Heavy fuel oil – still the dominant fuel quality for diesel engines

by Kai Juoperi

Wärtsilä is devoting substantial R&D resources to developing fuel versatility to meet the energy demands of its customers. Heavy fuel oil, however, is still the dominant fuel quality used in Wärtsilä and Sulzer marine diesel engines. This article takes a detailed look at the properties of HFO today and how they affect the operation of diesel engines.

The origin and properties of crude oil as well as the configuration of the fuel refinery directly affect the quality of heavy fuel oil (HFO). Figure 1 illustrates an example of the cut of a crude oil barrel from a modern European fuel refinery.

A general trend is towards higher conversion of heavy fractions to lighter products like gasoline and gas/diesel oil. This is because fuel refiners wish to maximize the production of the more valuable lighter components.

Naturally, this also affects certain properties of heavy fuel oil, which is a less valuable fraction of the crude oil barrel. Figure 2 shows a simplified configuration of a typical complex fuel refinery. The so-called 'straight run residue' derived from the atmospheric distillation process represents a very good quality of heavy fuel oil.

However, when additional refining steps are used, such as vacuum distillation, catalytic cracking and viscosity breaking, the quality of heavy fuel oil will deteriorate significantly.

Important heavy fuel properties

Viscosity is not actually a direct measure of heavy fuel oil quality, but it determines the complexity of the fuel heating and handling system. This is because heavy fuel oil must be heated to reach the correct injection viscosity to ensure optimized combustion and engine performance. Further, heavy fuel oils are typically classed and marketed according to their viscosity.

Density mainly affects the fuel separation. Traditional separators can remove water and to some extent solid particles from heavy fuel oils with densities up to 991 kg/m³ @ 15 °C. Separators of a newer design are now available that can clean heavy fuel oils with densities of up to 1010 kg/m³ @ 15 °C. An important issue is to ensure that the correct separation flow rate and temperature are used in order to achieve an efficient reduction of water, catalyst fines, sodium and sediment from the heavy fuel oil.

The *ignition quality* of heavy fuel oils varies a lot. Low ignition quality may cause trouble at engine start-up and during low-load operation, particularly if the engine is not sufficiently preheated. Low ignition quality may also result in a long ignition delay and may also cause a fast pressure rise and very high maximum pressures. Deposits on the piston top, on the exhaust valves, in the exhaust system, and on the turbine nozzle ring and turbine blades can also be expected. Turbocharger fouling will lead to decreased turbocharger efficiency and higher thermal load on the engine.

However, modern diesel engines with a higher compression ratio and optimized combustion process are not so sensitive to the ignition properties of heavy fuel oils compared to engines of older design.

A rough tool for estimating ignition properties is the Calculated Carbon Aromaticity Index (CCAI), which is determined from the heavy fuel oil viscosity and density. In recent years more sophisticated devices like the Fuel Ignition Analyzer (FIA) have been introduced for determining ignition quality more accurately.

The ***water content*** of heavy fuel oils varies widely. Water may come from several different sources, it can be either fresh or saline. It can also originate from e.g. condensation in the installation's storage tanks. If water is sweet and well emulsified in heavy fuel oil, the effective energy content of the fuel decreases with increasing water content, leading to an increase in fuel consumption. If heavy fuel oil is contaminated with seawater, the chlorine in the salt will cause corrosion of the fuel handling system, including the fuel injection equipment. The effects of sodium, which also originates from salt, are described in more detail below.

Sulphur in fuel may cause cold corrosion and corrosive wear, especially in low load operation. Sulphur also contributes to deposit formation in the exhaust system, normally together with vanadium and/or sodium in the form of sulphates. The deposits can also cause high-temperature corrosion as described below. Sulphur is a fuel property that has been the subject of much discussion recently. For example the IMO is proposing, and the European Union (EU) has set limits on fuel sulphur content to reduce emissions of sulphur oxides. Wide discussion on how to adapt the new legislation is in progress. Possible ways are to use low sulphur crude oils, to equip fuel refineries with desulphurization (DeSOX) units, to treat exhaust gases onboard marine vessels with DeSOX technologies, or to trade with sulphur emissions.

High ***ash content*** may be detrimental in several ways. Different ash constituents, like vanadium, nickel, sodium, aluminium and silicon can cause different kinds of problems.

Aluminium and ***silicon oxides*** originate from the refining process, and can cause severe abrasive wear mainly to the injection pumps and nozzles, but also to the cylinder liner and piston rings. Efficient fuel separation is a must for minimizing component wear.

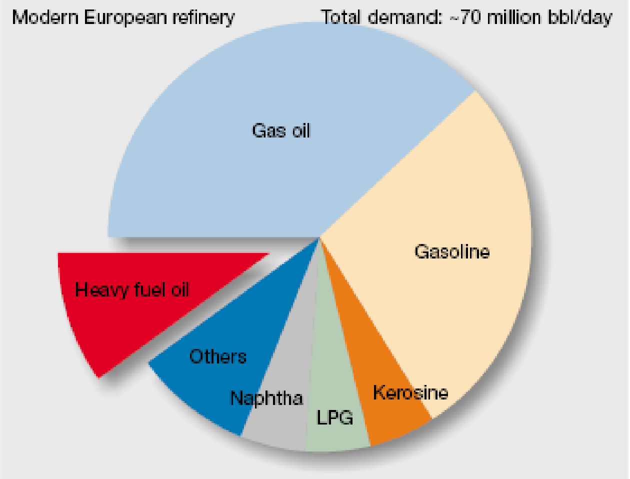

Fig. 1 Example of cut of a typical crude oil barrel.

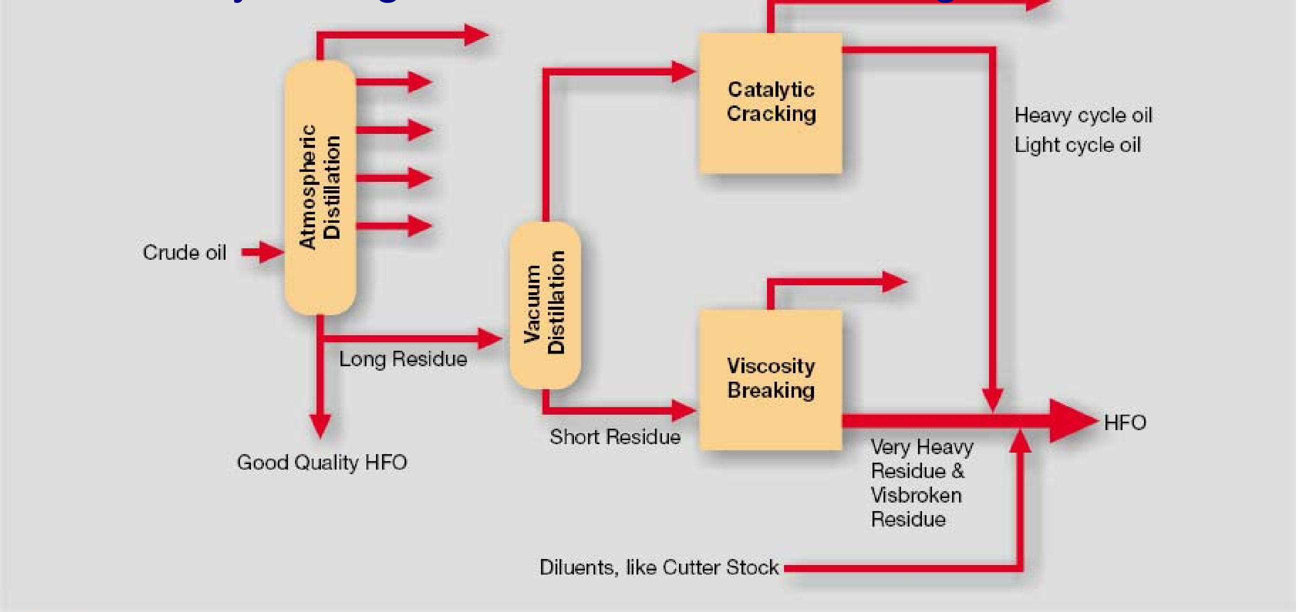

Fig. 2 Example of modern fuel refinery configuration.

Oxides of vanadium and sodium, mainly sodium vanadyl vanadates, are formed during combustion, and will mix or react with oxides and vanadates of other constituents, e.g. nickel, calcium, silicon and sulphur. The sticking temperature of the mixture may cause a deposit to be formed on an exhaust valve, in the exhaust gas system, or in the turbocharger. This deposit is highly corrosive in molten salt. It destroys the protective oxide layer, e.g. on an exhaust valve, and leads to hot corrosion and a burned valve. Deposits and hot corrosion in the turbocharger, especially on the nozzle ring and turbine blades, will reduce turbocharger efficiency.

The gas exchange will also be disturbed, less air flows through the engine, and thus the thermal load on the engine increases.

Deposit formation increases at increased temperatures and engine outputs. Several measures are necessary to avoid these problems when running on high-ash heavy fuel oils. It is important, for example, to have an efficient fuel separation system, to clean the turbocharger regularly, and to ensure strict quality control of the bunkered fuel, i.e. to see that the amounts of ash and dangerous ash constituents stay low. It is also essential to ensure clean air filters and charge air coolers by regular cleaning based on pressure drop monitoring.

A high ***carbon residue*** content may lead to deposit formation in the combustion chamber and in the exhaust system, especially at low engine loads.

Property	Unit	HFO I as Bunkered	HFO I bef. Engine	HFO II as Bunkered	HFO II bef. Engine	Test method Reference
Viscosity, max.	mm2/s at 50 °C	730	730	730	730	ISO 3104
Density, max.[1]*	kg/m³ at 15 °C	991/1010	991/1010	991/1010	991/1010	ISO 3675 or 12185
Water, max.	% V/V	1.0	0.3	1.0	0.3	ISO 3733
MCR, max.	% m/m	15	15	22	22	ISO 10370
Asphaltenes, max.	% m/m	8	8	14	14	ASTM D 3279
Flash point (PMCC),	min. °C	60	60	60	60	ISO 2719
Pour point,	max °C	30	30	30	30	ISO 3016
Total sediment potential,	max. % m/m	0.10	0.10	0.10	0.10	ISO 10307-2
Sulphur, max.[2]*	% m/m	2.0	2.0	5.0	5.0	ISO 8754
Ash,	max. % m/m	0.05	0.05	0.20	0.20	ISO 6245
Vanadium,	max. mg/kg	100	100	600	600	ISO 14597
Sodium,	max. mg/kg	50	30	100	30	ISO 10478
Aluminium+Silicon,	max. mg/kg	30	15	80	15	ISO 10478
CCAI,	max.	850	850	870	870	ISO 8217

* Foreign substances or chemical waste, hazardous to the safety of the installation or detrimental to the performance of engines, should not be contained in the fuel.
1) Density of 1010 kg/m³ is allowed provided that the fuel treatment system can remove water and solids.
2) For low-speed engines max. sulphur content for HFO I quality is 3.5 % m/m.

Table 1 Wärtsilä heavy fuel specification

A high ***asphaltene*** content may contribute to deposit formation in the combustion chamber and in the exhaust system, especially at low loads. Asphaltenes are complex, highly aromatic compounds with a high molecular weight that usually contain sulphur, nitrogen and oxygen, as well as metals like vanadium, nickel and iron. A high asphaltene content indicates that a fuel may be difficult to ignite and will burn slowly.

If heavy fuel oil is unstable, the asphaltenes will precipitate from the fuel and block filters and/or cause deposits in the fuel system, as well as lead to excessive sludge formation in the fuel separator. Moreover, when operating on heavy fuel oils with high asphaltene content, good performance of the lubricating oil should be emphasized. It is important that the lubricating oil is able to bind the combustion residues containing asphaltenes from blow-by gases entering the crankcase and thus prevent deposit formation on the engine component surfaces.

A low ***flash poin***t will not affect the combustion, but the fuel can be dangerous to handle and store. This is especially the case if the pour point is high, making it necessary to heat the heavy fuel oil close to its flash point. Special explosion-proof equipment and fuel separators can be used in extreme cases.

A high ***vapour pressure*** (which often indicates a low flash point) can also cause cavitation and gas pockets in the fuel pipes. These can be avoided by using an elevated pressure in the fuel handling system. It should be noted that some insurance companies demand the use of fuels with a flash point higher than 60 °C.

The ***pour point*** indicates the temperature below which the fuel does not flow, and determines how easy it is to handle the fuel. The whole fuel handling system, including tanks and pipes, must be heated to a temperature at least 10-15 °C above the pour point.

Sediment content. All heavy fuel oils contain a certain amount of sediment. The sediment can be both organic and inorganic. Total sediment content (TSP analysis) describes the fuel's

☐ cleanliness (presence of sand, rust, dirt, catalyst fines and other solid/inorganic contaminants)
☐ stability (resistance to breakdown and precipitate asphaltenes), and
☐ compatibility with another fuel quality.

Heavy fuel oil specifications

Wärtsilä's HFO specification is based mainly on the ISO 8217:1996(E) standard.

The company has also set limits on certain other important fuel properties like CCAI, asphaltenes and sodium, as well as maximum limits for fuel properties like water, sodium, and aluminium + silicon for treated fuel before the engine (the other specified property limits are valid only for bunkered fuel).

Wärtsilä also has a more stringent heavy fuel oil specification available offering longer overhaul intervals for engine components like the piston, piston rings, anti-polishing ring, cylinder liner, cylinder head, main bearings, big end bearings and camshaft bearings. Figure 3 outlines the heavy fuel oil specifications valid for all Wärtsilä and Sulzer low-speed and medium-speed diesel engine types.

Future heavy fuel oil quality trends

When examining worldwide trends in heavy fuel oil quality over the past ten years, the outcome is ambiguous; the quality of some heavy fuel oil properties has improved while others have deteriorated. Moreover, quality trends differ between geographical areas. Altogether, however, no dramatic changes are evident in heavy fuel oil quality.

The need to cut an increasing amount of lighter fractions out of the barrel in the future will naturally affect heavy fuel oil quality. The fuel properties that mainly affect diesel engine operation are the ash content along with different ash constituents like vanadium, nickel, sodium, etc. as well as the ignition properties.

Another issue which definitely influences heavy fuel oil quality, at least in certain geographical regions, is environmental legislation. The IMO and EU are setting much tighter limits on the sulphur content of heavy fuel than have so far been required.

IMO Annex VI of Marpol 73/78, into force on **19 May 2005**, will limit the sulphur content of heavy fuel oil to max. 4.5 % m/m globally and to max. 1.5 % m/m in so-called SOX Emission Control Areas (SECAs), except if the vessel is equipped with an approved after-treatment exhaust gas cleaning system or any other technical method that is verifiable and enforceable to limit SOX emissions to max. 6.0 g/kWh measured as SO2.

To date, the Baltic Sea, the North Sea and the English Channel have been designated as SECAs. Concerning SECAs, ships have a one-year transition period in the Baltic Sea and a two-year transition period in the North Sea and English Channel before they are required to start burning max. 1.5 % m/m heavy fuel oil when entering these SECAs.

The EU legislation is described in Directive 1999/32/EC and at this stage follows the content of the IMO Annex VI of Marpol 73/78. However, much tighter limits are expected to be valid later on, especially in ports where a sulphur limit of max. 0.1 % m/m is planned to be adopted. Since there are no heavy fuel oils available with such a low sulphur content, this decision will mean that ships will have to store two fuel qualities in the future. Figure 4 summarizes the decided and planned actions of the IMO and EU concerning the upcoming sulphur legislation of liquid fuels.

Summary

The following summarizes the points made above:
☐ Heavy fuel oil will still be the dominating fuel quality in the marine environment for at least another decade.
☐ The need to cut an increasing amount of lighter fractions out of the crude oil barrel have a negative effect on heavy fuel oil quality.
☐ Tighter environmental legislation will force ships to use low-sulphur fuels, which are expected to be of good quality also in other respects.

Table 2 Low sulphur fuels – legislative trends.

Decided actions – IMO

Annex VI of MARPOL 73/78
☐ 4.5% m/m sulphur cap from May 2006 globally
☐ 1.5% m/m sulphur cap from May 2006 in the Baltic Sea
☐ 1.5% m/m sulphur cap from February 2007 in the North Sea and English Channel

Proposed actions – EU

EU Directive 1999/32/EC
☐ 0.2% m/m sulphur cap (later 0.1 % m/m) for distillate fuel – all ships at berth in EU ports and all inland vessels
☐ 1.5% m/m sulphur cap – all ships operating in the Baltic Sea,
North Sea and English Channel and all cruise/passenger vessels on regular service inside European waters
☐ 4.5% m/m sulphur cap – all ships except cruise/passenger vessels on regular service to or from EU ports – EU waters except for the Baltic Sea, North Sea and English Channel
☐ Still under discussions – entry into force: 2007-2010

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