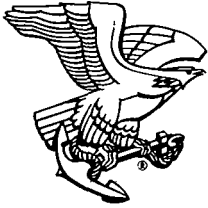




Notes on
Heavy Fuel Oil
1984



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1984

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SECTION 1

Introduction1.1 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:

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

- * The impact of marine fuel characteristic properties and contaminants on diesel engine and support system operation

- * Fuel sampling and analysis techniques and laboratory and onboard test procedures for various marine fuel properties

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

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

SECTION 2

Marine Fuel Oil Origins and the Influence of Refinery Processes2.1 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 ($C_NH_{(2N+2)}$) 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 ($C_NH_{(2N-6)}$) 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_NH_{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_nH_{2n} -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. Table 2.1 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 2.1
Crude Source Related Properties and Characteristics

- * Sulfur
- * Vanadium, Nickel, etc.
- * Pour point
- * 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. Table 2.2 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 3.0.

2.2 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. Table 2.3 a number of the properties and

TABLE 2.2
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		High Sulfur Crude Oil	
			Light Murban	Heavy (North Slope)	Light (Arabian)	Heavy (Venezuelan)
Crude Oil						
Gravity(°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(°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(°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(°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--°F)						
Yield(Vol%)	15.4	14.7	16.14	12.3	15.0	5.0
Gravity(°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(°F)	-70	<-70	---	---	---	-80
Distillate(500-650°F)						
Yield(Vol%)	23.2	29.7	10.4	12.1	19.8	15.5
Gravity(°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 (°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(°API)	25.4	19.7	33.6	25.8	---	---
Sulfur(Wt%)	0.21	0.31	1.06	0.90	---	---
Pour Point(°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(°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(°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

characteristics associated with marine fuels which are strongly influenced by the refinery processes utilized.

TABLE 2.3
Refining Process Related Characteristics and Properties

- * Specific Gravity
- * Viscosity
- * Conradson Carbon Residue-(CCR)/Asphaltenes
- * Sediment
- * Water
- * Flash point
- * Compatibility
- * Sodium

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.

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. Figure 2.1 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 compatability. 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.

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 Figure 2.2, 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.

Thermal Cracking: This procedure is shown in Figure 2.3. 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 Figure 2.3. 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.

Catalytic Cracking: This process is a variation of thermal cracking. It is shown diagrammatically in Figure 2.4. 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

FIGURE 2.1
Atmospheric or Straight-Run Method of Crude Oil Distillation

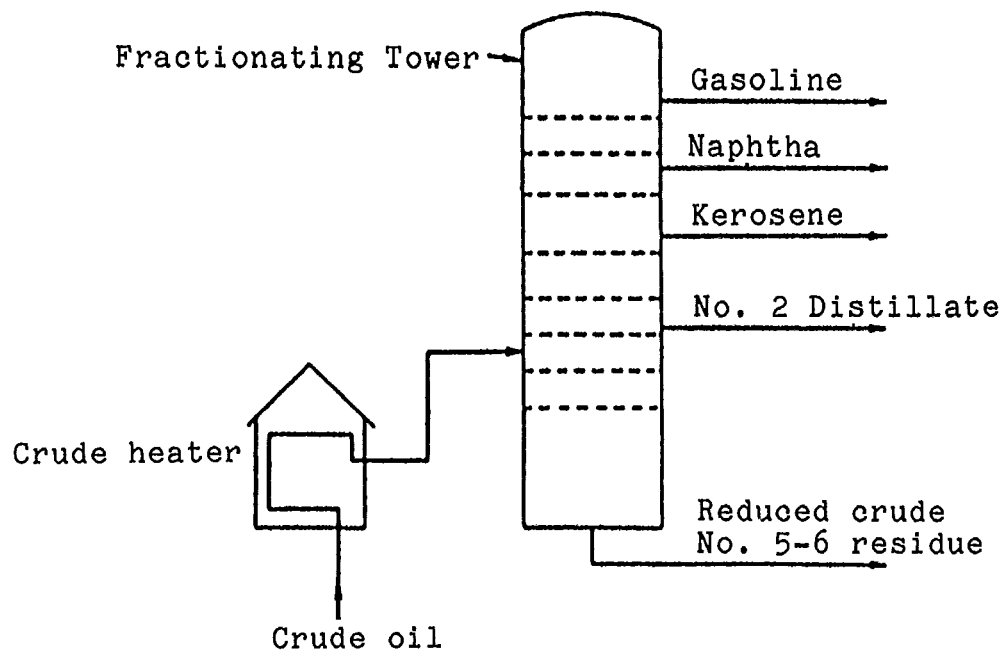


FIGURE 2.2
Vacuum Distillation and Visbreaking Processes

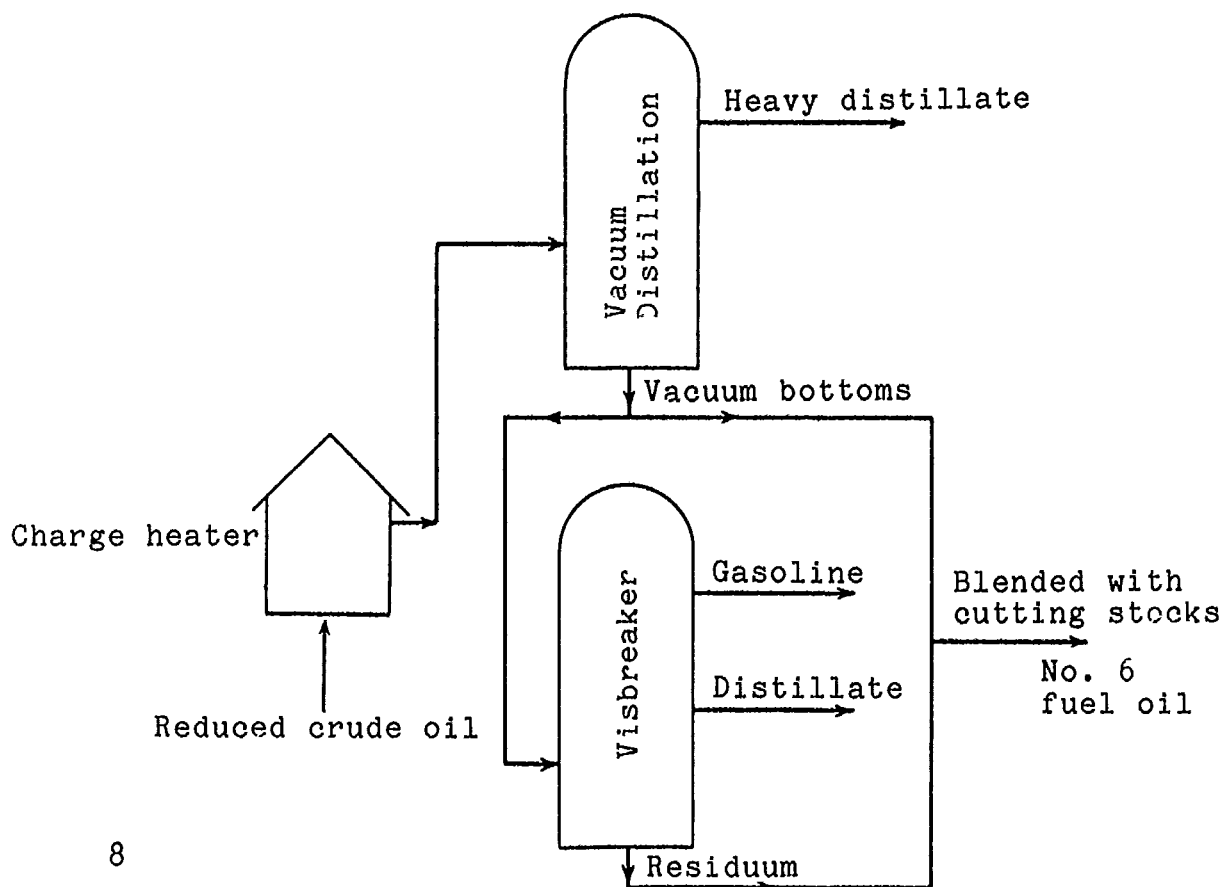


FIGURE 2.3
Thermal Cracking Process

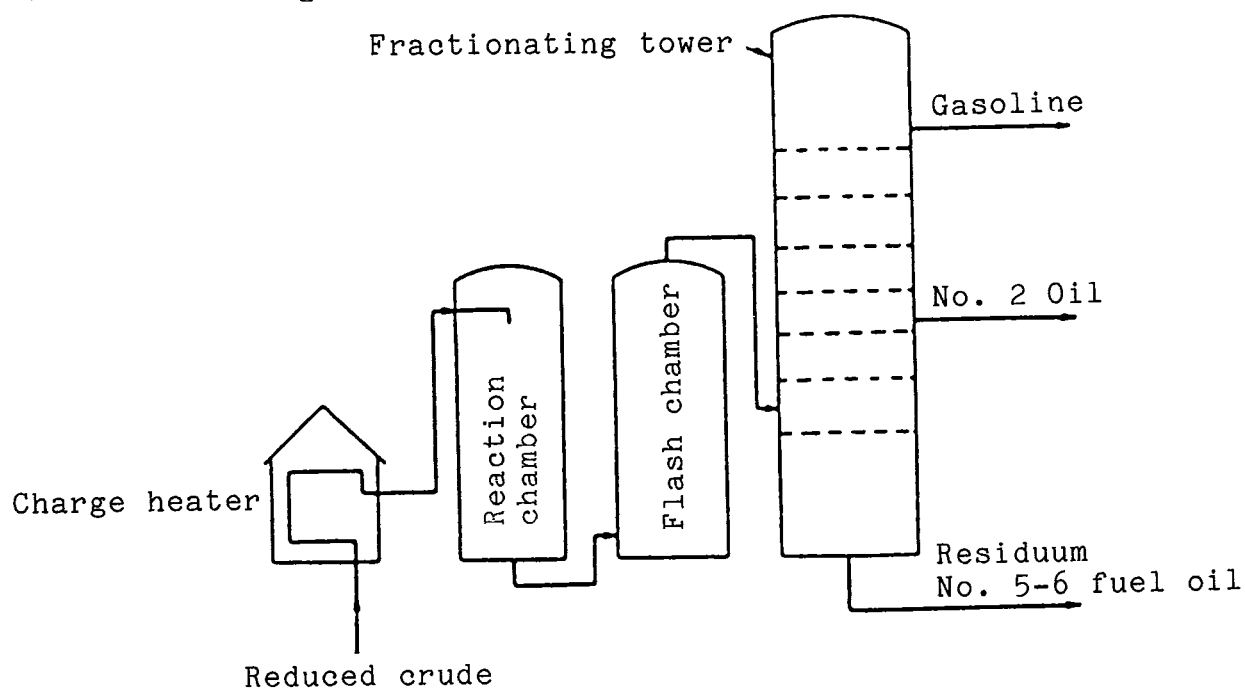
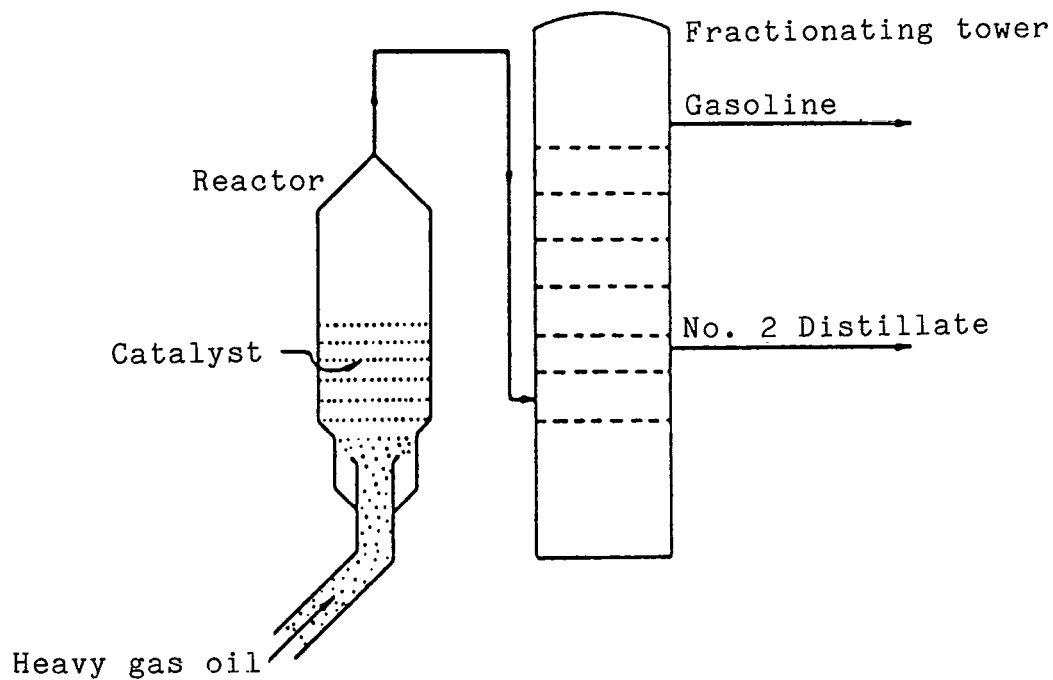


FIGURE 2.4
Catalytic Cracking Process



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.

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.

2.3 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.

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

- * Viscosity
- * Specific Gravity
- * Carbon Residue/Asphaltenes
- * Sulfur
- * Ash
- * Vanadium
- * Compatibility
- * Cetane
- * Flash Point
- * Pour Point
- * Heating Value

Contaminants

- * Water
- * Sodium
- * Sediment
- * Alumina/Silica
(Catalytic Fines)
- * Sludge
- * Fibers
- * Oxidation Products
(Gums, Varnish)

3.1 Marine Fuel Oil Characteristic PropertiesViscosity

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-445) 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 80 degrees Centigrade (instead of 50 degrees Centigrade) in line with CIMAC and BSI recommendations.

For convenience, Table 3.1 is provided with equivalents between the two systems, while Figures 3.1 and 3.2 provide temperature/viscosity relationships for the two systems.

TABLE 3.1
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

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.

FIGURE 3.1
Relationship between Redwood and SI Viscosity Systems

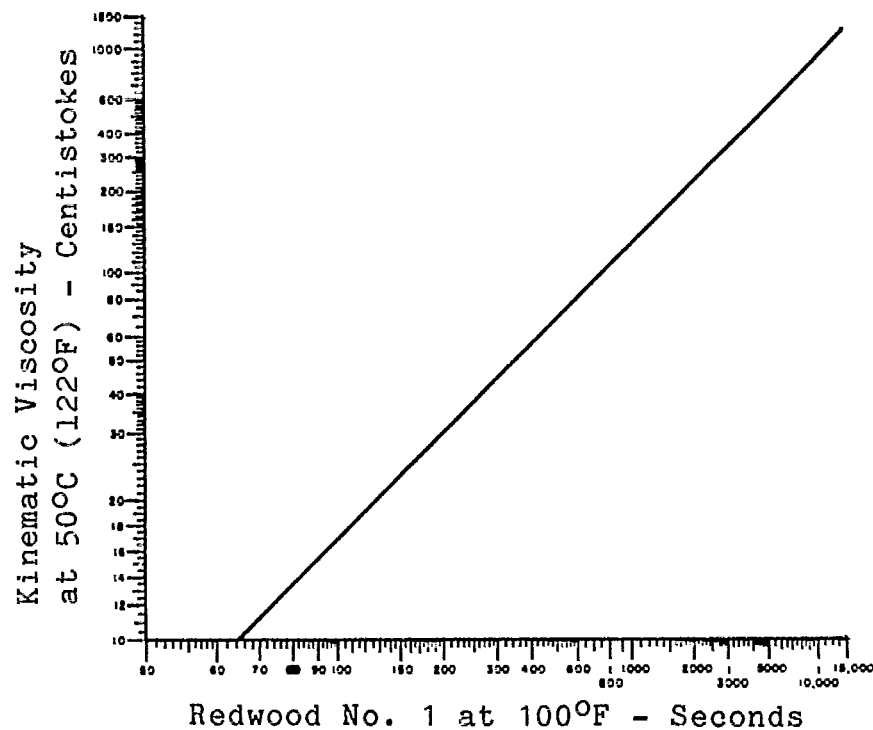
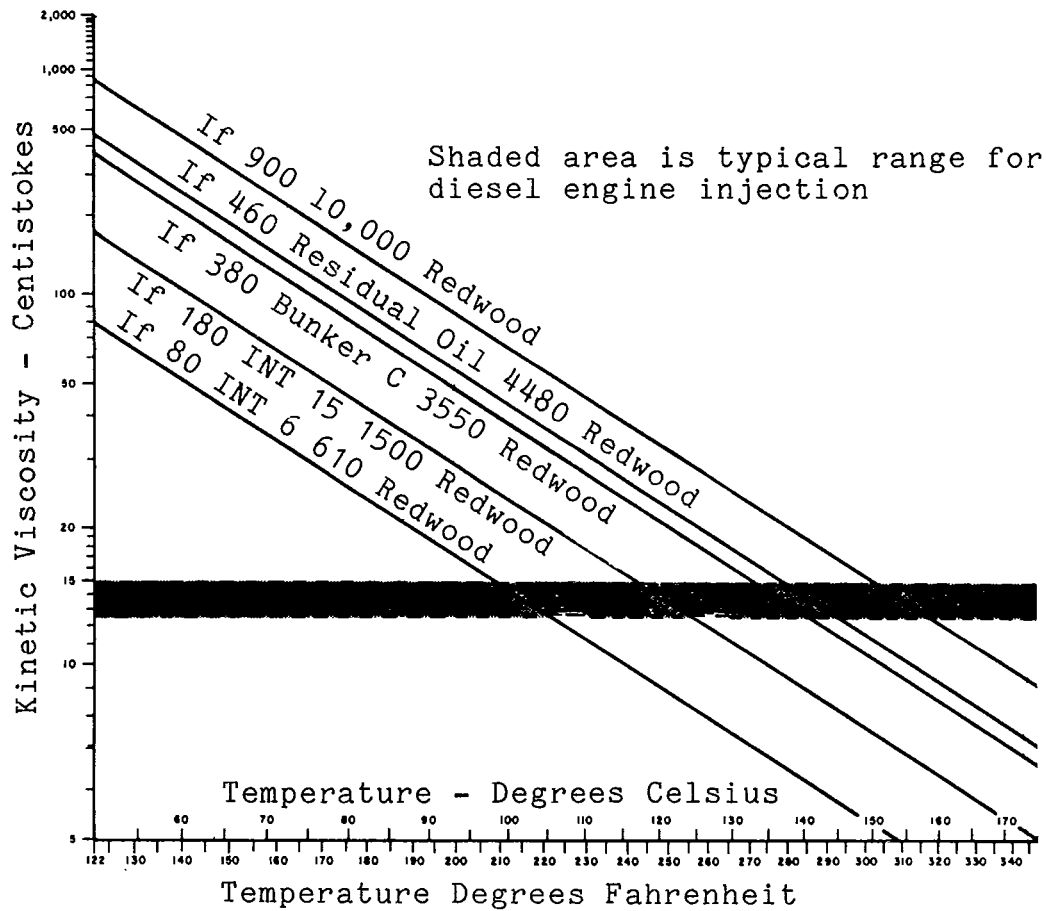


FIGURE 3.2
Relationship between Temperature and Viscosity for Marine Fuels



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 Section 5.4: 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.

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 turbo-chargers, 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.

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.

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 turbo-charger 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.

Vanadium

Vanadium is a metallic element that chemically combines with