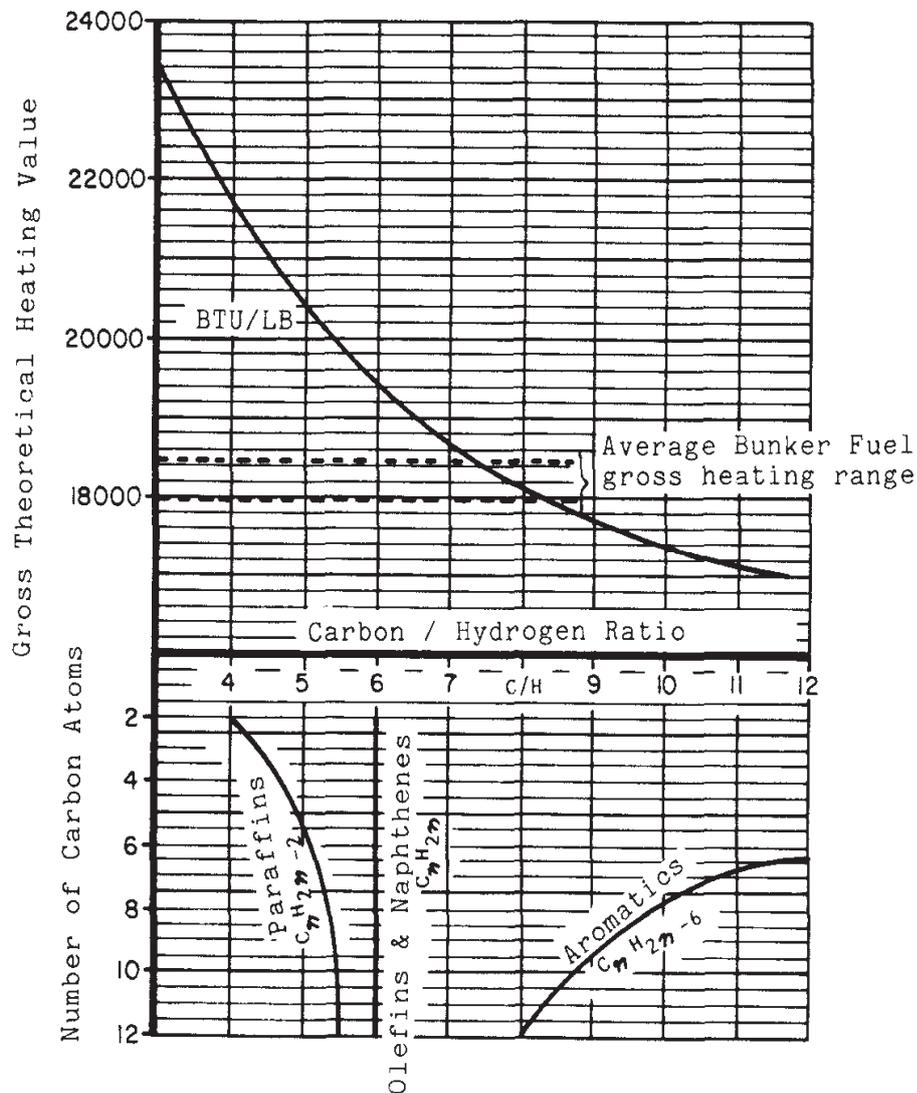
FIGURE 4
Heating Values Relative to Gravity and Sulfur Content

Heating Value
BTU/LB

Specific Gravity at 60°F
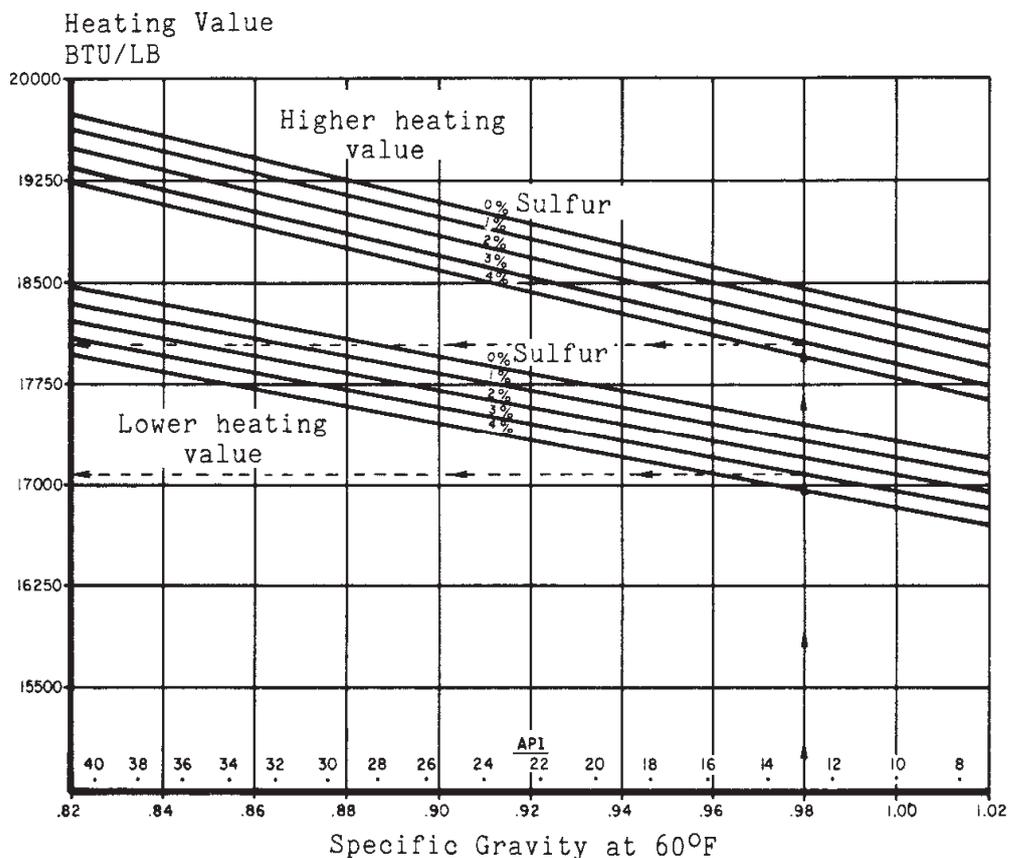
3   Marine Fuel Oil Contaminants

3.1   Water

Water, considered here as a fuel oil contaminant, is the water introduced into the fuel through salt or fresh water intrusion during shipment, or as a result of condensation during prolonged storage.

For residual fuels, water content may be determined by distillation (ASTM D-95), or by a centrifuge method (ASTM D-96) which determines the combined water and sediment content, or by titration (ASTM D-l744). Water content of a tanker- or barge-delivered product may occasionally be above specified limits as a result of direct sea water contamination. Fresh water contamination may also cause an additional problem as a collector of water soluble metals and salts present in a heavier fuel.

Water, especially salt water, is objectionable in diesel fuel as it may cause injector and piston groove deposits and corrode engine components. Operators of diesels that burn residual fuel or blends centrifuge these fuels to remove water and sediment. Salt water is the greatest single cause of fouling, deposits and corrosion, especially in the higher temperature areas of a diesel. Salt water can also cause excessive separator sludge volume as a result of water/sludge emulsification during centrifuging.

Water can provide the beginning for microbial growth in heavy fuels. These very simple life forms live in the water and feed on the heavy fuel at the water-fuel interface. The result of microbial matter in the fuel can be a slime, which is sometime corrosive, that will foul strainers, filters and separators. The short range solution would be to add a "biocide" chemical additive to the fuel to kill the growth. The much preferred, long range solution would be to regularly drain the tank bottoms to eliminate the water, without which this growth cannot exist.

3.3   Sodium (Na)

Sodium is an alkaline, metallic element that is found in the combined form of common salt, NaCl. It is extremely active chemically. The sodium found in fuel can come from several sources. But most of it is a direct result of storing and handling procedures from the time the fuel leaves the refinery until it is delivered to bunkers. Salt water contamination in barges used to transport the fuel is not uncommon. To some extent, even salt air condensation in fuel tanks contributes to the overall sodium content.

Regardless of the manner of contamination, sodium in fuel is usually water soluble and can, therefore, be removed with the centrifugal separator.

Sodium acts as a paste (flux) for vanadium slag. When unfavorable quantities of vanadium and sodium are present in a fuel they react at combustion temperatures to form (eutectic) compounds with ash melting points within operating temperatures. In molten form sodium/vanadium ash can corrode alloy steels, and when this condition is allowed to persist unchecked, high temperature corrosion, overheating, and eventual burning away of exhaust valves, valve faces, and piston crowns is not uncommon. This sodium/vanadium ratio and its relationship to ash melting temperature are shown in Section 3, Figure 5.

The chief corrosive constituents in heavy fuel, oil ash formed during combustion are vanadium pentoxide, sodium sulphate, and other complex forms of these primary compounds. The chemical nature of these compounds and their interaction with steel surfaces on exhaust valve seats are of real concern, as the relatively low melting points of most of these compounds make them very corrosive at normal engine exhaust temperatures. The thickness of the various oxide layers depends on the temperature and the exhaust gas composition. In their molten states, the vanadium-sodium-sulfur compounds also act to dissolve the exhaust valve surface ferric oxide (Fe_2O_3) layer, thus exposing the underlying steel surface to further oxidation attack and subsequent erosion.

The oxidation attack takes place by two mechanisms: gas phase oxidation and liquid phase oxidation. In the gas phase oxidation, the high temperature oxygen-containing exhaust gases react with steel to form oxides. Liquid phase oxidation (corrosion) takes place when molten sulfates and pyrosulfates in the exhaust gases deposit on valve surfaces. In extreme situations, similar sodium/vanadium ash corrosion attack can also occur downstream of the exhaust valves in the turbocharger exhaust gas turbine and blading.

3.5   Sediment

Sediment is another contaminant which finds its way into marine bunkers. Rust, scale, weld slag, dirt and other debris can be introduced in storage or in pipeline or barge transport. The majority of this sediment can be removed by settling, straining or filtration, or centrifuging in the shipboard fuel oil system.

As the specific gravity and the viscosity of fuel oils increase, the sediment level, which originates primarily from transport and storage contamination, will increase as a result of a slowing of the natural settlement process. As both the water and sediment content of heavy fuel oil increase, the usable energy in the fuel decreases. Usually, if sediment (and water) exceed one percent (1%), most oil suppliers will adjust bunkered fuel cost to compensate the buyer. However, since sediment (and water) contamination frequently occur during storage and fuel transport over water, the buyer must accurately and continuously sample the fuel oil during bunkering to obtain a representative bunker sample to be assured he is getting what he is paying for. Sediment (and water) can be settled out to a large degree during heated storage. However, as the specific gravity of heavy fuel oil approaches that of water, the settling process becomes less and less effective. The effectiveness of purification/clarification treatment also is reduced. Sediment removal is essential to reduce high ash or particulate contamination of a fuel since both can contribute to increased deposits, corrosion or abrasive wear.

FIGURE 5
Sodium-Vanadium Phase Diagram
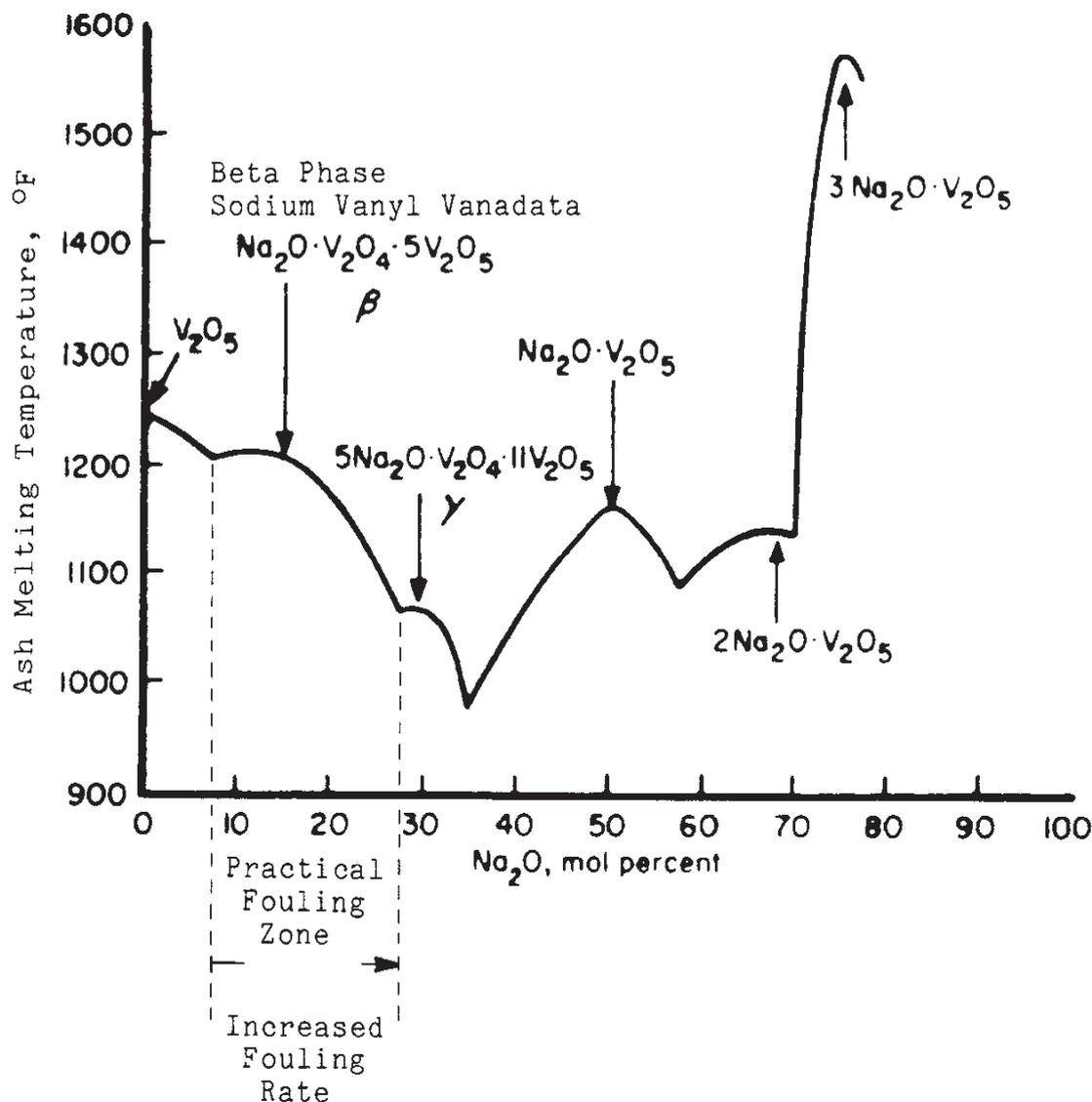
3.7 Alumina/Silica

Hard, abrasive particles, such as alumina/silica catalyst carry-over, originate in the refinery when this powdered catalyst is added to the charge stock of a fluidic catalytic cracking (F.C.C.) unit. Due to erosion and fracture, some of the catalyst is not recovered but is carried over with the bottoms from the F.C.C. unit. Larger sized catalyst particles, greater than ten (10) microns, also can be carried over if there is a defect in the catalyst removal equipment (such as cyclone separators), if there is an upset in the operation of the F.C.C. unit, or if the heavy (low API gravity) bottoms (containing catalyst particles) are not permitted sufficient time to settle-out in heated storage (when this method is used to control catalyst carry-over).

It is also possible to contaminate a clean marine residual fuel oil with catalyst particles during transport. For example, if steamship fuel (frequently containing catalyst particles) has been transported by barge prior to moving a clean heavy fuel oil for a diesel powered ship, the barge bottom sediment will be mixed with the clean fuel oil and will contaminate it.

Because cat-fines are generally small, very hard, and quite abrasive to pumps, atomizers, piston rings and liners, a number of major diesel engine builders have concluded that thirty parts per million (30 ppm) of alumina in the bunkered fuel oil is the upper limit for successful treatment and engine operation. The average particle size, as well as the concentration, greatly impacts the wear rate of engine components. Small sized catalyst particles, in the one to ten (1-10) micron range, typically cause accelerated wear in injection pumps and injectors and only moderate increases in cylinder assembly wear, such as piston rings, piston grooves, and liners. The larger sized catalyst particles, in the ten to seventy (10-70) micron range, typically cause very accelerated wear rates in the cylinder assembly area. Accelerated damage can also be expected on injection pump inlet valves, exhaust valve seating areas, and turbocharger turbine blading. These larger sized particles have been associated with catastrophic wear rates.

3.9   Sludge

Sludge is a contaminant that results from the handling, mixing, blending, and pumping of heavy fuel while stored at and after it leaves the refinery. Storage tanks, heavy fuel pipe lines, and barging can all contribute to the sludge. Water contamination of a high asphaltene fuel oil can produce an emulsion during fuel handling which can contain more than fifty percent (50%) water. Shipboard transfer pumps frequently can provide the necessary energy to produce emulsified sludges during normal fuel transfers. These emulsified sludges can cause rapid fouling and shutdown of centrifugal purifiers and clogging of strainers and filters in the fuel oil system, and rapid fouling if burned in the engine.

3.11   Fibers

Fiber contamination can cause significant problems in fuel handling aboard ship. This type of contamination usually occurs during transport and storage. Fibers can plug suction strainers protecting pumps within minutes of initial operation. Whereas cleaning strainers is not a difficult task, the frequency of cleaning and the need for round-the-clock attention generally create problems. A centrifuge normally is ineffective in removing oil soaked fibers because they have the same density as the oil being purified. Hence, downstream manual or auto-strainers and fine filters can be expected to clog in a short period of time and continue to clog frequently until the entire amount of a fiber-contaminated fuel has been consumed or removed.

3.13   Oxidation Products

This form of contamination is the result of the marine residual fuel aging, either before or after it is bunkered. Residual fuels are not stable for long periods of time at elevated storage temperatures. The elapsed time from the refinery to use onboard, ideally, should be less than three (3) months. Further, it is anticipated that future residual fuels resulting from more intense secondary processing will be even less stable. Heated heavy fuels, stored in uncoated steel tanks and exposed to air (oxygen) oxidize and polymerize with time. The resultant sludges, gums and resins will initially form in solution and then agglomerate and settle or adhere to the tank's surfaces. Also, as heavy fuels age, their shipboard conditioning and treatment become more difficult. In the extreme, the diesel engine's combustion process can deteriorate causing increased fouling, deposits and corrosion as a result of burning such partially oxidized older fuel oils.

Generally, residual fuel oils should not be bunkered and utilized as ballast, trim, or held in reserve for extended periods of time. The oldest fuel on the ship should be burned first to prevent any heavy fuel oil from aging beyond three (3) months from its bunkering date.

SECTION **4**   **Fuel Sampling and Analysis**

CONTENTS

SECTION 4   Fuel Sampling and Analysis

Characteristic properties and contaminants may vary widely in heavy fuel oil, even though traditional criteria of viscosity, specific gravity and flash point may appear as standard for a given fuel grade. This inconsistency between accepted criteria and actual properties and high contaminant levels can mask the fact that fuel received is of a quality which can increase overall engine wear, cause premature engine component failures, and significantly raise overall maintenance costs. The increasing uncertainty as to marine fuel quality has made the onboard sampling and shipboard and shoreside analysis of a fuel's physical characteristics necessary to ensure that shipboard fuel treatment and fuel conditioning equipment can be properly adjusted and maintained to secure efficient diesel engine operation and extended operating life.

The characteristics of heavy fuel oil of importance to the user have been reviewed in previous sections. The traditional criteria of viscosity, specific gravity and flash point no longer yield sufficient information to the user as other important characteristics or contamination levels must be known to safeguard the machinery and ensure proper utilization of the fuel.

To summarize, the properties of interest are:

> Density (specific gravity)
>
> Viscosity
>
> Upper pour point
>
> Conradson Carbon Residue
>
> Ash
>
> Water
>
> Sulfur
>
> Vanadium
>
> Aluminum
>
> Silicon
>
> Sodium
>
> Sediment
>
> Asphaltenes
>
> Compatibility
>
> Heating Value

The accurate determination of these characteristics is best performed by a shoreside laboratory experienced and skilled in the art of heavy fuel oil analysis. In addition, shipboard test kits are available which permit some of these tests to be performed on a continuing basis. Such tests are useful when there is any doubt that samples previously tested are really representative of the fuel being used at any given time.

1   Sampling Procedures

Prior to testing, it is necessary to obtain a representative sample of the fuel oil as it is being delivered onboard the vessel.

The fuel analysis will be of value only if it is representative of the bunkers actually loaded onboard and, for this reason, the taking of the sample is of greatest importance. It should be realized that the sample which is sent to the laboratory is only a tiny fraction of actual bunkers loaded and, therefore, it is most important that all containers and other apparatus used be clean and that sampling connections be flushed through before sampling is started. It is also important that sampling be continued throughout the entire bunkering period, as the quality may change, due to stratification within the bunkering barge or changes in the blending ratios.

A typical sampling connection is shown in Section 4, Figure 1. The container should be of adequate size (say, about 20 liters) and the valve adjusted so that an adequate sample can be drawn off over the bunkering period without changing the sampling rate and, at the same time, not overflowing the container. At the conclusion of the bunkering, the sample should be thoroughly mixed in its container and two one-liter sample bottles filled and properly marked for identification. One sample will be sent to the laboratory for analysis and the other retained onboard. The balance of the fuel oil sample drawn can then be returned to the fuel tanks. The onboard samples of bunkers should be stored in a cool space in order that the properties will not change during storage.

While most sampling is carried out for the purpose of analyzing bunkers as delivered, it is also useful to draw samples from various points in the fuel oil processing system, such as the settling tanks, or after the fuel oil centrifuges, in order to check the efficacy of the purification system. In drawing samples from settling tanks, the samples should be drawn from a location high enough to ensure that the sample is free of the free water which has separated out or, if the sample must be drawn from a low point in the tank, that the bottom of the tank has been purged of separated water and contaminants. It may also be desirable to draw samples from storage tanks, in which case a weighted bottle with loose stopper can be used. Several arrangements of such bottles are illustrated in ASTM D-270.

FIGURE 1
Typical Sample Connection
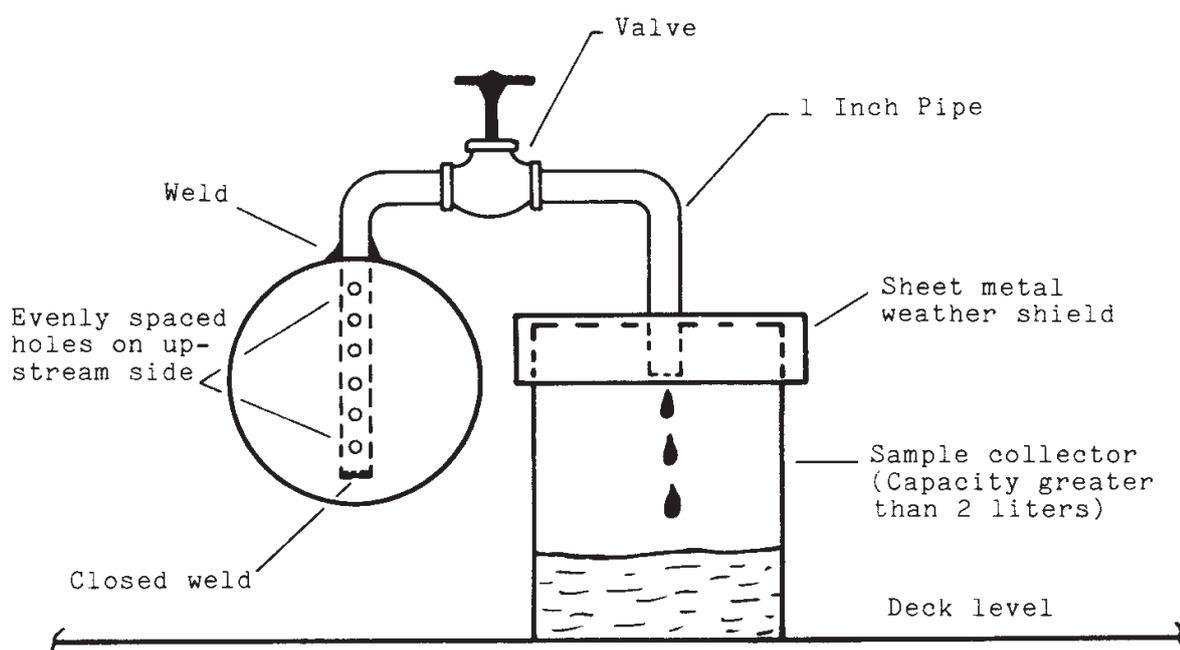
In all cases, when samples are taken for shoreside analysis, it is good practice to take two samples at each sample location and to retain one sample onboard. Should any questions arise as to the findings, a back-up sample is then available for confirmatory testing. It is also most important that all pertinent information relative to each sample, such as the ship's name, fuel oil supplier, date, specified grade, sample locations, etc., should be recorded and attached to the sample container.

At all times in the taking of samples, care must be exercised to protect the crew from contact with hot oil, pipes or tanks, and exposure to petroleum vapors. Additionally, it should not be assumed that heavy fuel oil is not capable of releasing potentially explosive vapors; many fuels as bunkered are blended with lighter stocks in order to provide the specified viscosity and, in many cases, the flash point is not reported, or is in error.

3   Shoreside Analysis

The benefit of a complete and accurate shoreside analysis can be summarized as follows:

i)   Confirmation that bunkers as received meet purchase specifications (or do not meet specs, as the case may be).

ii)   Provides warning of contaminant levels, incompatibility, excessive water content, etc.

iii)   Enables engineers to adopt suitable strategies for proper utilization of the fuel.

iv)   Provides permanent independent third-party report (analysis) of fuel oil received and enables owner to claim against bunker supplier in case of failure to meet purchase specifications or in case of delivery of unmarketable product.

v)   Shoreside laboratory will normally alert owner to any unusual or potentially damaging characteristics or fuel oil and will suggest proper countervailing strategies.

The single most important constraint in this process is time. It is highly desirable to have the results of the shoreside analysis available to the owner (and, of course, the ship's engineer) before the fuel is to be used. As will be discussed in Section 5, modern practice requires that new bunkers be segregated from existing bunkers to the greatest extent possible. The efficient shoreside laboratory should be able to complete a sample analysis and transmit telex advice of results within 24 hours of receipt of sample, and the proper management of the dispatch and routing of the sample is of great importance. In general, it is preferable to use one shoreside laboratory using known and accepted analytical techniques rather than a variety of laboratories around the world. A laboratory located on the Middle Atlantic (East Coast) region of the United States is particularly favorably located with respect to airline service, and experienced courier services can provide rapid custom clearance and sample delivery. By using a single laboratory, the results from all samples analyzed can be considered comparable, which will not be the case for analyses from different laboratories located in various parts of the world.

5   Shipboard Analyses

Shipboard fuel testing kits provide a means for the ship's engineering personnel to perform several of the tests previously discussed. The kits are of moderate cost and are generally arranged to provide for the following tests:

Density (specific gravity)

Pour Point

Viscosity

Water content

Salt water

Compatibility

Catalyst particles

Sludge/Wax determination

All of the above can be performed with relative ease and, although the same accuracy or reliability expected from shoreside analyses cannot be attained, they are useful for adjustment of purifying equipment, assuring proper temperature for required viscosity, quick and easy checks on bunker receipts, etc.

7   Fuel Specifications and Standards

Two documents are available to the owner for use in specifying fuel quality. The first is the British Standards Institute BSMA 100:1982, "Petroleum Fuels for Marine Oil Engines and Boilers," and the other is the CIMAC (International Congress on Combustion Engines, Congress International des Machines a Combustion) "Requirements for Specifications of Intermediate Marine Fuels." In addition, the ISO (International Organization for Standardization) has a draft standard in preparation. Both the British Standard and the CIMAC document are outgrowths of the ISO work.

It is important to recognize that the BSI standard is a supply standard; i.e., it is based on what may be available rather than what is required; the CIMAC recommendations represent the work of the representatives of the engine builders and are intended to establish certain quality categories suitable for different types of engines. According to the chairman of the CIMAC Working Group "Future Fuels," the engine manufacturers have agreed to base their fuel specifications on the CIMAC recommendations although, in individual cases, they may be amplified according to type of engine.

In all cases, the owner should give close attention to the engine builder's specifications, as these may be an issue in any engine damage warranty claims which may be related to fuel quality.

SECTION **5** **Shipboard Fuel Handling and Treatment for Diesel Engines**

CONTENTS

S E C T I O N   **5   Shipboard Fuel Handling and Treatment for Diesel Engines**

The ship owner's first point of active fuel control and handling begins at the ship's bunkering connection. The ultimate movement, storage, inventory and final processing of the fuel is the responsibility of the ship's operating personnel. Pre-planned and prudent execution of fuel oil management within the ship's transfer and processing systems will minimize the potential for creating unworkable fuel compatibility and combustion problems.

1   Marine Diesel Oil Systems

1.1   Fill, Transfer, Storage and Purification System

Marine diesel oil (MDO) is a middle distillate fuel oil which can contain traces to ten percent (10%) or more residual fuel oil from transportation contamination and/or heavy fuel oil blending.

Section 5, Figure 1 illustrates a basic diesel oil fill, transfer, storage and purification system. The diesel oil is bunkered at a dedicated deck connection for transfer and distribution to the ship's storage tanks. A sample cock is provided at the deck connection to permit obtaining fuel samples during the bunkering process.

Diesel oil is transferred from the storage tanks by means of a transfer pump and/or a purifier mounted pump. Single stage purification is typically operated at 100% throughput. However, a reduction in throughput to 60-70% of rated capacity may be made when purifying the more contaminated diesel oils. The only heating requirement for diesel oil is a preheater for purification purposes.

Storage tank stripping connections should be provided to permit pumping the tank contents to any other storage tank, the purifier, or a sludge tank.

The basic system illustrated in Section 5, Figure 1 provides the following capabilities:

i)   Diesel oil sampling while bunkering

ii)   Diesel oil transfer from storage to service tank(s) by way of the purifier system

iii)   Diesel oil transfer from any storage tank to any other storage tank, or directly to the service tank

iv)   Diesel oil supplied to the emergency diesel generator by either the transfer pump or the purifier

v)   Diesel oil service tank bottom drains directly to the sludge tank

FIGURE 1
Typical Diesel Oil Fill, Transfer, Storage and Purification System

Deck fill
connection

Deck fill
connection

Sample
connection
(Typical)

Fuel oil
service tank

Fuel oil
storage tank

Stripping
connection
(Typical)

Stripping connection

Drain to sludge tank

Fuel oil
transfer pump

Water supply

Purifier pump   Heater

Diesel oil
purifier

To sludge tank
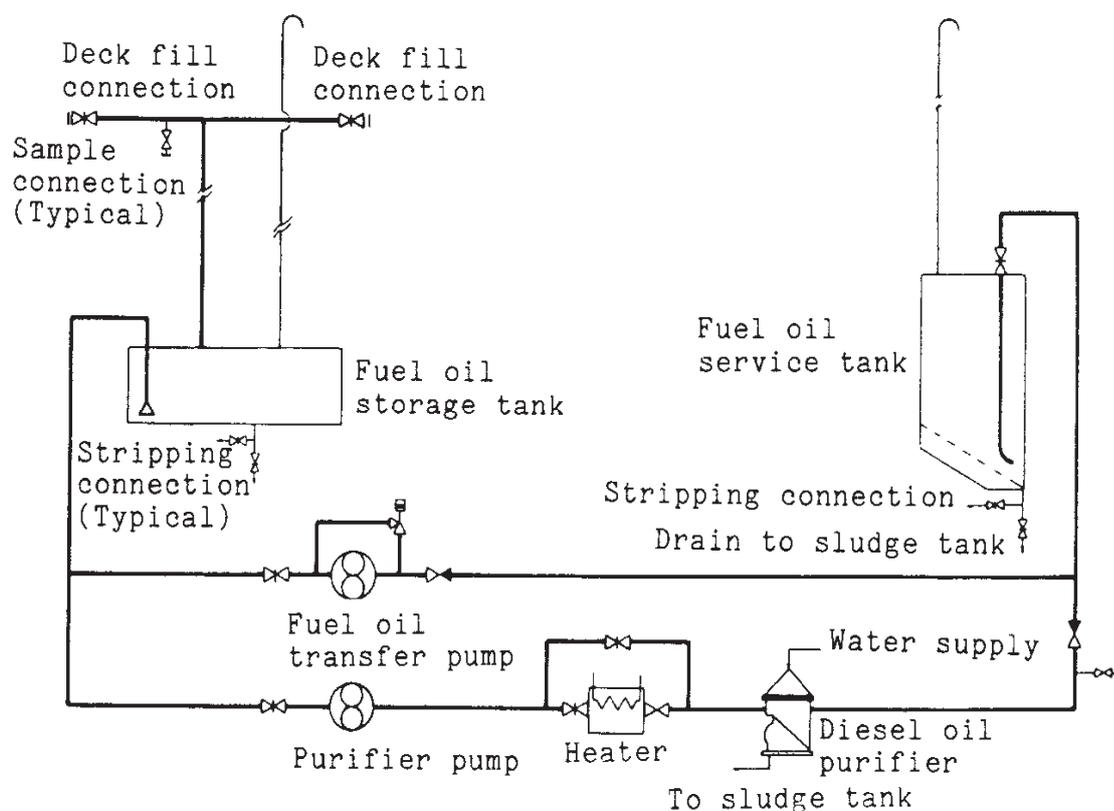
1.3   Service System

The diesel oil service system depicted in Section 5, Figure 2 can supply purified fuel from the service tank to any of the following consumers:

i)   Main Propulsion Engine(s)

ii)   Auxiliary Boiler

iii)   Ship's Service Diesel Generator

Diesel oil flows from the service tank to the engine driven fuel oil service pump via a duplex strainer. Next, a fuel oil meter and bypass are fitted. The fuel then flows to the engine via a final "last chance" filter designed to remove impurities which may have been introduced downstream of the service pump discharge filter. Excess fuel is returned to the top of the service tank via a second fuel oil meter bypass. The engine's fuel oil return line is fitted with a pressure control valve to maintain the proper inlet pressure at the engine's injection pumps.

FIGURE 2
Typical Diesel Oil Service System
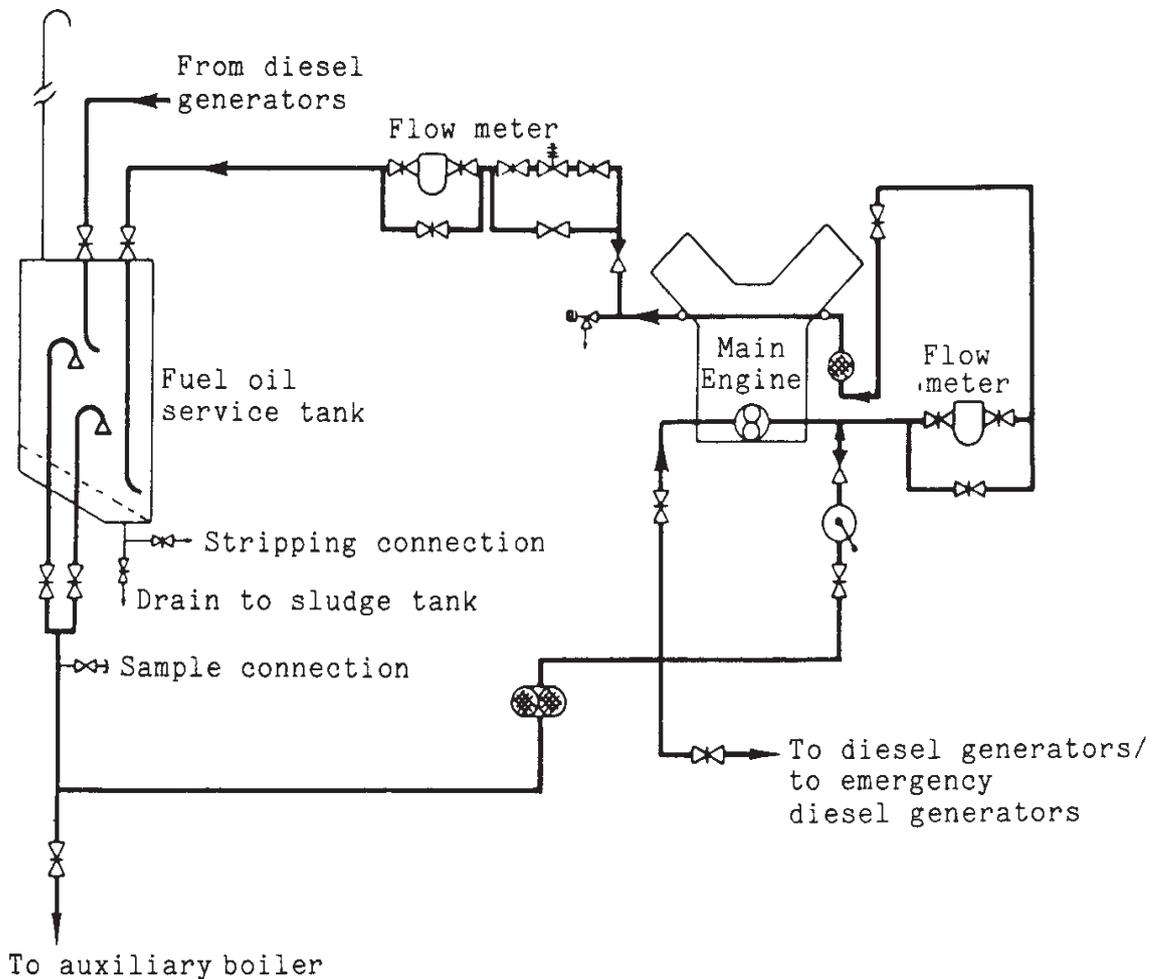
3   Heavy Fuel Oil Systems

3.1   Fill, Transfer, Storage and Purification System

Section 5, Figure 3 illustrates a basic fill, transfer, storage and purification system for a heavy fuel oil propulsion plant. The configuration represents the typical flow path for heavy fuel oil from storage to consumption. Fuel oil is transferred from storage tanks to settling tanks via a fuel oil transfer pump and its associated suction strainer. From the settling tanks it is transferred to service tanks by way of the purification system. Two fuel oil centrifugal separators are installed with appropriate supply pumps, heaters and controls. The system and equipment is configured to permit operation of the separators in parallel or in series, either in a purifier/purifier or clarifier/clarifier or purifier/clarifier sequence. Centrifuge heater crossover capability also is illustrated. Fuel oil is discharged from the separators to the service tanks either directly, or via an additional duplex filter if it is suspected that the separators have not removed all contaminants. The fuel oil is retained in the service tanks until it is drawn to the main engine via the fuel oil service system. Trace heating of the fuel oil piping, if fitted, should be activated during these transfer operations.

FIGURE 3
Typical Heavy Fuel Oil Fill, Transfer, Storage, and Purification System
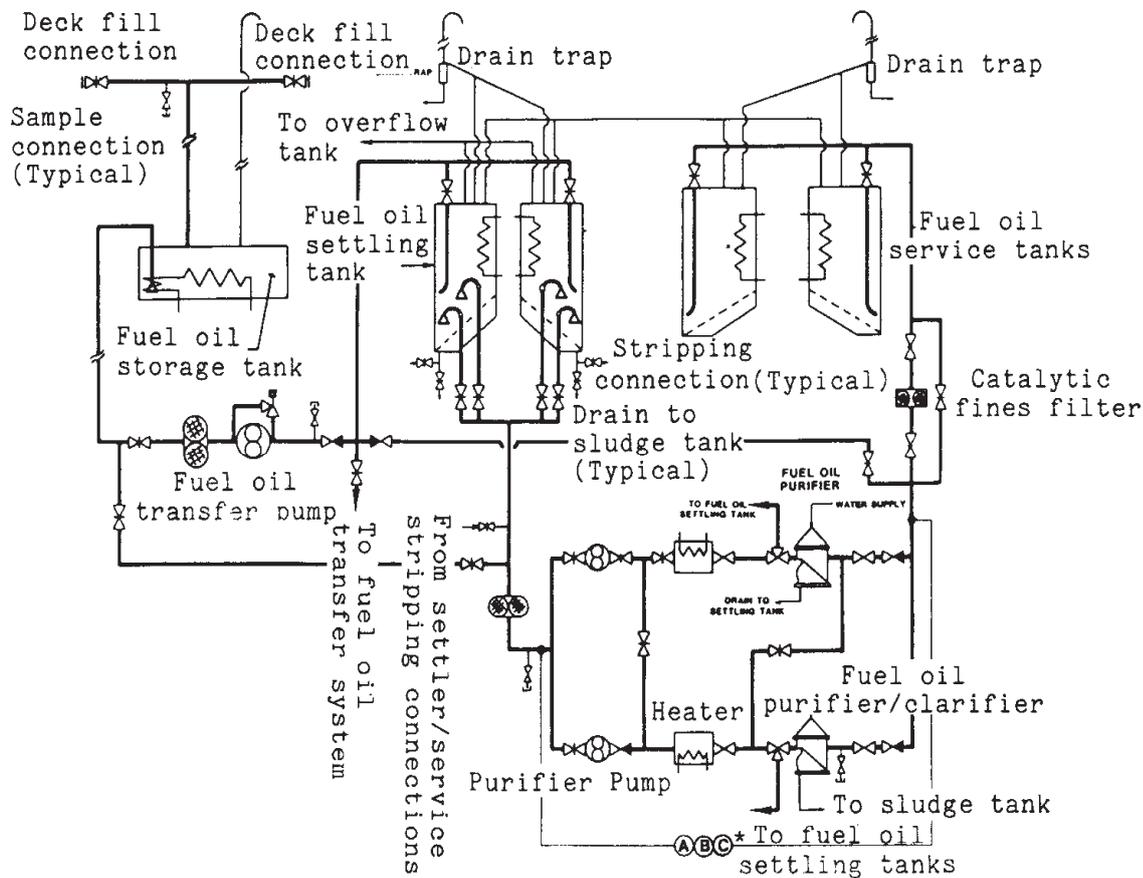
3.3   Transfer Pump Suction Strainers

Duplex suction strainers protect fuel oil transfer pumps from solid debris that could cause them mechanical damage. The suction strainers are duplexed to permit continuous service. Typically they are equipped with reinforced, corrosion resistant steel mesh baskets with a 20 to 40 mesh rating. Crossover valving at the strainers provides continuous flow to the transfer pumps when one strainer is down for cleaning.

3.5   Transfer Pump

A transfer pump normally is installed to move fuel oil from storage tanks to settling tanks. One positive displacement transfer pump, protected by suction strainers and a pressure relief valve, and a pump bypass line, is normally fitted. The transfer pump flow rate is dependent upon engine fuel consumption rate and service and settling tank size.

Proper arrangement of valving adds distribution flexibility to the transfer system. This valving normally permits fuel oil from any storage tank to be pumped to either settling tank, to either service tank, to the remainder of the fuel oil storage tanks or, in some systems, overboard to a barge or other storage facility.

3.7   Settling Tanks

Settling tanks have several important functions in the proper treatment of heavy fuel oil. They provide a settling function for gross water and solids, a heating function, a deaeration function, and a thermal stabilizing function. Ships' settling tanks are designed to accept fuel oils with a 60 degrees Centigrade minimum flash point. The two settling tank concept is the most common arrangement, with each tank holding up to one day's required fuel oil supply at full power. More conservative designs have increased settling tank residence time up to four (4) days per tank. Normally, one tank is being filled from the transfer system and holding fuel while the other tank is supplying fuel to service tanks via heaters and separators. As soon as a settling tank is filled, it is heated to 72 degrees Centigrade, or 6 degrees Centigrade below the flash point, whichever is lower. From a safety standpoint, fuel oils must never be heated in ships' tankage at or above the fuel's flash point. In a diesel propulsion system, once tank contents have been heated to the selected temperature, settling tank heat should be secured and the fuel allowed to settle undisturbed for as long as possible. The tanks should be insulated where possible to reduce heat loss. It is important to secure the settling tank heat source once its contents are up to temperature, because continuous heating will produce thermal currents within the tank which interfere with the settling process (Stokes' law). Because of constant heat loss from a settling tank, it may be necessary to reactivate the tank heating system periodically in order to maintain its contents at 60 degrees Centigrade or better.

Settling tanks should have bottom drains for water and sludge stripping. And, water and sludge should be removed on a regular basis by means of these drains.

3.9   Separator Pump Suction Strainers

Duplex suction strainers are used to protect separator service pumps from debris in the delivered fuel. The 20 to 40 mesh baskets should be reinforced, corrosion resistant, and protected by a differential pressure system. The strainers should have non-interrupting, crossover valving to provide continuous flow to the purifier service pumps on one strainer while cleaning the other.

3.11   Separator Heaters

Separator heaters are horizontal shell and tube or plate type units. Each heater normally services one separator and is designed to provide an oil outlet temperature of 98 degrees Centigrade. The temperature control circuit utilizes a temperature probe and transmitter, a steam control valve and steam drain trap. Heaters are piped for one or two heater operation and are fitted with suitable isolation valving for single unit servicing. Successful separator operation dictates that these heaters and associated control circuits supply heavy fuel oils at the required temperature for reliable, efficient separator operation.

3.13   Separators

Two properly sized, properly adjusted, correctly operated, self-cleaning separators are considered to be necessary for any reliable, shipboard heavy fuel treatment system operating on today's heavy fuel oils, Whereas separator systems are a necessity, these basic units cannot supply total system protection under all circumstances. Other systems, discussed in 5/7, may be necessary to supplement, but not replace, these basic units.

Efficient and consistent separator operation depends on an understanding of and the application of the basic principles of fuel handling, treating and conditioning:

i)   The separator is the first major stage of fuel treatment

ii)   To treat degraded fuel oils, supplementary systems in addition to the separators may be required

iii)   The following heavy fuel oil properties should be known to achieve proper adjustment and operation of separators:

        Viscosity

        Specific Gravity (or API Gravity)

        Compatibility of fuel oil

        Water content

        Ash content

        Other contaminant content (such as BS&W)

iv)   All installed heavy fuel oil separators should be online and operated continuously. The only acceptable reason for not operating a unit is during manual cleaning or overhaul.

v)   Single separator flow rate (for series operation) or combined separator flow rate (for parallel operation) should not exceed the existing engine fuel consumption rate by more than ten percent (10%)

vi)   Each time a new settling tank is pumped, a specific gravity check of the settling tank should be made and the separator gravity disc checked and changed if necessary.

vii)   Each separator should have all parts necessary to operate as a purifier and as a clarifier, as well as a complete set of tools and spares

The centrifugal separator is the foundation of the total shipboard fuel treatment system. Its efficient operation is critical to the safety and reliability of the main and auxiliary propulsion equipment. Its operation must be thoroughly understood by the shipboard engineers so that they can immediately troubleshoot heavy fuel oil problems as they occur. A treatment problem cannot wait until the next port. Major main engine damage can result quickly from lack of proper treatment of degraded fuel oil. Some basic situations which can cause separators to operate below maximum efficiency, or not work at all, are:

i)   Incorrect fuel handling before the centrifuge

ii)   Unstable flow

iii)   Incorrect flow, (usually too high a flow)

iv)   Unstable temperature

v)   Incorrect temperature

vi)   Incorrect positioning of the water/oil interface, thereby inhibiting the correct flow of oil through all discs, (usually caused by incorrect gravity data and/or choice of an incorrect gravity disc)

vii)   Overfilling of sludge space caused by extended intervals between desludging, or incompatible heavy fuel oils with higher than normal sludge deposits

The following observations are indicative of inefficient or incorrect separator operation which may be caused by changes in the fuel oil characteristics. A separator which breaks the water seal after experiencing balanced operation may be the result of increased fuel density, increased viscosity, increased flow rate, or a decrease in temperature. If the oil/water interface moves towards the axis of the bowl to give poor fuel separation or water carryover into the oil phase, the potential causes may be decreased flow rate, or increased temperature. If the separator failure occurs because of an uncontrollable fuel oil characteristic, such as increased density or viscosity, the gravity disc should be changed to achieve efficient operation. It also may be necessary to decrease throughput to effectively purify higher viscosity fuels.

3.15   Filters

A filtration system before the service tank is recommended and is currently in use in many modern shipboard fuel treating and conditioning systems. The higher ash, solids, and catalyst particle content being found more frequently in heavy fuels make such an installation prudent. A properly designed filtration system would positively control solids that can damage high pressure pumps, injection systems, and the cylinder bores of diesel engines. Under normal operating conditions, properly designed and operated filtration systems can provide positive protection with 2000-3000 hour intervals between filter element replacement.

Because heavy fuel oils may contain more sediment, dirt, ash and catalyst particles, the separator system, preferably operating in series, can provide a sizeable initial reduction in these solids, but not always enough to prevent an increase in engine wear rates. The remainder of the small solids, as well as a small percentage of large particles, can be effectively stopped by a five (5) micron (nominal), replaceable element, depth type, filtration system. The filtration units should be designed to prevent bypassing of fuel around the end sealing cups. The filter housing should be equipped with a bottom water drain, an air vent and a differential pressure gauge correlation to indicate the pressure drop across the filter so that an accurate determination of filter element replacement requirement can be made.

In addition to solids, trace quantities of free water carried over from the separators also are removed by these filters. Whereas removing trace water may seem unimportant, shipboard experience has shown that injection pump life can increase by as much as 100 percent (100%) by its elimination. The filter water sumps should be drained daily to prevent water from rising above the sump level and "wetting" the filter elements.

3.17   Service System

Section 5, Figure 4 illustrates a typical heavy fuel oil service system for a diesel propulsion system. The fuel oil service system forwards the oil from the respective service tanks to the main propulsion engine(s), auxiliary diesel generator(s) and/or auxiliary boiler.
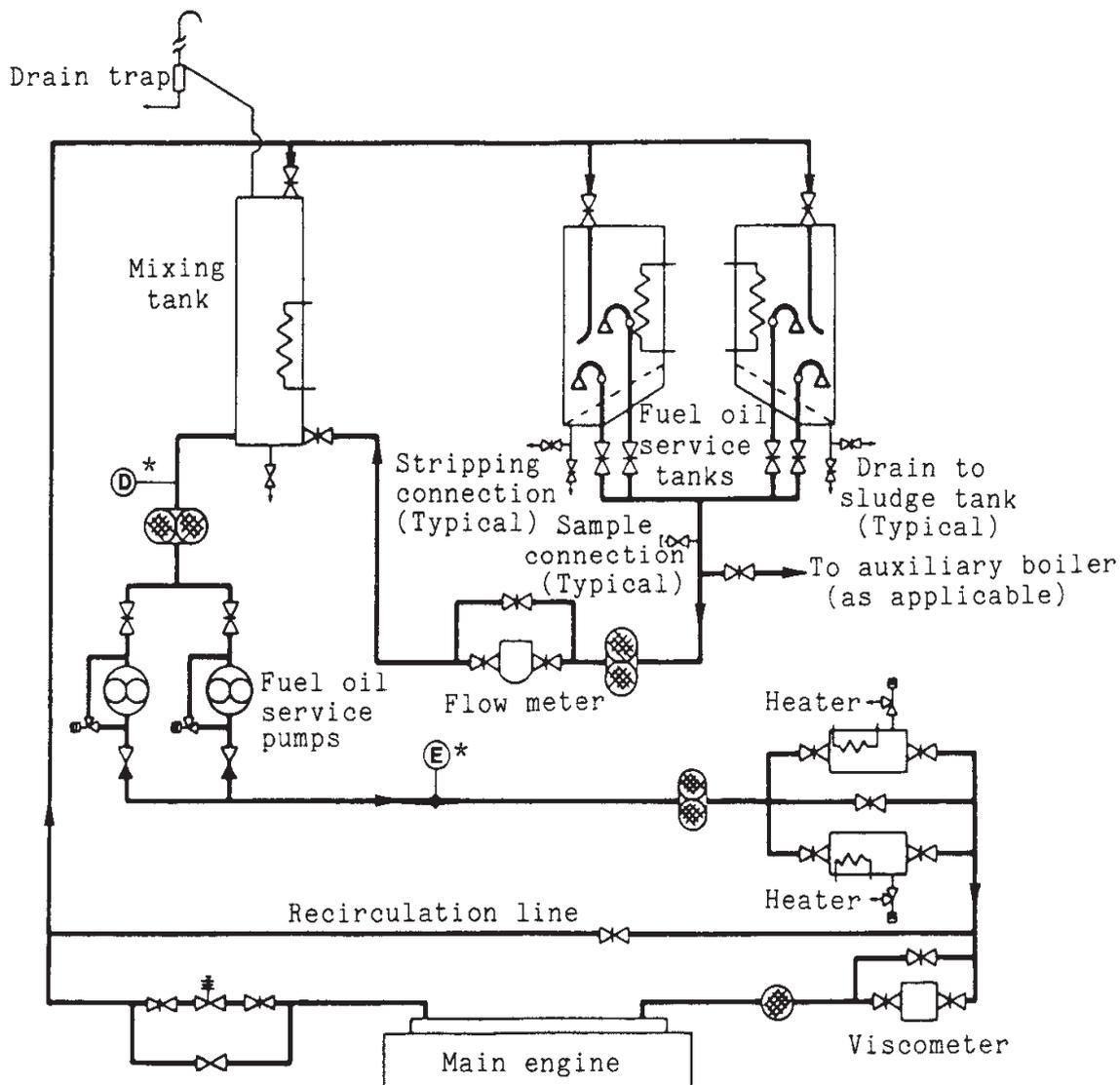
Fuel oil flows from the service tank via the fuel changeover valve to a mixing tank. From the mixing tank, one of two booster pumps delivers the fuel through a fuel oil service heater, a viscosity controller, and a final filter to the main engine fuel pumps. Excess oil is normally returned to the mixing tank or, if desired, to the service tank through a changeover valve.

3.19   Service Tank

Service tanks, or day tanks, have a very important function in the overall treatment of heavy fuel oil for diesel engines. They provide a final settling function for water and solids, a heating function and a thermal stabilizing function. The settling function is primarily a backup in the event of a performance failure of the separators and/or during a by-pass of the filtration system. Two service tanks are normally provided.

While one service tank is supplying fuel oil to the system, the other is receiving fuel oil conditioned through the separator and filtration systems. The tanks normally have high and low suction lines with downturned diffusers. The cleanest fuel oil is available from the upper (high) suction. Therefore it should be used whenever possible. The service tanks should have bottom drain connections for water and sludge stripping. The water and sludge from this bottom drain should be removed at regular intervals.

FIGURE 4
Typical Heavy Fuel Oil Service System

3.21 Mixing Tank

The mixing tank is usually a narrow, cylindrical insulated tank into which clean, heavy fuel oil flows from the fuel oil service tank. It also functions as a return tank for recirculated fuel oil from the engine injection pump return rail. A primary function of the tank is to stabilize service fuel oil temperature by mixing hotter return oil with cooler service tank fuel oil. The mixing tank is fitted with a bottom drain. Steam heating coils maintain stable temperature during start-up.

3.23 Service Pump Suction Strainers

Duplex suction strainers provide protection to the fuel oil service pumps from any solid debris from the fuel oil service tanks. A 20 to 140 mesh reinforced, corrosion resistant basket strainer should be used, together with magnetic elements to remove all coarse metallic/magnetic particles from the heavy fuel oil stream.

3.25   Fuel Oil Service Pumps

Two fuel oil service pumps (one standby and one operational) are provided to supply heavy fuel oil to the downstream service system (service heaters, viscometer, flow meter and main engine). Each fuel oil service pump is capable of supplying the total required fuel flow plus an additional margin.

3.27   Fuel Oil Service Heaters

Two fuel oil service, steam heated, shell and tube or plate-type heat exchangers with a capability of heating heavy fuel oil to 150 degrees Centigrade should be installed. The final fuel oil outlet temperature is controlled by the viscometer. The viscometer continuously provides a viscosity readout and control signal to the steam control valve regulating the steam flow to the heat exchanger. In this system, the viscosity to the diesel engine injectors is held constant even though the fuel oil temperature might vary slightly. When heating heavy fuel oils to almost 150 degrees centigrade the use of properly sized, steam heat exchangers will provide the necessary heat without thermally stressing the fuel oil with hot spots which produce coked heaters and cracked fuel.

3.29   Viscometer

The viscometer is a critical component which ensures uniform and accurate viscosity control. The viscometer constantly samples the heavy fuel oil and produces a signal which is proportional to viscosity. Typical sensors employ calibrated capillary tubes, falling pistons, or vibrating rods. Irrespective of the method of determining viscosity, the viscometer output signal is utilized to modulate an automatic steam control valve on the fuel oil service heaters. Since the viscometer is constantly sampling and adjusting the fuel oil heater outlet temperature to maintain a constant preset viscosity, the accuracy of this unit must be checked and calibrated periodically. Experience suggests that service once every six (6) months by disassembly and recalibration is prudent. The unit should be carefully installed according to the manufacturer's recommendations. A valved bypass and isolation valves also should be provided to allow for service without plant shutdown.

3.31   Final Filter

A duplex, final protection, ten (10) micron filter usually is installed immediately prior to the inlet of the fuel injection pumps to protect pump plungers and barrels from any untreated contamination or random debris remaining in the fuel. While it may appear that this final filter is not necessary due to the cleaning and treatment equipment upstream, high pressure diesel injection pumps are very sensitive to minute particles of debris. This material can cause micro-seizures and finally total failure of the pump plunger and barrel.

5   Operating Guidelines and Recommendations

There are a number of observations which lead to recommended procedures and operational changes which can improve the efficiency of fuel oil treatment and can reduce unnecessary extra maintenance on the fuel system and the diesel engine-

For the most part, these procedures can be accomplished with little or no investment of capital funds. The observations and recommended procedures are enumerated in the following:

5.1   General Fuel Handling

i)   Marine fuel oil quality is degrading and contamination levels are increasing.

ii)   Diesel engines in many instances cannot operate on heavy fuel oils as bunkered.

iii)   Viscosity does not define quality. Quality determinations based solely on viscosity are dangerous.

iv)   As marine fuel oil quality degrades, the fuel treatment system must carry a greater load to protect the engine adequately.

v)   With degrading fuel quality, the fuel treatment system will be operating closer to the limit of its capabilities. Less margin for error will exist.

vi)   Bunker receipts do not tell the story – sometimes they are wrong – they are always inadequate

vii)   Observe delivery oil temperature. High temperatures could mean a waxy fuel is being supplied.

viii)   Shipboard personnel should take and retain a two-liter sample from the ship's bunker line during each bunkering.

ix)   Drain settling and service (day) tank bottoms daily. Note and report gross water discharge.

x)   On a regular basis, every six to twelve months, have the viscometer checked and calibrated by factory service representative.

xi)   Simple shipboard testing is necessary to accurately adjust the fuel treatment system and to check on system operation.

xii)   New bunkers must be segregated in storage, settling, and service tanks, particularly when compatibility information is not available. Limit the transfer of fuel oil to prevent unwanted mixing.

xiii)   Shipboard fuel treatment impacts the performance, operation and maintenance requirements of a diesel engine.

xiv)   It is important to recognize the nature of the deficiencies and contaminants in poor quality fuel oil as soon as possible after receiving it.

xv)   Early recognition and evaluation of the problem properties and early adjustment of the fuel oil treatment systems to compensate is the only practical way to protect a diesel engine from potential damage.

xvi)   The key to successful operation of ships using fuel of high viscosity and low quality lies in good engine room practices, together with carefully controlled treatment.

5.3   Centrifugal Separator

i)   It is important that the separators be correctly adjusted for the specific gravity of the fuel being treated- All fuel oil separators available should be operated continuously. Fuel flow rate and temperature control also are important.

ii)   Experience has shown that the correct temperature for centrifuging high viscosity fuels is in the region of 95 to 98 degrees Centigrade.

iii)   If excessive sludging should occur, giving evidence of incompatibility, the fuel should be separated at the slowest possible rate using purifiers in parallel. When drawing from a fuel tank for the first time, it is very important that a careful watch be kept on the purifier for the first twelve (12) hours of separation.

iv)   When starting a separator, the fuel oil discharge should be returned to the settling tank until stable efficient operation has been confirmed. Then it is safe to reroute the fuel oil to the service tank.

v)   For most operating situations, series separation is recommended. The purifier backed up by the clarifier offers the best operation from a water, sediment and sludge removal, and safety of operation viewpoint.

vi)   If the specific gravity of the fuel oil exceeds 0.991, the purifier should be reconfigured as a clarifier and the shoot or sludge discharge cycle decreased to between five (5) and twenty (20) minutes.

vii)   Fuel oil flow through a separator can best be controlled by a variable speed motor fitted on the feed pump supplying the separator. This method is highly recommended over throttling a single speed feed pump. The approach minimizes formation of troublesome third phase, water-in-oil emulsions that require extra maintenance to manually clean the separator.

5.5   Preheating and Combustion

i)   Most engine manufacturers require that fuel should be of a specified viscosity at the fuel pump inlet. Where the viscosity has been altered due to mixing fuel from a different source, it is important to check on the new viscosity both from the point of view of correct separation and from the need to attain the correct level of preheating.

ii)   Vessels fitted with automatic viscometers can cope readily with changing viscosity, if the viscometers are regularly maintained and calibrated.

iii)   To determine a specific engine's recommended injection viscosity, consult the engine builder's operating manual.

iv)   When burning high viscosity, carbon rich fuels, it is of paramount importance that the correct operating limits be maintained in the engine, Scavenge air temperature, cooling water temperature and cylinder oil feed rates must all be carefully monitored and adjusted.

v)   In order to cope with the possible problems associated with deterioration in fuel quality, the normal well-proven standards applicable to good combustion assume ever greater importance, i.e., injector maintenance, cooling temperature control, and scavenge air temperature control.

7   Recommended Procedures for the Onboard Treatment of Problem Fuels: Very Poor Quality or Highly Contaminated Fuel Oils

Some percentage of fuel oil bunkerings will have a problem in that various fuel properties and contamination levels will be very poor and will greatly exceed the engine manufacturer's fuel requirements. Some operators would suggest that one fuel delivery in every seven liftings has a problem in meeting extremes in specified characteristics and quality. From another viewpoint, this would translate into every ship having a fuel problem at least once every year. An example of this might be a fuel oil with high water contamination, possibly caused by a leak in the bunker delivery barge. Recently, the fuel properties that have most frequently exceeded specification are free water, specific gravity and cat fines content The lifting of a problem fuel may never occur for many operators, occasionally for some and frequently for others who, because of particular trade route requirements, must routinely bunker a specific fuel, or from a specific fuel oil supplier, or from a specific port. To improve the diesel vessel's capability to tolerate extremes in fuel properties and contaminants, certain specialized components and subsystems can be installed aboard ship. Additionally, modified operational procedures for existing fuel system components may be used. This equipment and related procedures, as they are applied to the more common fuel related problems of very poor quality of highly contaminated fuel oils, are described in the following paragraphs.

7.1   High Water and Sediment

High water and sediment levels in heavy fuel oils usually result from extreme contamination in transportation or as a result of an upset in refinery storage operations. To prevent diesel injection system corrosion and cavitation, and/or accelerated bore wear rates, the high water and sediment rates must be controlled by the fuel treatment system.

Both separators should be operated in parallel and configured in the purifier mode with both purifiers operated at all times. The purifier sludge tank stripping and cleaning frequency should be increased as

the high water and sediment content of the heavy fuel oil will cause it to fill more rapidly. If this is anticipated to be a continuing problem, the sludge tank capacity should be doubled.

When separating high water and sediment content fuel oils, a third phase of emulsified water and sludge can form in the purifier, causing the separator efficiency to decrease. This problem can be minimized and the separator efficiency increased by the use of a chemical demulsifier. This low cost chemical is metered into the transfer flow prior to the transfer pump and the settling tank. The demulsifier modifies the interfacial tension between the fuel and the water such that emulsions are not formed in purifying, pumping and fuel transfer. Additionally, existing emulsions are resolved into their basic fuel and water components and then separated in the purifier. These chemicals are readily available and are generally low in cost. Section 5, Figure 5 presents a schematic of the previously described purifier configuration for heavy fuel operation.

FIGURE 5
# Typical Purifier/Purifier System for High Water and Sediment (1 to 2%)
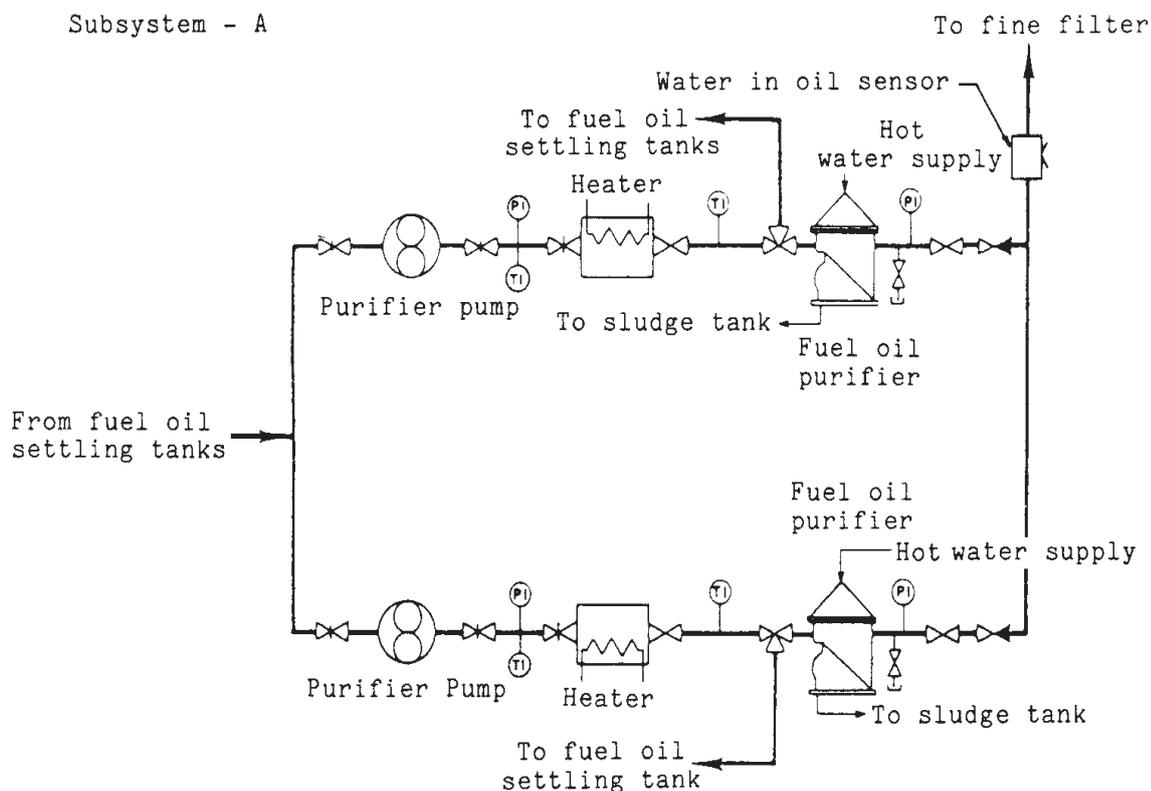
7.3   High Catalyst Particle and Ash Content

Higher ash fuel oils usually result from some type of contamination. The contamination could be sand, rust, fibers, catalyst particles, or combinations of other inorganic debris. Some portion of this inorganic material will be abrasive and can cause accelerated wear rates. Efficient removal of the critical size ranges of the abrasive portion of the ash is the major objective of the treatment subsystem. Because most shipboard fuel system components cannot (efficiently) handle higher concentrations (greater than 50 ppm Al), size ranges, and densities of inorganic ash that can exist in the wide variety of delivered bunkers, it is necessary to utilize a combination of fuel system components and subsystems to efficiently cope with the contaminated fuel oil to prevent overburdening any single component in the heavy fuel oil system.

The recommended practice for the control of high levels of ash and catalyst particles requires operation of the centrifuges in series. The first centrifuge is configured in the purifier mode and the second centrifuge is configured in the clarifier mode. If the sludge tank cannot be enlarged, its cleaning frequency could increase by a factor of up to three. The fuel treatment system fine filter (if fitted) for abrasive solids control, such as catalyst particles, should be in operation during the separation of high ash fuel oils to back up the operation of the separators. Section 5, Figure 6 presents a diagram of the previously described arrangement.

FIGURE 6
Typical Centrifuge Configuration for High Ash (0.20 to 0.50% wt.)
## High Catalytic Fines (60 ppm to 300 ppm Total)
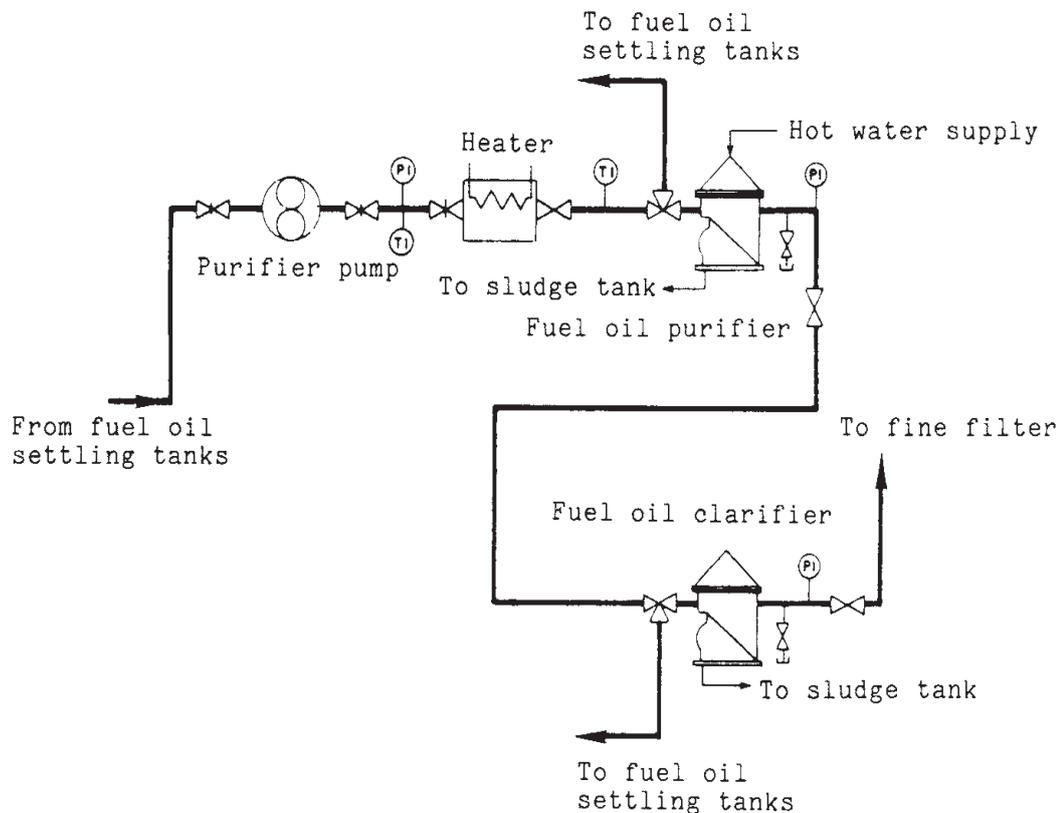
7.5   High Specific Gravity

The fuel oil property with greatest refinery industry pressure for change (increase) is specific gravity. The current 0.991 specific gravity limit for purifier operation on ships has required blending back heavier, low cost fuels to reduce the specific gravity to values below 0.991. Since blending requires the use of higher cost, high gravity cutter fuels, the requirement increases the cost of motor ship fuel oil, however, even when blended, these heavily processed fuel oils have difficulty meeting current specific gravity limits of 0.991. Where only out-of-specification fuels are available, centrifuges should be operated in parallel at reduced throughput as clarifiers to remove the higher sludge and sediment content. Because both sludge and water are discharged to the sludge tank in this operational mode, instead of to separate tanks as when separators are operated in the purifier mode, sludge tank capacity should be increased three hundred percent (300%) for each operating separator. If sludge tank size cannot be increased, the number of sludge tank cleanings in a given period of time will be increased over the original number. Section 5, Figure 7 presents a typical clarifier/clarifier configuration for high gravity fuels.

To further improve operation as a clarifier, a water (in fuel oil) monitor is needed and should be placed downstream from clarifiers, as an indication of the water content of the fuel oil, and to monitor and to initiate the automatic cleaning cycles of the clarifiers. This latter feature can reduce unnecessary cleaning cycles without introducing lower operational efficiencies because of water over-loaded separator bowls.

FIGURE 7
Typical Clarifier/Clarifier System for
High Specific Gravity (0.991 to 1.006) Fuel Oils
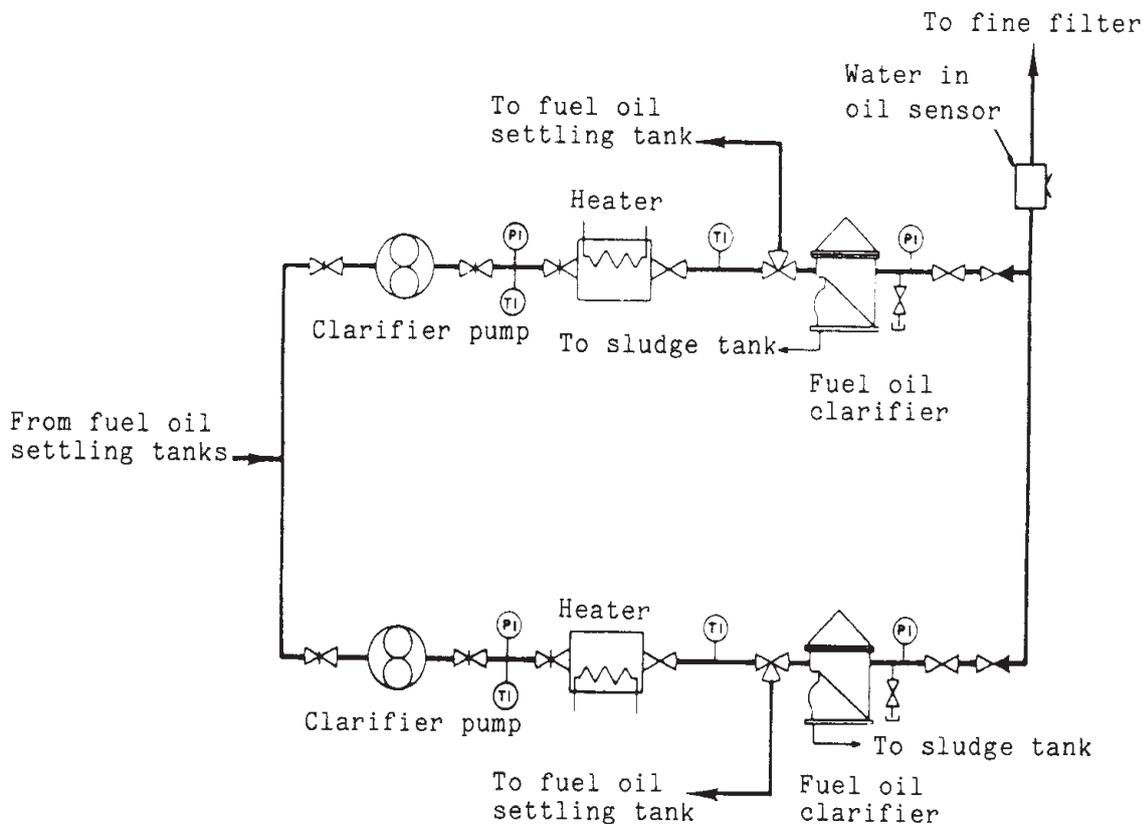
7.7   High Vanadium, Nickel and Lead

Heavy fuel oils with high trace metal (oil soluble) concentrations of vanadium, nickel, and lead can cause accelerated fouling and tenacious deposits, performance reductions, and corrosion. To compensate for the affects of these trace metals on exhaust valves and turbocharger blading, a chemical inhibitor can be mixed with the heavy fuel oil to modify the chemical and physical properties of the resulting ash, which is the source of previously mentioned deposits and fouling. These chemical inhibitors are added to the heavy fuel oil in proportion to the metal content of the fuel. The manufacturer of the chemical additive should be consulted for specific inhibitor injection rates.

Chemical additives containing magnesium and/or silicon active metallic ingredients have demonstrated successful results in the past. Section 5, Figure 8 illustrates a typical chemical inhibitor injection system.

The chemical additive can be injected into the heavy fuel oils by a metering pump. A fuel system pump or a static mixer will improve the mixing of the fuel additive into the fuel oil flow, thus increasing its effectiveness. Once mixed, stable fuel oil additives should remain mixed and should not affect strainers, heaters or filters. A caution however: some chemical additives are not stable when the fuel oil contains small amounts of water. Unstable additives that react with water in the fuel oil can precipitate active metals plugging strainers, fine filters, and injection nozzles

7.9   High Conradson Carbon Content/High Asphaltene Content

To cope with high CCR/high asphaltene content of heavy fuel oils, it is necessary to reduce the size of these insoluble agglomerates in the oil and to reduce the atomized droplet mean diameters prior to combustion. This will reduce the ignition delay, improve the burnout of the heavy, high boiling point hydrocarbons at the end of the combustion process, as well as to improve the beginning of the combustion process.

This subsystem processes the heavy oil after efficient fuel centrifugal separation has taken place. Due to the extensive refinery processing which produces high Conradson Carbon content in heavy fuel oils, the separators will also be removing larger amounts of sludge than typical fuel oils with lower carbon contents. Therefore it may be necessary to increase the sludge tank capacity or to increase the frequency of cleaning of this tank.
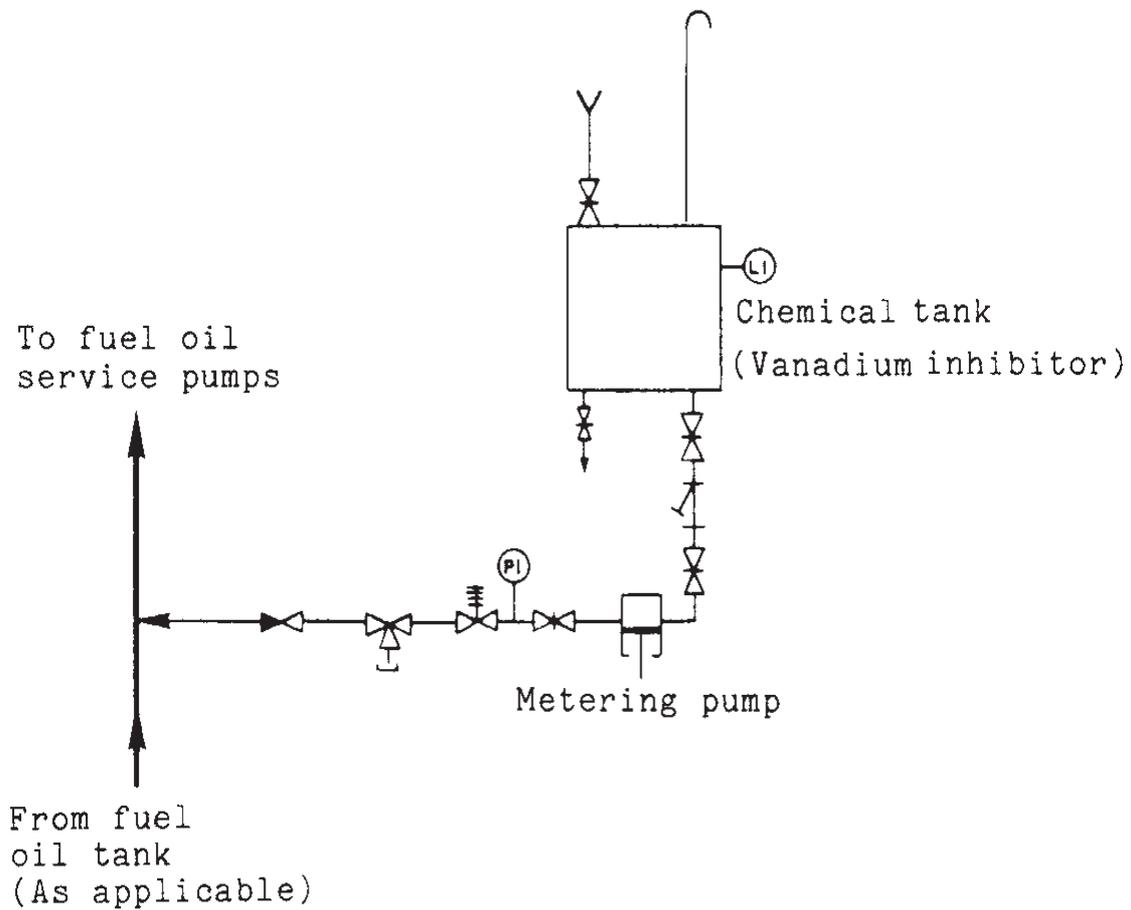
The homogenizer depicted in Section 5, Figure 9 produces efficient dispersal and size reduction of heavy hydrocarbon insolubles in heavy fuel oil through a combination of high shear and cavitation forces. The homogenizer/emulsifier also provides a method to improve the initial combustion process as a result of secondary atomization caused by very fine water droplet/fuel emulsion produced by the system. Fuel oil/water emulsions are produced by adding small quantities of potable water to the heavy fuel oil. The water is metered into the heavy fuel oil and is dispersed by a static mixer prior to fuel entering the suction of the homogenizer.

In addition to reducing the fouling and corrosion rates of the affected areas, there may be a nominal reduction in fuel consumption especially during reduced power operation (i.e., off-design operation).

The emulsification system operates by shearing and cavitating a dispersion of fresh water and heavy fuel oil to produce an emulsion with the majority of the water droplets (internal phase) in the two (2) to five (5) micron range. Once injected into the combustion space by the injector, the fuel oil/water droplets begin to heat rapidly. During this droplet heating process, but prior to major droplet vaporization or burning, the droplet temperature approaches 150 degrees Centigrade and the small droplets of water within the droplet of fuel oil flash to steam. This rapid expansion breaks away portions of the original fuel droplet, thereby producing much smaller fuel droplets. This process occurs in many hundreds of water droplet locations within each original fuel droplet and is commonly referred to as secondary atomization. As a result, an additional degree of fuel-air mixing occurs, which tends to reduce fuel rich zones in the initial fuel oil spray, thereby reducing carbon formation and soot accumulation.

FIGURE 8
Typical Additive Injection System for High Concentrations of Oil Soluble Heavy Metals

Subsystem – D

To fuel oil service pumps

Chemical tank
(Vanadium inhibitor)

Metering pump

From fuel oil tank
(As applicable)

FIGURE 9
Typical Water in Oil Emulsification/Homogenization for High Conradson Carbon Content Fuels (15 to 22% wt.)

Subsystem - E
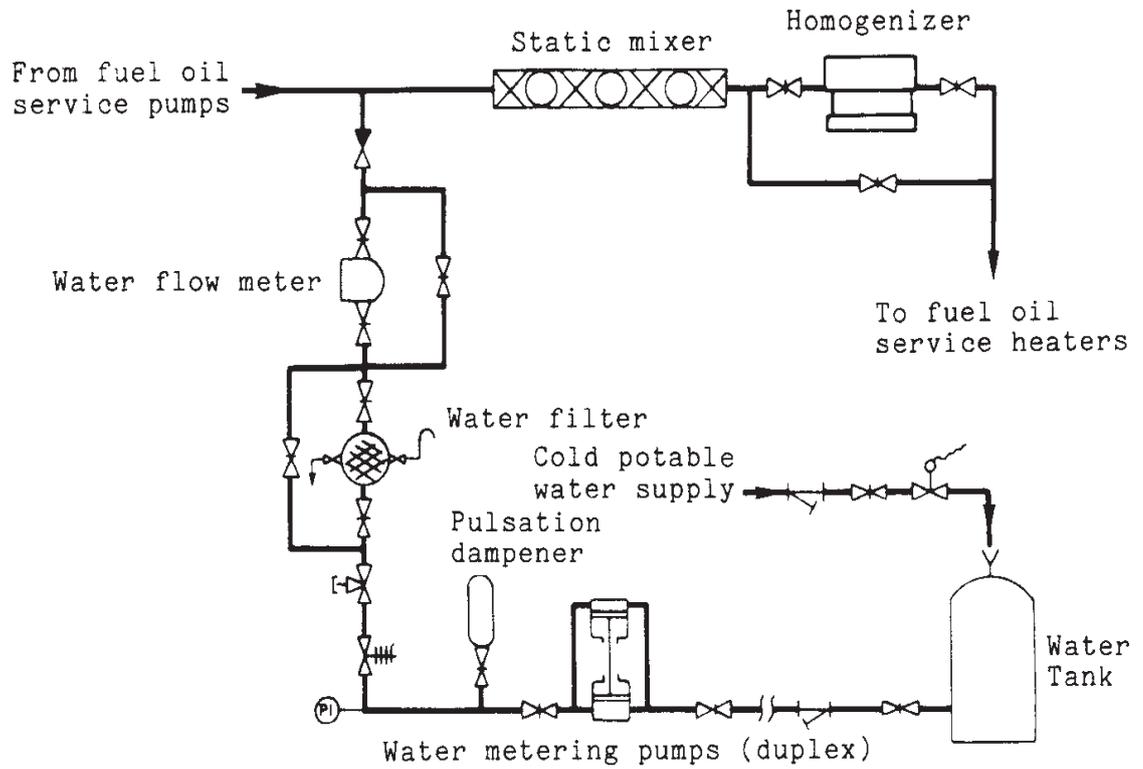
TABLE 1
Fuel Property/contaminant Problem Resolution Matrix

FUEL PROPERTY/CONTAMINANT	PROBLEM	RECOMMENDED CORRECTIVE ACTION
1. HIGH VISCOSITY	Fuel transfer and injection diffi-culties	**Increase fuel heating to obtain desired viscosity***
2. HIGH SPECIFIC GRAVITY	Reduced centrifuge operating effi-ciency	Operate both purifiers continuously in clarifier/clarifier mode
3. HIGH CONRADSON CARBON RESIDUE	Increased gas ways fouling, exhaust turbine deposits, excessive filter clogging, and poor combustion	Operate centrifuges at reduced throughput to handle increased sludge content. Incorporation of a water-in-fuel homogenization/emul-sification system will also reduce associated problems by complete mixing of the heavy and light fuel ends by homogenization and improved combustion resulting from water-in-oil emulsification.
4. HIGH SULFUR CONTENT	Hot and cold corrosion attack on cylinder assemblies	Maintain correct operating tempera-tures, especially at low loads. Check and maintain proper lube oil Total Base Number (TBN)
5. HIGH ASH CONTENT	Increased engine component abrasive wear and exhaust valve, piston groove and exhaust turbine deposits	Configure centrifuges for series purifier operation and incorporate fine filtration capability
6. HIGH VANADIUM CONTENT	Increased hot component corrosion and deposit build-up	Incorporate chemical inhibition system to neutralize vanadium based hot corrosion attack
7. SODIUM (SALT WATER)	Increased exhaust turbine deposits, exhaust valve corrosion excessive centrifuge sludge build-up, injector deposits and piston groove deposits	Configure centrifuges for parallel reduced output operation. Use of a demulsifying agent to remove water prior to centrifuging and fine filters after centrifuging will also increase water removal efficiency.
8. HIGH ALUMINA/SILICA (CAT FINES) CONTENT	Increased/excessive piston ring, piston groove, cylinder liner and injection pump wear	Configure centrifuges for series re-duced output operation. Add fine filtration capability before engine(s).
9. INCOMPATIBILITY	Increased/excessive centrifuge sludge, injection pump wear, and injector deposits, if burned in-creased exhaust turbines and ex-haust valve deposits may also result	**Incorporate a homogenization** system to completely mix incom-patible fuel components prior to injection. Shipboard blending should be done on line rather than as a batch process to avoid incompati-bility problems.

*In extreme case blending with MDO may be required.
Compatibility should be checked prior to blending.

ABS

APPENDIX **1** **Glossary and Abbreviations**

CONTENTS

APPENDIX 1 Glossary and Abbreviations

Glossary

Aliphatic	A class of saturated or unsaturated carbon compounds, in which the carbon atoms are joined in open chains.
API	American Petroleum Institute.
API Gravity	Gravity (weight per unit volume) of oils as measured by the API scale whereby:

$$\text{API Gravity} = \frac{141.5}{\text{Sp.Gr.}@15°/15°C} - 131.5$$

Aromatics (C_NH_{2N-6})	Group of hydrocarbons of which benzene is the parent. They are called "aromatics" because many of their derivatives have sweet or aromatic odors.
Asphaltenes	Insoluble, semi-solid, or solid particles which are combustible and are highly aromatic. Asphaltenes contain a high carbon to hydrogen ratio and entrap water, fuel ashes and other impurities
ASTM	American Society for Testing Materials. Grade and quality specifications for petroleum products are determined by ASTM in test methods
Barrel	A unit of volume measurement used for petroleum and its products. 1 barrel = 42 U.S. gallons.
Blender	A device for mixing two fuel oils to achieve a less viscous and more uniform fuel.
Blending	Mixing of two compatible fuels having different properties in order to produce an intermediate fuel.
BS&W	Bottom sediment and water.
BS&W Monitor	An instrument which detects entrained water content in petroleum products wherein the water changes the capacitive reactance as a function of the dielectric constant.
Bunker Fuel Oil	Heavy, residual fuel oil used in ships' boilers.
Calorific Value	Amount of heat produced by the complete combustion of a unit weight of fuel. Usually expressed in calories per gram or BTU's (British Thermal Units) per pound, the latter being numerically 1.8 times the former.
Catalyst	A substance which promotes a chemical reaction, but does not itself enter into the reaction.

Catalytic Fines	Hard, abrasive crystalline particles of alumina, silica, and/or alumina silica that can be carried over from the fluidic catalytic cracking process of residual fuel stocks. Particle size can range from sub-micron to greater than sixty (60) microns in size. These particles become more common in the higher viscosity marine bunker fuels.
Cat Cracker	A large refinery vessel for processing reduced crudes or other feed-stocks in the presence of a catalyst, as opposed to the older method of thermal cracking, which employs heat and pressure only. Catalytic cracking is generally preferred since it produces less gas and other highly volatile byproducts. It produces a motor fuel of higher octane than the thermal process.
Cetane Index	An empirical measure of ignition quality. Defined as the percentage by volume of cetane in a mixture of cetane and methyl naphthalene which has the same ignition quality when used in an engine as a fuel under test.
Clarifier	A machine used for a liquid-sludge separation in which the particles with a higher specific gravity are separated from the lower specific gravity of the liquid. A clarifier bowl has one outlet for the light phase oil; the heavier phase particles are retained on the bowl wall.
Cloud Point	Temperature at which wax begins to crystallize from a distillate fuel.
Cracked	Refers to a petroleum product produced by a secondary refining process, such as thermal cracking or vis-breaking processes, which yield very low quality residua.
Cutter stock (Flux Stock)	A petroleum stock which is used to reduce the viscosity of a heavier residual stock by dilution
Flash Point	The lowest temperature at which a liquid will generate sufficient vapor to flash when exposed to a source of ignition.
Force Majeure	A standard clause which indemnifies either or both parties to a transaction whenever events reasonably beyond the control of either or both parties occur to prevent fulfillment of the terms of the contract.
Fraction	A separate identifiable part of crude oil; the product of a refining or distillation process.
Fuel Oil	The heavy distillates from the oil refining process; used as fuel for power stations, marine boilers.
Fungible	Interchangeable. Products which can be commingled for purposes of pipeline shipment.
Gasoil	Designation for No. 2 heating oils and diesel fuels. A clean distillate fuel oil.
Heavy crude	Crude oil with a high specific gravity and a low API gravity due to the presence of a high proportion of heavy hydrocarbon fractions and metallic content.
Homogenizer	A mechanical device which is used to create a stable, uniform dispersion of an insoluble phase (asphaltenes) within a liquid phase (fuel oil).
Layering	This occurs in tanks when a high density fuel is mixed with a low density fuel.
Lifting	Refers to tankers and barges taking on cargoes of oil or refined product at a terminal or transshipment point.
Light crude	Crude oil with a low specific gravity and high API gravity due to the presence of a high proportion of light hydrocarbon fractions and low metallic content.

Light Ends	The more volatile products of petroleum refining; e.g., butane, propane, gasoline.
Long Ton	An avoirdupois weight measure equaling 2,240 pounds.
Marine Diesel Oil (MDO)	Marine Diesel Oil (MDO) is a middle distillate fuel oil which can contain traces to ten percent (10%) or more residual fuel oil from transportation contamination and/or heavy fuel oil blending. The MDO does not require heated storage.
Metric Ton	A weight measure equal to 1,000 kilograms, 2,204.62 pounds, and 0.9842 long tons.
Middle Distillate	Term applied to hydrocarbons in the so-called "middle range" of refinery distillation. Examples are heating oil, diesel fuels, and kerosene.
Motor Gasoline	A complex mixture of relatively volatile hydrocarbons with or without small quantities of additives, that have been blended to form a fuel suitable for use in spark-ignition engines.
Naphtha	A volatile, colorless product of petroleum distillation. Used primarily as paint solvent, cleaning fluid, and blendstock in gasoline production, to produce motor gasoline by blending with straight-run gasoline.
Naphthenes (CNH_2M)	One of three basic hydrocarbon classifications found naturally in crude oil. Naphthenes are widely used as petrochemical feedstock. Examples are; cyclopentane; methyl-, ethyl-, and propylcyclopentane
Oil	Crude petroleum and other hydrocarbons produced at the wellhead in liquid form.
Olefins	Class of unsaturated paraffin hydrocarbons recovered from petrol. Typical examples include butene, ethylene and propylene.
Petrochemical	An intermediate chemical derived from petroleum, hydrocarbon liquids or natural gas, e.g., ethylene, propylene, benzene, toluene and xylene.
Petroleum	A generic name for hydrocarbons, including crude oil, natural gas liquids, natural gas and their products.
Polymerization	Process of combining two or more simple molecules of the same type, called monomers, to form a single molecule having the same elements in the same proportion as in the original molecules but having a different molecular weight. The product of the combination is a polymer.
Pour Point	Lowest temperature at which an oil will pour or flow under certain prescribed conditions.
Purifier	A machine used for a liquid-liquid separation in which the two intermixed liquids which are insoluble in each other have different specific gravities. Solids with specific gravities higher than those of the liquids can be separated off at the same time- A purifier bowl has two outlets; one for the light phase liquid and one for the heavy phase liquid.
Reduced Crude Oil	Crude oil that has undergone at least one distillation process to separate some of the lighter hydrocarbons. Reducing crude lowers its API gravity but increases the handling safety by raising the flash point.
Refinery	A plant used to separate the various components present in crude oil and convert them into usable products or feedstock for other processes.

Residual Fuel Oil	Heavy fuel oils produced from the non-volatile residue from the fractional distillation process. Heavy oils that are "leftovers" from various refining processes. Heavy black oils used in ships' boilers and in heating plants.
Short Ton	An avoirdupois measure of weight equal to 2,000 lbs.
Slagging	Formation of hard deposits on boiler tubes and/or piston crowns, usually due to the presence of sodium, vanadium and sulfur.
Sludge	Deposits in fuel tanks and caused by the presence of wax, sand, scale, asphaltenes, tars, water, etc.
Solvent	A substance, normally a liquid, which is capable of absorbing another liquid, gas or solid to form a homogeneous mixture.
Specifications	Term referring to the properties of a given crude oil or petroleum product, which are "specified" since they often vary widely even within the same grade of product. In the normal process of negotiation, seller will guarantee buyer that product or crude to be sold will meet certain specified limits, and will agree to have such limits certified in writing.
	Generally, the major properties of oil for which a buyer would demand a guarantee are: API gravity (or specific gravity, in some cases); Sulfur, pct. wt.; Pour Point, deg C. max.; Viscosity, min./max; BS&W, pct. wt., etc.
Specific Gravity	the ratio of the density of a substance at a particular temperature to the density of water at 15 degrees Centigrade
Static Mixer	A motionless mixer which has a series of fixed, geometric elements enclosed within a tubular housing. The internal elements impart flow division and radial mixing to the media flowing through the housing to produce a uniform dilution of the production.
Straight-Run	Refers to a petroleum product produced by the primary distillation of crude oil and free of cracked components.
Stratification	Occurs in blended fuels that have a compatibility problem. It is usually experienced when paraffinic-based oils are mixed with asphaltic-based oils, causing asphaltenes to precipitate and settle to the bottom of a tank.
Sulfur	An element that is present in crude oil and natural gas as an impurity in the form of its various compounds.
Topped Crude Oil	Oil from which the light ends have been removed by a simple refining process. Also referred to as "reduced crude oil."
Total Existent Sediment	Combination of inorganic and hydrocarbon sediments existing in a fuel as delivered.
Vanadium Inhibitor	An organic and/or inorganic metal bearing chemical intended to chemically and/or physically combine with the compounds formed during combustion of heavy fuel oil to improve the surface properties of the treated ash compounds.
Viscometer	A device for determining the viscosity of oil. There are several methods or devices in general use. Basically, a fixed quantity of oil is allowed to pass through a fixed orifice at a specified temperature over a measured time span and then compared to a standard liquid such as a calibration oil or water.

Viscosity	Measure of the internal friction or resistance of an oil to flow. As the temperature of an oil is increased, its viscosity decreases and it is therefore able to flow more readily. Viscosity is measured on several different scales, including Redwood No. 1 at 100 degrees Fahrenheit, Engler Degrees, Saybolt Seconds, etc. The most common method for the designation of viscosity is kinematic viscosity, in Centistokes, cSt, at SO degrees Centigrade.
Vis-Breaking	A light thermal cracking process carried out on the fuel oil during the refining to reduce product viscosity without blending.

List of Abbreviations

API	American Petroleum Institute
BHP	Brake Horsepower
BS&W	Bottom Sediment and Water
BTU	British Thermal Unit
C/H Ratio	Carbon/Hydrogen Ratio
CCR	Conradson Carbon Residue
cSt	Centistokes @ 50 degrees Centigrade
HHV	Higher Heating Value
HP	Horsepower
LHV	Lower Heating Value
MCR	Maximum Continuous Rating
MDO	Marine Diesel Oil
mm	Millimeter
ppm	Parts per million (by weight)
rpm	Revolutions per minute
Sp. Gr	Specific Gravity
SR1	Seconds Redwood #1 @ 100 degrees Fahrenheit
TBN	Total Base Number
TDC	Top Dead Center
YR	Year