



marine products

everything you need to know about marine fuels







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This publication was prepared by Monique B. Vermeire of Chevron Products and Technology in Belgium. Monique does exclusive work for Chevron Marine Products in the area of fuel technology, with related field support for matters concerning fuel quality issues and supports Chevron Marine Products with international fuel projects and at industry seminars. Since 2011, Monique is the Convenor of ISO/TC 28/SC4/WG6, Classification and specification of marine fuels, and was appointed as Convenor of ISO/TC 28/SC4/WG18, Specifications of alternative fuels for marine applications in 2021.

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liquid fuel..combustion..mechanical energy
..propulsion energy and electricity



I. introduction

through thermal plants, marine engines and gas turbines, the energy obtained from fuel oil combustion is made available to fulfill our needs, be it for transport purposes or for electrical power applications.

From the early 19th century until the third quarter of the 20th century, steamships crossed the seven seas, gradually eliminating sailing ships from commercial shipping.

In the second half of the 20th century, the motor ship started to dominate. The history of the diesel engine began in 1892 with Rudolf Diesel and twenty years later, the first four-stroke marine diesel engine ships were operational.

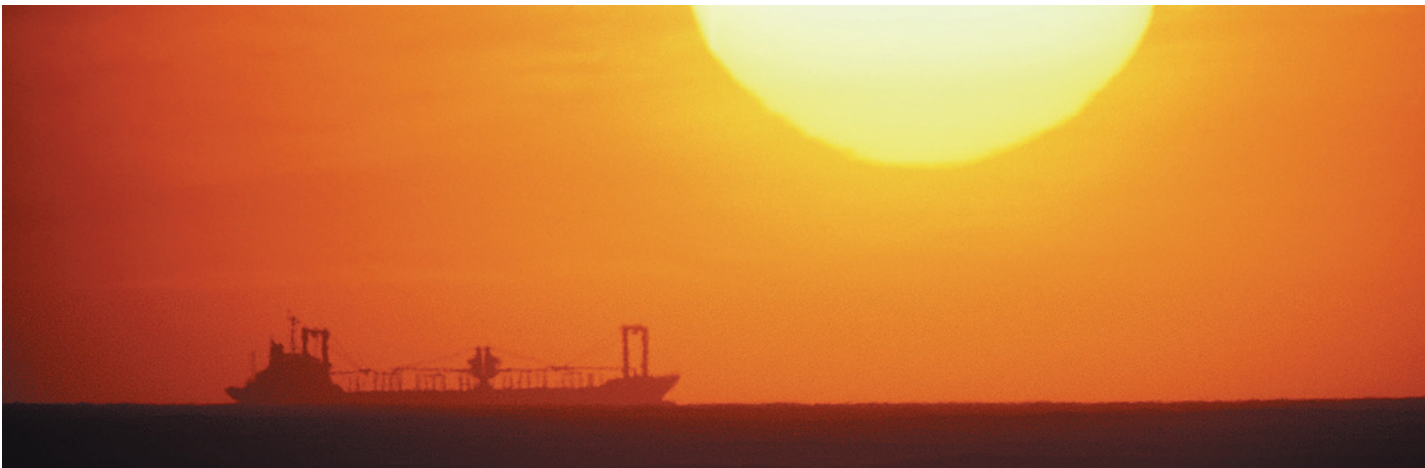
Around 1930, two-stroke designs took a strong lead as ships became larger and faster.

Between World War I and World War II, the share of marine engine-driven ships increased to approximately 25 percent of the overall ocean-going fleet tonnage.

A series of innovations of the diesel engine followed, which made it possible to use heavy fuel oil in medium-speed trunk piston engines, pioneered by the MV *The Princess of Vancouver*. In the mid-1950s, high alkalinity cylinder lubricants became available to neutralize the acids generated by the combustion of high sulphur residual fuels, and wear rates became comparable to those found when using distillate diesel fuel.

Diesel ships using residual fuel oil gained in popularity and in the second half of the 1960s, motor ships overtook steamships, both in terms of numbers, and in gross tonnage. By the start of the 21st century, motor ships accounted for 98 percent of the world fleet.

Marine engines have also found their way into the power industry.



**chevron has been in the business
of finding, producing, trading, and
refining crude oil for over 125 years**



II. crude oil

1. How is a crude oil field formed?

The generally accepted theory is that crude oil was formed over millions of years from the remains of plants and animals that lived in the seas. As they died, they sank to the seabed, were buried with sand and mud, and became an organic-rich layer. Steadily, these layers piled up, tens of meters thick. The sand and mud became sedimentary rock, and the organic remains became droplets of oil and gas. Oil and gas passed through the porous rock and were eventually trapped by an impervious layer of rock, collecting at the highest point.

The formation of an oil/gas field requires the presence of four geological features:

- *Source rock*: contains suitable organic matter, which, under the conditions of heat and pressure, produces hydrocarbons
- *Reservoir rock*: a porous layer of rock in which the hydrocarbons are retained
- *Cap rock*: a rock or clay, which prevents the hydrocarbons from escaping
- *Trap*: a rock formation bent into a dome or broken by a fault which blocks the escape of the hydrocarbons either upward or sideways

Most importantly, these four factors have to occur at the right time, place and in the right order for oil and gas to be formed and trapped. Currently, successful petroleum exploration relies on modern techniques such as seismic surveying. The fundamental principle of seismic surveying is to initiate a seismic pulse at or near the earth's surface and to record the amplitudes and travel times of waves returning to the surface after being reflected or refracted from the interface(s) between one or more layers of rock. Once seismic data has been acquired, it must be processed into a format suitable for geological interpretation and petroleum reservoir detection.

2. Composition and classification of crude oil

Crude oil is a mixture of many different hydrocarbons and small amounts of impurities. The composition of crude oil can vary significantly depending on its source. Crude oils from the same geographical area can be very different due to different petroleum formation strata. Different classifications of crude oil are based on:

1. Hydrocarbons:

- Paraffinic crudes
- Naphthenic crudes
- Asphaltenic (aromatic) crudes

Each crude oil contains the three different types of hydrocarbons, but the relative percentage may vary widely. For example, there is paraffinic crude in Saudi Arabia, naphthenic crude in some Nigerian formations and asphaltenic crude in Venezuela.

2. American Petroleum Institute (API) gravity: The lower the density of the crude oil, the higher its API gravity. A higher API gravity means that the crude contains more valuable lower-boiling fractions.
3. Sulphur content: The ever-growing concern for the environment and the impact on refining cost calculations are the basis for this classification.
 - Sweet crude (low sulphur)
 - Sour crude (high sulphur)

3. Crude oil refining and stocks for marine fuel blending

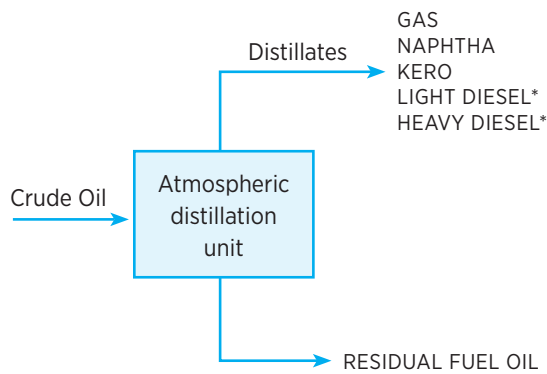
Petroleum refineries are a complex system of multiple operations. The processes used at a given refinery depend upon the desired product slate and characteristics of the crude oil mix. Today, complex refining has a definite impact on the characteristics of marine diesel and intermediate fuel oil (IFO) bunker fuel.



Typical refining schemes and the influence on marine fuels

Straight run refinery

Atmospheric crude distillation and further refining of distillates:



* Diesel refers here to specific atmospheric distillation cuts, and is not related to an engine application.

Straight run stocks for marine fuel blending

Light diesel, heavy diesel, and straight run residue

Straight run marine gasoil and distillate marine diesel (MDO)

Marine gasoil and distillate marine diesel oil (MDO) are manufactured from kero, light, and heavy gasoil fractions.

Straight run IFO 380 mm²/s (at 50°C)

This intermediate fuel oil (IFO) grade is obtained by blending the atmospheric residue fraction (typical viscosity of about 800 mm²/s at 50°C) with a gasoil fraction.

Straight run lower viscosity grade IFOs

Blending to lower grade IFOs is done from the IFO 380 mm²/s (at 50°C) using a gasoil cutter stock or with marine diesel.

All IFOs have good ignition characteristics, due to the high percentage of paraffinic material still present in the atmospheric residue, and the paraffinic nature of the cutterstocks used. The high amount of paraffinic hydrocarbons in the straight run marine fuels leads to relatively low densities for these products, ensuring easy and efficient onboard fuel purification.

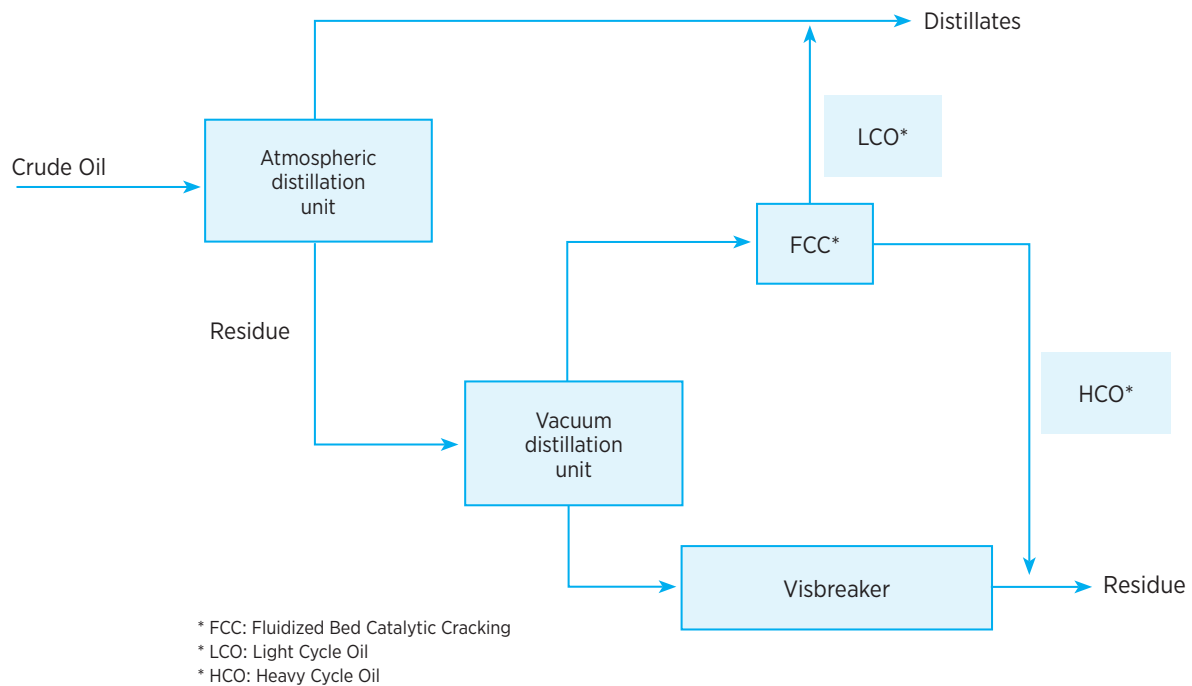
The product slate of a straight run refinery, with its heavy fuel production of approximately 50% of the crude feed, does not correspond to the product demand in industrialized countries where the ever-growing demand for light products (jet fuel, gasoline, and gasoil) coincides with a strong reduction in the demand for heavy fuel (10 to 15% of the crude oil). This results in the need to convert the residue fraction into lighter, hence, more valuable, fractions and to the construction of complex refineries.

A complex refinery processing scheme can be separated into two parts:

1. Crude oil distillation (atmospheric and vacuum distillation)
2. Streams from the vacuum distillation unit are converted through catalytic and thermal cracking processes.

Complex refineries have been favored since the early 1980s and are intended to boost gasoline production. All further information herein is based on a complex refinery. The main marine fuel blending components from a fluidized bed catalytic cracking (FCC) refinery with visbreaker are the same distillates as those from a straight run refinery (light and heavy diesel) as well as light cycle (gas) oil (LC(G)O) and heavy cycle oil (HCO) from the catcracker and visbroken residue from the visbreaker.

Example: Complex refinery with (fluid) catalytic cracking and visbreaking



Atmospheric residue is used as feedstock for the vacuum unit and will seldom be available for fuel blending.

More detailed information on complex refining is provided in [Appendix I](#).

Marine fuels resulting from a catalytic cracking/visbreaking refinery have a composition that is markedly different from that of an atmospheric refinery.

Marine gasoil (MGO/DMA/DMZ/DFA/DFZ)¹

A new blend component has appeared — light cycle (gas) oil — that contains about 60% aromatics. Due to the high aromatic nature of LC(G)O, the density of a marine gasoil blended with LC(G)O will be higher than when using gasoil from an atmospheric distillation refinery. The density will typically be close to 860 kg/m³ (at 15°C). No performance or handling differences with atmospheric gasoil are to be expected. In 2010, the fourth edition of ISO 8217 standard introduced an additional grade of marine gasoil, DMZ, which has a higher minimum viscosity than DMA but is otherwise identical in its characteristics to DMA marine gasoil.

1. Marine products or grades are designated by a symbol consisting of a group of letters which together constitute a code. This code consists of:

- the initials "ISO";
- the letter "F" for the class of fuel;
- the category of fuel, consisting of three letters:
 - the family letter, "D" for distillate or "R" for residual,
 - "M", designating the application "Marine", where for fuels that contain FAME, "M" is replaced by "F",
 - a letter, e.g., "A", "B"... "Z", which taken separately has no significance, but has meaning in relation to the particular properties in accordance with the product specification, ISO 8217:2017;
- a number that corresponds to the maximum kinematic viscosity of the residual fuel, in square millimeters per second (mm²/s) at 50°C.

A product or grade may be designated in the complete form or in an abbreviated form, e.g.: ISO-F-RMG 380 or RMG 380.

Many countries mandate the use of biodiesel in diesel fuel for road transport. In 2017, the sixth edition of ISO 8217 standard introduced two additional marine gasoil grades, DFA and DFZ, with a maximum fatty acid methyl ester(s) (FAME) content of 7.0 volume % (see also [Chapter III-8](#) on biofuels).

Note: In some areas marine gasoil DMA is, in fact, automotive diesel (not including biodiesel), with added marker and dye and without the excise duty applicable to automotive fuel. In the EU, the maximum S level of automotive diesel is currently 0.0010 mass % or 10 ppm. The alkalinity (BN) of the lubricant may have to be adjusted accordingly (see also [Chapter III-2a](#) on Sulphur).

Distillate marine diesel (MDO/DMB/DFB)

Distillate marine diesel (commercial denomination) typically has a lower cetane index than marine gasoil, and has a higher density. With the production slate of a catalytic cracking refinery, distillate marine diesel can therefore contain a higher percentage of LC(G)O than marine gasoil. In 2017, the sixth edition of ISO 8217 standard introduced an additional distillate marine diesel grade, DFB, with a maximum fatty acid methyl ester(s) (FAME) content of 7.0 volume % (see also [Chapter III-8](#) on biodiesel).

IFO-380 (sulphur > 0.50% maximum)

This grade is usually manufactured at the refinery and contains visbroken residue, HCO and LC(G)O. These three components influence the characteristics of the visbroken IFO-380.

Vacuum distillation reduces the residue yield to about 20% of the crude feed, unavoidably leading to a concentration of the heaviest molecules in this fraction. Visbreaking converts about 25% of its vacuum residue feed into distillate fractions. This means that about 15% of the original crude remains as visbroken residue. The asphaltenes², sulphur and metal content in visbroken residue are 3 to 3.5 times higher than in atmospheric residue. Visbreaking affects the molecular structure: molecules are broken thermally, and this can deteriorate the stability of the asphaltenes.

HCO (typical viscosity at 50°C: 130 mm²/s) contains approximately 60% aromatics, and is a high-density fraction: the density at 15°C is above 1 kg/l (typically 1.02). It is the bottom fraction of the FCC unit. The catalytic process of this unit is based on an aluminum silicate. Some mechanical deterioration of the catalyst occurs in the FCC process, and the resulting catalyst fines are removed from the HCO in the refinery. This removal, however, is not 100% efficient and a certain amount (ppm level) of cat fines remains in the HCO. From there they end up in heavy fuel blended with HCO (see also [Chapter III-2](#)).

The aromaticity of HCO assists in ensuring optimum stability for the visbroken fuel blend.

LC(G)O (typical viscosity at 50°C: 2.5 mm²/s) has the same aromaticity as HCO, but is a distillate fraction of the FCC unit, with a distillation range comparable to that of gasoil. With a typical density of 0.94 kg/l at 15°C, it is used to fine-tune the marine heavy fuel oil blending where generally a density maximum limit of 0.9910 kg/l has to be observed.

IFOs < 380 mm²/s (sulphur > 0.50% maximum)

In ISO 8217:2010, blended marine diesel known as DMC was reclassified as a residual fuel oil, RMA10. With atmospheric refining, RMA10 can contain up to 10% IFO with either marine gasoil or distillate marine diesel. With complex refining, RMA10 no longer corresponds to a specific composition and extreme care must be used when blending this grade to prevent stability and/or combustion problems.

The other low viscosity residual fuel oil grades are generally blended starting from 380 mm²/s IFOs (at 50°C), by using a suitable cutterstock (marine diesel, gasoil, LC(G)O, or a mixture of these). The blend composition has to be constructed in such a way that the product stability is safeguarded, while at the same time direct or indirect density limits are fulfilled (see also [Chapters III-2](#)).

ECA compliant fuels

The reduction of the sulphur (S) content of fuel for use in all established Emission Controlled Areas (ECAs) on 1st of January 2015 to 0.10 % maximum (see also [Chapter III-2a](#)), as required by Marpol Annex VI, has resulted in

unconventional fuels and fuels with different chemistry (often more paraffinic) entering into the marine fuels market. Some of these fuels only fit in part under the existing grade categorizations of ISO 8217:2017 Table 1 or Table 2 (see [Chapter III-2](#)), but for the most part can be defined as an existing category with some deviating characteristic(s).

Hydrowax (paraffinic fraction from the hydrocracker (see [Appendix I](#)), desulfurized vacuum gasoil (VGO), or ultra-low sulphur gasoil are only a few new product streams that can be used as blending components for these ECA compliant products.

IMO 2020 compliant fuels

The introduction of the 0.50% maximum S limit as of 1 January 2020 for marine fuels has also, due to the limited availability of these fuels prior to 1 January 2020, resulted in a wide variety of new blend formulations entering into the market. Straight run vacuum residue, straight run vacuum distillate, hydrocracked distillate, catalytically cracked distillate, and residue are only a few product streams that can be used for the blending of 0.50% maximum sulphur fuels.

². Asphaltenes: residual fuel components that are insoluble in heptane but soluble in toluene

III. fuel oil

1. Fuel oil applications

All fuel oil applications create energy by burning fuel oil. Fuel oil combustion (oxidation reaction) releases a large amount of heat, which can be used for steam generation, for example, in steam boilers. The high volume (pressure) of the combustion gases can be used to drive an engine, or (less frequent for HFO, but widespread for gasoil) a gas turbine.

When fuel oil is burned, an amount of heat is released, which is defined by the specific energy (international unit MJ/kg) of the fuel.

Thermal plants use this heat to generate steam, which then drives steam turbines, thus providing mechanical energy that can be used for propulsion or to be converted into electrical energy.

For marine engines and gas turbines, mechanical energy provided by the combustion gases is used either directly for propulsion or converted into electrical energy for power plants. For larger installations, cost efficiency optimization and environmental constraints led to the introduction of co-generation. In co-generation, some of the electrical energy lost is used to generate low-pressure steam, suitable for a wide range of heating applications.

2. Fuel specifications

Different types of fuel oil applications and environmental considerations have led to different types of fuel oil specifications. These are much more demanding than the original fuel oil n° 6 or Bunker C requirements when all heavy fuel was used for thermal plants and steam turbines. Emission standards for thermal plants can vary widely, depending on the geographical area. Since all emitted sulphur dioxide (SO₂) originates from sulphur in the fuel, emission standards on SO₂ automatically limit the sulphur content of the fuel, except for large combustion plants, where the standard can be economically met by flue gas desulphurization.

In the late 1960s, marine diesel engines were the primary means of ship propulsion. Through the late 1970s, marine engine heavy fuel oil grades remained identified solely by their maximum viscosity. This worked well with heavy fuel originating from atmospheric refineries. Fuel-related operational problems arose with the generalized upgrading of refinery operations in the second half of the 1970s from straight run to complex refining.

1982 saw the publication of marine fuel specification requirements by the British Standard Organization (BS MA 100), and by CIMAC (Conseil International de Machines à Combustion).

An international ISO standard has existed since 1987: ISO 8217. The stated purpose of ISO 8217 is to define the requirements for fuels for use in marine diesel engines and prior to conventional onboard treatment (settling, centrifuging, filtration) before use, and is provided for the guidance of interested parties such as marine equipment designers, suppliers and purchasers of marine fuels. These specifications are regularly revised to accommodate changes in marine diesel engine technology, crude oil refining processes and environmental developments. ISO 8217: 2017 takes into consideration the burgeoning demands of environmental legislation and allows marine fuels to include not only hydrocarbons from petroleum crude oil, oil sands and shale oil but also hydrocarbons from synthetic or renewable sources and allows some grades to contain fatty acid methyl esters (FAME).

The ISO 8217:2017 specifications for marine fuels will be discussed in detail in [Chapter III-2a](#) (see pages 8 and 9, Tables 1 and 2). ISO 8217:2017 is applicable to all fuels, including the 0.10% and 0.50% maximum sulphur fuels, respectively known in the industry as Ultra Low Sulphur Fuel Oils (ULSFO) and Very Low Sulphur Fuel Oils (VLSFO).

continued on page 10

Table 1: Requirements for distillate marine fuels

Characteristics	Unit	Limit	Category ISO-F-						Test method reference	
			DMX	DMA	DFA	DMZ	DFZ	DMB		DFB
Kinematic viscosity at 40°C	mm ² /s ^a	max.	5.500	6.000		6.000		11.00	ISO 3104	
		min.	1.400	2.000		3.000		2.000		
Density at 15°C	kg/m ³	max.	—	890.0		890.0		900.0	ISO 3675 or ISO 12185; see 6.1	
Cetane index	—	min.	45	40		40		35	ISO 4264	
Sulfur ^b	mass %	max.	1.00	1.00		1.00		1.50	ISO 8754 or ISO 14596, ASTM D4294; see 6.3	
Flash point	°C	min.	43.0	60.0		60.0		60.0	ISO 2719; see 6.4	
Hydrogen sulfide	mg/kg	max.	2.00	2.00		2.00		2.00	IP 570; see 6.5	
Acid number	mg KOH/g	max.	0.5	0.5		0.5		0.5	ASTM D664; see 6.6	
Total sediment by hot filtration	mass %	max.	—	—		—		0.10 ^c	ISO 10307-1; see 6.8	
Oxidation stability	g/m ³	max.	25	25		25		25 ^d	ISO 12205	
Fatty acid methyl ester (FAME) ^e	volume %	max.	—	—	7.0	—	7.0	—	7.0	ASTM D7963 or IP 579; see 6.10
Carbon residue — micro method on the 10% volume distillation residue	mass %	max.	0.30	0.30		0.30		—	ISO 10370	
Carbon residue — micro method	mass %	max.	—	—		—		0.30	ISO 10370	
cloud point ^f	winter	°C	max.	-16	report	report		—	ISO 3015; see 6.11	
	summer	°C	max.	-16	—	—		—		
Cold filter plugging point ^f	winter	°C	max.	—	report	report		—	IP 309 or IP 612; see 6.11	
	summer	°C	max.	—	—	—		—		
Pour point (upper) ^f	winter	°C	max.	—	-6	-6		0	ISO 3015; see 6.11	
	summer	°C	max.	—	0	0		6		
Appearance	—	—	Clear and Bright ^g					^c	see 6.12	
Water	volume %	max.	—	—		—		0.30 ^c	ISO 3733	
Ash	mass %	max.	0.010	0.010		0.010		0.010	ISO 6245	
Lubricity, corrected wear scar diameter (WSD) at 60°C ^h	µm	max.	520	520		520		520 ^d	ISO 12156-1	

a 1 mm²/s = 1 cSt.

b Notwithstanding the limits given, the purchaser shall define the maximum sulfur content in accordance with relevant statutory limitations. See Introduction.

c If the sample is not clear and bright, the total sediment by hot filtration and water tests shall be required, see 6.8 and 6.12.

d If the sample is not clear and bright, the test cannot be undertaken and therefore compliance with this limit cannot be shown.

e See 5.1 and Annex A.

f Pour point cannot guarantee operability for all ships in all climates. The purchaser should confirm that the cold flow characteristics (pour point, cloud point, cold filter plugging point) are suitable for the ship's design and intended voyage. See 6.11.

g If the sample is dyed and not transparent, then the water limit and test method as given in 6.12 shall apply.

h This requirement is applicable to fuels with a sulfur content below 500 mg/kg (0.050 mass %).

For test method reference, see also ISO 8217:2017.

Table 2: Requirements for residual marine fuels

Characteristics	Unit	Limit	Category ISO-F-										Test method(s) and references	
			RMA	RMB	RMD	RME	RMG				RMK			
			10	30	80	180	180	380	500	700	380	500		700
Kinematic viscosity at 50°C	mm ² /s ^a	max.	10.00	30.00	80.00	180.0	180.0	380.0	500.0	700.0	380.0	500.0	700.0	ISO 3104
Density at 15°C	kg/m ³	max.	920.0	960.0	975.0	991.0	991.0				1010.0		ISO 3675 or ISO 12185; see 6.1	
CCAI	—	max.	850	860	860	860	870				870		see 6.2	
Sulfur ^b	mass %	max.	Statutory requirements										ISO 3675 or ISO 12185 or ASTM D4294; see 6.3	
Flash point	°C	min.	60.0	60.0	60.0	60.0	60.0				60.0		ISO 2719; see 6.4	
Hydrogen sulfide	mg/kg	max.	2.00	2.00	2.00	2.00	2.00				2.00		IP 570; see 6.5	
Acid number ^c	mg KOH/g	max.	2.5	2.5	2.5	2.5	2.5				2.5		ASTM D664; see 6.6	
Total sediment – aged	mass %	max.	0.10	0.10	0.10	0.10	0.10				0.10		ISO 10307-2; see 6.9	
Carbon residue – micro method	mass %	max.	2.50	10.00	14.00	15.00	18.00				20.00		ISO 10370	
Pour point (upper) ^d	winter	°C	max.	0	0	30	30	30				30		ISO 3016
	summer	°C	max.	6	6	30	30	30				30		
Water	volume %	max.	0.30	0.50	0.50	0.50	0.50				0.50		ISO 3733	
Ash	mass %	max.	0.040	0.070	0.070	0.070	0.100				0.150		ISO 6245	
Vanadium	mg/kg	max.	50	150	150	150	350				450		IP 501, IP 470 or ISO 14597; see 6.14	
Sodium	mg/kg	max.	50	100	100	50	100				100		IP 501, IP 470; see 6.16	
Aluminium plus silicon	mg/kg	max.	25	40	40	50	60				60		see 7.9 IP 501, IP 470 or ISO 10478	
Used lubricating oils (ULO): calcium and zinc; or calcium and phosphorus	mg/kg	—	calcium > 30 and zinc > 15 or calcium > 30 and phosphorus > 15										IP 501 or IP 470, IP 500; see 6.17	

a 1 mm²/s = 1 cSt.

b The purchaser shall define the maximum sulfur content in accordance with relevant statutory limitations. See Introduction.

c See Annex E.

d The purchaser should confirm that this pour point is suitable for the ship's intended area of operation.

For test method reference, see also ISO 8217:2017.

As it was anticipated that the reduction of the maximum sulphur content of marine fuels to 0.50 m/m % would lead to a transition in the nature of marine fuels and a revision of ISO 8217:2017 not possible by 1 January 2020, ISO/PAS 23263:2019 was developed to address fuel quality considerations in view of the implementation of the maximum 0.50% S limit in 2020 and the range of marine fuels expected to be placed on the market.

ISO/PAS 23263:2019 addresses general considerations on the sulphur content and flashpoint of 0.50 m/m % S fuels, the application of ISO 8217:2017 to these fuels but also specific considerations which may apply to some of these fuels. In particular, kinematic viscosity, catalyst fines, stability, cold flow properties/wax formation and ignition characteristics are addressed. As it was expected to see a higher variety of fuel blend formulations as of 1 January 2020 and although compatibility is not a specification within ISO 8217, ISO/PAS 23263:2019 provides information on how to minimize the risk of incompatibility between fuels when commingling onboard is unavoidable and how to evaluate compatibility (see also [Chapter III-5](#) and 6).

Important specifications to ensure reliable engine operation with residual fuel are:

- Maximum density limit: Important for classical purifier operation and to ensure satisfactory ignition quality for low viscosity fuel grades
- Maximum Aluminum and Silicon (Al+Si) limit: In a complex refinery, HCO is used as a blending component. Mechanically damaged aluminum silicate catalyst particles of the catalytic cracker are not completely removed from the HCO stream, and are found in mg/kg amounts in heavy fuel blended with HCO. In order to avoid abrasive damage in the fuel system onboard the vessel, it is necessary to limit the amount of Al+Si to a level which can be adequately removed by the ship's fuel cleaning system.
- Maximum total sediment aged limit: The stability of asphaltenes is deteriorated by the visbreaking process, and instability problems can cause fuel purification and filter-blocking problems, hence the need for a specification to ensure adequate fuel stability.
- With the introduction of lower maximum sulphur limits, more paraffinic product streams are used for the blending of these fuels. Especially for low viscosity 0.50% S residual-type fuels, attention should be given to the cold flow properties of the fuel intended to be used for a particular voyage.

The ISO 8217:2017 specifications can also be applicable to fuels for stationary diesel engines of same or similar make as those used for marine purposes.

A less widespread application of heavy fuel is found in heavy-duty gas turbines: here the fuel specification requirements before the injection are very severe, and can

only be obtained by an extremely thorough precleaning of the fuel.

The fuel treatment consists of the removal of the alkali metal ions by fuel precleaning and inhibition of vanadium-induced corrosion by injecting magnesium-containing additives that react with the vanadium to form non-corrosive compounds. The heavy-duty gas-turbine application of heavy fuel is further discussed in Appendix II.

2a. Significance of the marine fuel properties listed in ISO 8217:2017

Acid Number:

All fuels have a naturally occurring acid number, however fuels with high acid numbers arising from acidic compounds can cause accelerated damage to large diesel engines, especially the fuel injection equipment. However, fuels manufactured from naphthenic crudes can have an acid number exceeding the maximum specified in ISO 8217:2017 but still be acceptable for use. Currently no identified correlation between the acid number of a fuel oil and its corrosivity exists.

Ash:

The ash content is a measure of the inorganic incombustible components present in the fuel, either as inherent to the fuel or as contamination.

Carbon residue:

Carbon residue is determined by a laboratory test performed under specified reduced air supply. It does not represent combustion conditions in an engine. It gives an indication of the amount of hydrocarbons in the fuel which have difficult combustion characteristics, but there is no conclusive correlation between carbon residue figures and actual field experience. The micro carbon residue method is specified by ISO 8217.

Catalyst fines:

Heavy cycle oil is used worldwide in complex refining as a blending component for heavy fuel. Mechanically damaged catalyst particles (aluminum silicate) cannot be removed completely in a cost-effective way, and are found in blended heavy fuel. Fuel precleaning onboard ships has a removal efficiency of approximately 80% for catalyst fines. In order to avoid abrasive wear of fuel pumps, injectors and cylinder liners the maximum limit for Al+Si is 60 mg/kg for RMG and RMK category fuels since 2010.

CCAI:

The Calculated Carbon Aromaticity Index (CCAI) is only applicable to residual fuel oils and provides an indication of the ignition delay of a fuel oil. The CCAI is calculated from the density and viscosity of a residual fuel oil. Some engine manufacturers specify CCAI limits for their engines, depending on engine type and application.

Cetane index:

Cetane index is only applicable for gasoil and distillate fuels. It is a measure for the ignition quality of the fuel

in a diesel engine. The higher the rpm of the engine, the higher the required cetane index. The cetane index is an approximate calculated value of the cetane number, based on the density and the distillation of the fuel. The cetane index is not applicable when cetane-improving additives have been used.

Cloud point, cold filter plugging point:

The cloud point is defined as the temperature at which wax crystals start to visibly form in the fuel and a transparent fuel becomes cloudy.

The cold filter plugging point is the lowest temperature where the fuel of a set volume drawn, by vacuum, through a standardised filter within a specified time still continues to flow.

Marine distillate fuels with a higher content of heavier n-paraffins may lead to cold flow operability issues as wax settling can occur, even when the pour point specification is met, when a ship is operating in colder climate regions or when a ship is having restricted heating capabilities for their distillate fuel tanks. Therefore, ISO 8217:2017 requires for winter grades of DMA, DFA, DMZ and DFZ the cloud point and cold filter plugging point to be reported.

The International Council on Combustion Engines (CIMAC) has developed a guideline on cold flow properties of marine fuel oils. This guideline aims to provide ships crews with a better understanding of a fuel's cold flow characteristics which have become more important but are often overlooked when storing and handling distillate fuels.

Density:

The official unit is kg/m³ at 15°C, while kg/l at 15°C is the most commonly used unit. Density is used to calculate the quantity of fuel delivered. The density gives an indication of the ignition quality of the fuel within a certain product class. This is particularly the case for the low-viscosity IFOs. The product density is important for the onboard purification of the fuel; the higher the density, the more critical it becomes (see [Chapter III-4](#) on fuel oil treatment).

Elements:

Vanadium and nickel are elements found in certain heavy fuel oil molecules (asphaltenes). Upon combustion, vanadium oxides are formed, and some have critical melting temperatures. The most critical are the double oxides/sulphates with sodium. Some countries have implemented maximum Ni concentrations for inland use of heavy fuel. The elements calcium, zinc and phosphorous are considered "fingerprint" elements of used lubricating oil (see [Chapter III-2a](#), Used lubricating oil)

Flash point:

Flash point is the temperature at which the vapors of a fuel ignite (under specified test conditions), when a test flame is applied. The flash point for all fuels to be used in bulk onboard vessels is set at Pensky–Martens closed-cup 60°C minimum (SOLAS agreement). DMX, a special low cloud point gasoil, may only be stored onboard in drums because of its < 60°C flash point.

Hydrogen sulphide (H₂S):

H₂S is a highly toxic gas and exposure to high vapor concentrations is hazardous and can be fatal in extreme cases. It is naturally present in crude oils and can be formed during the refining processes used to produce the fuel. H₂S can also evolve from the fuels in storage tanks, barges and customer tanks. Residual fuel oils can contain varying levels of H₂S in the liquid phase and in some circumstances higher levels of H₂S can be observed in marine distillate fuel oils. H₂S can be present in both liquid and vapor phase and the partitioning between the liquid and vapor phase depends on a number of factors (e.g., fuel temperature, viscosity, level of agitation, etc.).

The fifth edition of ISO 8217 defined a liquid-phase H₂S limit of maximum 2.00 mg/kg as measured by test method IP 570 as of July 2012. This limit intends to provide an improved margin of safety. The limit alone does not constitute a safe level or eliminate the risk of very high levels of H₂S vapor being evolved in enclosed spaces.

Kinematic viscosity:

Kinematic viscosity is a measure of the fluidity of the product at a certain temperature. The viscosity of a fuel decreases with increasing temperature. The viscosity at the moment the fuel leaves the injectors must be within the limits prescribed by the engine manufacturer to obtain an optimal spray pattern. Viscosity outside manufacturers' specifications at the injectors will lead to poor combustion, deposit formation and energy loss. The viscosity of the fuel must be such that the required injection viscosity can be reached by the ship's preheating system.

For distillate marine fuels, most large diesel engine builders request a minimum viscosity of the fuel before the fuel injection pump of about 2.0 mm²/s (cSt). Hence, for distillate marine fuels with a minimum viscosity of 2.0 mm²/s (cSt) at 40°C, according to the ISO 8217:2017 standard, cooling or chilling may be required to maintain the required minimum viscosity before the fuel injection pump.

Lubricity:

Lubricity is the ability to reduce friction between solid surfaces in relative motion. The fuel itself protects some moving parts of fuel pumps and injectors from wear. Higher viscosity fuels provide sufficient lubricity. To avoid excessive wear, the fuel must have some minimum level of lubricity.

Lubricity enhancing compounds are naturally present in diesel fuel derived from petroleum crude by distillation. They can be altered or changed by hydrotreating, the process used to reduce sulfur and aromatic contents. However, lowering sulfur or aromatics, per se, does not necessarily lower fuel lubricity.

The use of fuels with poor lubricity can increase fuel pump and injector wear. In order to avoid this, a lubricity wear scar diameter limit of maximum 520 µm is applied for distillate marine fuels with S content less than 500 ppm. In some areas ultra low sulphur automotive diesel is supplied as a marine distillate fuel in order to comply with regulatory sulphur requirements.

Oxidation Stability:

Degradation of distillate fuels by oxidation can cause fuel stability problems. Unstable distillate fuels can form insoluble organic particles which may clog fuel filters, cause wear and contribute to injector deposits. Also, fatty acid methyl esters (FAME) can impact the oxidation stability of the fuel (see also [Chapter 8](#) on Biofuels).

Pour point:

Pour point is the lowest temperature at which a fuel will continue to flow when it is cooled under specified standard conditions.

Straight run heavy fuels have a pour point typically in the +20°C range while high sulphur bunker fuels from a complex refinery generally have pour points below 0°C (range -10 to -20°C). This can lead to problems if a vessel receives high pour (straight run) bunker fuel and the bunker fuel tanks are not completely or only before the fuel transfer pump heated.

With the introduction of lower maximum sulphur limits, more paraffinic product streams are used for the blending of marine fuels with a maximum sulphur content of 0.50% and therefore can have higher pourpoint as well.

Sulphur:

The sulphur content of a marine fuel depends on the crude oil origin and the refining process. When a fuel burns, sulphur is converted into sulphur oxides. These oxides reach the lubricating oil via the blow-by gas. These oxides are corrosive to engine piston liners and must be neutralized by the cylinder lubricant. Marine engine lubricants are developed to cope with this acidity. If the correct lubricant is used, the sulphur content of a marine fuel is technically not important but may have environmental implications.

Since the early 2000s, regulations to reduce emissions from shipping are in place and have been tightened over the years. The increasing restrictions on marine fuel sulphur content have shifted the primary blend target of marine fuels from viscosity and density to sulphur.

MARPOL Annex VI, first adopted in 1997, limits the main air pollutants contained in ships exhaust gas, including sulphur oxides (SO_x) and nitrous oxides (NO_x). In 2008, the revised Annex VI to Marpol 73/78 was adopted and required the sulphur content of any fuel used on board ships not to exceed 3.50 m/m % as of 1 January 2012. The revised Annex VI also restricted the sulphur content of fuel oil used on board ships operating within an Emission Control Area (ECA) to 0.10 m/m % as of 1 January 2015.

Currently existing ECAs are the Baltic Sea, the North Sea and English Channel, and the North American ECA which includes waters adjacent to the Pacific coast, the Atlantic/Gulf coast and the eight main Hawaiian Islands. The North American ECA extends up to 200 nautical miles from the United States coasts.

The revised Annex VI also included the requirement to further restrict the sulphur content to 0.50 m/m % on and after 1 January 2020. However, a provision was adopted, requiring IMO to review by 2018 the availability of 0.50 m/m % fuel oil for use by ships, to determine whether the new lower global limit on sulphur emissions from international shipping should come into effect on 1 January 2020 or be deferred until 1 January 2025. At its 70th meeting (October 2016) the Marine Environment Protection Committee (MEPC) confirmed 1 January 2020 as the effective date of implementation for ships to comply with the 0.50 m/m % sulphur content of fuel oil requirement. Furthermore, the IMO adopted in 2019 the amendment to MARPOL Annex VI prohibiting the carriage of non-compliant fuel oil for combustion purposes for propulsion or operation on board a ship as of 1 March 2020.

Annex VI to Marpol 73/78 allows however for alternative technologies/methods, such as scrubbers, which are at least as effective in terms of emissions reductions.

The EU directive 2016/802 of the European Parliament and of the Council of 11 May 2016 relating to a reduction in the sulphur content of certain liquid fuels also restricts the sulphur content of fuels used in the areas of their territorial seas, exclusive economic zones and pollution control zones to 0.50 m/m % maximum as of 1 January 2020.

The EU Directive allows the use of fuels exceeding sulphur content of 3.50 m/m % supplied to ships using emission abatement methods operating in closed mode.

The EU directive also has set a maximum limit of 0.10 m/m % on the sulphur content of marine fuels used by ships when at berth for more than 2 hours.

Both Marpol Annex VI and the EU directive require a representative sample of the fuel delivered to be taken and retained on board which, if necessary, can be used to demonstrate compliance with the sulphur limits. This sample, often referred to as “MARPOL sample” is to be drawn continuously throughout the bunker delivery period at the receiving vessel’s inlet bunker manifold. However, when this is not possible (e.g., safety aspects), it can also be taken at a mutually agreed location. The “Marpol sample” shall be retained on board the vessel until the fuel is substantially consumed but for not less than 12 months. The fuel supplier shall include the seal number of the representative sample and the sulphur content of the fuel on the bunker delivery note (BDN) in addition to a declaration stating that the fuel supplied complies with regulation 18.3 (fuel oil quality) of Annex VI, as well as that the sulphur content of the fuel supplied does not exceed 0.50 or 0.10 m/m % S or will be used in combination with an equivalent means of compliance (e.g., scrubber), in addition to other information such as density at 15°C,

port, and quantity delivered. In California, the Ocean-Going Vessels (OGV) Clean Fuel regulation applies to OGV main diesel engines, auxiliary diesel engines and auxiliary boilers, and requires the use of marine distillate grade fuel marine gasoil or marine diesel oil with a maximum sulfur level of 0.10% and does not allow compliance via scrubbers.

The California OGV fuel regulation includes a sunset provision which states that the regulation requirements will cease to apply if the United States adopts and enforces requirements that will achieve equivalent emissions reductions to the California OGV Fuel Regulation within Regulated California Waters. In April 2016, the California Air Resource Board concluded that the federal ECA alone would not likely achieve equivalent emission reductions within Regulated California Waters.

Total sediment aged:

The total sediment aged is the total amount of sediment that can be formed under normal storage conditions, excluding external influences. If the total sediment aged of the fuel oil markedly exceeds the specification value (0.10 m/m % maximum for all grades of IFOs and HFOs), problems with the fuel cleaning system can occur, fuel filters can get plugged and combustion can become erratic. Inorganic material naturally occurring in crude oil is removed in the refineries prior to the atmospheric distillation. Some minor contamination (for example, iron oxides) of a finished heavy fuel cannot be excluded. The biggest risk for sediment formation in residual fuel is due to potential coagulation of organic material inherent to the fuel itself. Visbroken asphaltenes, if insufficiently stable, can form sediment (coagulation is influenced by time and temperature). A decrease in aromaticity of the fuel matrix by blending with paraffinic cutterstocks can also deteriorate the stability of the asphaltenes. In cases of residual fuel instability, only a relatively small fraction of the asphaltenes form sediment. However this organic sediment includes in its mass some of the fuel itself as well as water (if there are onboard purifying problems), so the amount of generated sludge can become quite high.

Used lubricating oil (ULO):

The use of used lubricants (predominantly used motor vehicle crankcase oils) in marine fuels first surfaced as a potential problem in the mid-1980s. Both CIMAC and ISO 8217 working groups discussed the technical and commercial considerations at length. Calcium, zinc and phosphorous were considered “fingerprint” elements of ULOs, and limits for these elements were first set in ISO 8217:2005. As additives used in crankcase oils have changed, ISO 8217:2010 considered a fuel oil to contain ULO when either calcium and zinc or calcium and phosphorus exceed these limits. This, however, does not necessarily imply that the fuel oil is not suitable for use. Generally, 10 mg/kg Zn corresponds to approximately 1% used oil in the fuel. This is only an approximation; the zinc dithiophosphate content of lubricants can vary considerably.

The reduction of the maximum sulphur content of marine fuels has resulted in new blend compositions which may contain Ca exceeding the limit of 30 mg/kg, which when a Zn based H₂S scavenger is being used, might result in both Ca and Zn exceeding the limits without containing ULO.

Water content:

Water in fuel is a contaminant and does not yield any energy. The percentage of water in the fuel can be translated into a corresponding energy loss for the customer. Water is removed onboard the vessel by centrifugal purification. If after purification, the water content remains too high, water vapor lock can occur and pumps can cut out. If water-contaminated fuel reaches the injectors, combustion can be erratic. Water in fuel that remains standing in lines for a longer period can cause corrosion.

2b. Correspondence of specifications and test methods

ISO 8217:2017 lists test requirements and methods for testing. While these methods should be used worldwide for testing marine fuels, experience has shown that they are not. In some areas, precursors of the presently defined ISO methods are still being used. The correspondence (discrepancy) between such test methods/results and the test methods/data of ISO 8217 are described hereafter.

Al+Si:

The ISO 8217 prescribed test methods are ISO 10478 or IP 501 or IP 470. Only these methods and fully equivalent methods from national standardization organizations should be used. A former industry-wide maximum limit for catalyst fines in heavy fuel was defined on Al alone (30 mg/kg). The ratio between Al and Si can, however, vary considerably between different types and manufacturers of aluminum silicate catalyst. This is why the test measures the sum of Al and Si. In practice, the two ways of limiting the catalyst fines content in heavy fuel give the same degree of protection.

API gravity:

A function of the specific gravity 60/60°F. API gravity is expressed as degrees API.

API gravity, deg = (141.5/spec. gr. 60/60°F) – 131.5

Density:

The mass (weight in vacuum) of the liquid per unit volume at 15°C. Official unit: kg/m³. Often used variant: kg/l. The density limits in ISO 8217 are expressed in kg/m³. Specific gravity 60/60°F: Specific gravity is the ratio of the mass of a given volume of liquid at 60°F to the mass of an equal volume of pure water at the same temperature. No unit.

Micro Carbon Residue (MCR):

MCR is the carbon residue test prescribed as of ISO 8217:2005. Formerly, the carbon residue test was Conradson Carbon Residue. MCR is quicker and more precise than CCR.

Total sediment by hot filtration & total sediment aged:

According to ISO 8217:2017 the total sediment by hot filtration (ISO 10307-1) shall be measured on all DMB/DFB category products that fail the visual inspection requirement to be bright and clear.

Organic type sediment can occur in DMB/DFB marine diesel and in intermediate fuel oils. The cause of the formation of organic sediment is due to the thermal cracking of the heaviest molecules of crude, generally in visbreaking operations. Asphaltenes, the heaviest molecules of crude, can be made unstable by thermal cracking, and must be carefully monitored by the refineries. Once visbroken, the asphaltenes can be more sensitive to changes in the aromaticity of the total fuel matrix. This must be taken into account for fuel blending when using visbroken heavy fuel and gasoil or other paraffinic blending stocks. The asphaltene sediment formation is a function of time and temperature (excluding external influences), and an unstable fuel will only reach its final sediment formation after a certain storage time. The sediment present in a sample of heavy fuel at a particular moment is given by the total sediment by hot filtration test, but there is no certainty that this figure corresponds to the condition of the bulk of the fuel at that same time. The total sediment aged test shows the total amount of sediment that can be formed under normal storage conditions, excluding external influences. The prescribed test method is ISO 10307-2 (IP 390+375 is equivalent). Either of the standard procedures for aging in ISO 10307-2 can be used: accelerated total sediment (TSA) or potential total sediment test (TSP). In the event of a dispute, the referee method (TSP) shall be used.

The test method originally used in the industry for determining the total sediment was the Shell Hot Filtration Test. The test results can be existing sediment or potential sediment, depending on the aging procedure. The results of this test are not equivalent to those of ISO 10307-2, due to a difference in the solvent used for the test. The Shell Hot Filtration Test with aging generally gives slightly higher results.

Viscosity:

Kinematic viscosity is the only accepted method, expressed as mm²/s at a certain temperature (note: 1 mm²/s = 1 cSt). SSU, SSF and RW1 (Saybolt Seconds Universal, Saybolt Seconds Furol and Redwood No. 1) are obsolete units.

3. Test specifications and precision

ISO 8217:2017 and earlier editions not only specify the requirements for marine distillate and residual fuels and the test method references, it also lists ISO 4259, "Petroleum products — determination and application of precision data in relation to methods of test".

The application of precision data in relation to methods of test automatically assumes that acquiring the sample was performed to the best industry standard possible, and that

the sample is representative for the supply. Experience shows that the sample itself is often the weakest point in the chain. Chevron recognizes only the bunker fuel retain samples taken by its representative (for example, bunker barge attendant) at the moment of bunkering as valid.

Should a dispute arise due to a difference between test data obtained on valid retain samples by two different laboratories (one acting on behalf of the supplier, the other on behalf of the customer), ISO 4259 should be used to evaluate the validity of the results. If the reproducibility of the test method is met, both values are considered acceptable, and the average of the two is taken as the true value. If the reproducibility is not met, both results have to be rejected, and the guidelines set forth in ISO 4259 should be followed to solve the problem. This can be very time-consuming, and is very seldom done in practice. Both parties generally agree to the use of a third laboratory, the result of which will then be binding for both parties.

The testing margin, however, has an effect on a single result; for example, the analysis result of a certain specification test obtained by the end user. If the end user has no other information on the true value of the characteristic than a single test result, the end user shall consider the product to fail the specification only when the result exceeds the specification limit by more than 0.59R in case of an upper limit (where R is reproducibility of the test method), or is more than 0.59R lower than the specification limit in case of a lower limit.

The significance of reproducibility should not be underestimated. It is the basis for all quality control against specifications. Without reproducibility data, test results would lose a major part of their significance, since there would be no way to define how close a test result approaches the true value.

[Appendix II](#) contains the methods for marine fuel testing listed in ISO 8217:2017, together with reproducibility. Whenever national standardization methods of testing are used, the full correspondence with the ISO prescribed method has to be checked. There can also be some differences in the precision data.

4. Onboard fuel oil treatment

In the late 1970s, the increasing market demand for distillate fuels (gasoline, diesel) and the resulting changes in refinery processes to cope with this demand, resulted in a deterioration of heavy fuel quality. Efficient fuel treatment (settling, centrifuging, filtration) of heavy fuel oil is mandatory to achieve reliable and economical operation of diesel engines burning heavy fuel.

Examples:

- Water is a common contaminant in fuel oil. Along with water content in the fuel oil due to transport, there can be a further contamination in the storage tank due to water condensation as a result of temperature changes.

- Catalyst fines from aluminum silicate catalyst used in the catalytic cracking process may end up in the heavy fuel and need to be removed to avoid abrasive wear of various engine parts.

Fuel from the storage tank is pumped to the settling tank and contaminants (water, solids) sink to the bottom of the tank under influence of gravity (g). The rate of separation by gravity, V_g , is defined by Stokes law:

$$V_g = [d^2 (D_2 - D_1) / 18 \eta] g$$

- d: particle diameter
- D_2 : particle density
- D_1 : density of the fuel oil
- η : viscosity of the fuel oil
- g: gravitational acceleration

Complete separation in a reasonable period of time can only be achieved by mechanically generated centrifugal force. Fuel from the settling tank is fed to a centrifugal system or purifier and water and solids are separated out of the fuel. The rate of separation in a centrifugal field (V) is defined as:

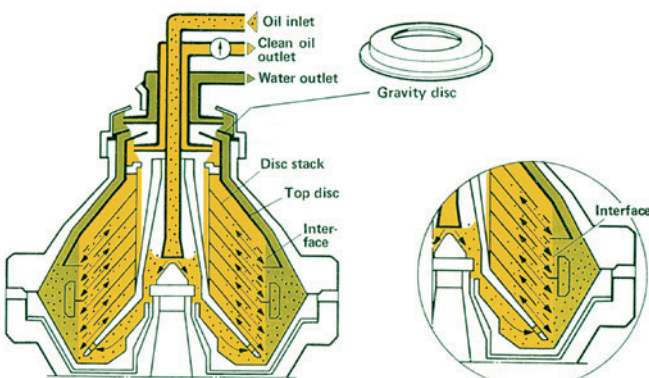
$$V = V_g \times Z$$

Where Z equals $r \omega^2 / g$ (r = distance of the particle from the axis of rotation, ω is the angular velocity). The factor Z specifies how much greater the sedimentation rate is in the centrifugal field compared to the gravitational field.

4a. Conventional cleaning with purifiers/clarifiers

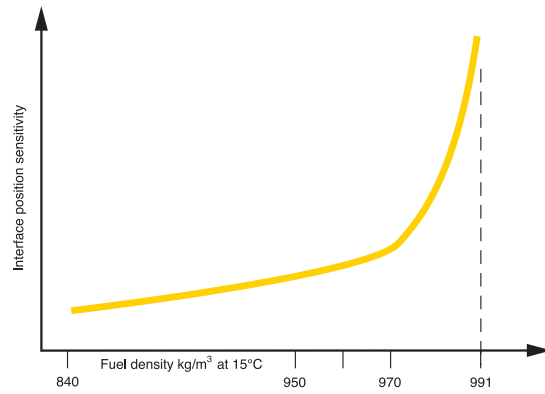
The increasing difference in density between water and fuel oil with increasing temperature is the basis for centrifugal cleaning (purification).

In a purifier separator, cleaned oil and separated water are continuously discharged during operation. An interface is formed in the bowl between the water and the oil (see Figure 1). This interface position is affected by several factors, such as density and viscosity of the fuel oil, temperature and flow rate. Figure 2 illustrates that the position of the interface becomes progressively more sensitive with increasing fuel density. The generally accepted maximum density limit for a conventional purifier is 991 kg/m^3 (at 15°C).



(Source: Alfa Laval)

Figure 1: Correct interface position — Oil distributed to all channels in the disc stack



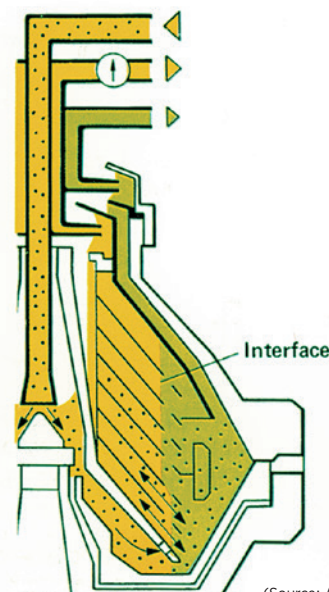
(Source: Alfa Laval)

Figure 2: Interface position sensitivity

In order to achieve optimum separation results with purifiers, the interface between oil and water in the bowl must be outside the disc stack but at the inside of the outer edge of the top disc (detailed view in Figure 1). The position of the interface is affected mainly by the density and the viscosity of the fuel oil and is adjusted by means of gravity discs. The correct gravity disc is defined as the largest disc that does not cause a broken water seal. With the correct interface position, the oil feed can enter the narrow channels of the disc stack along its entire height. This is important since separation takes place in these channels.

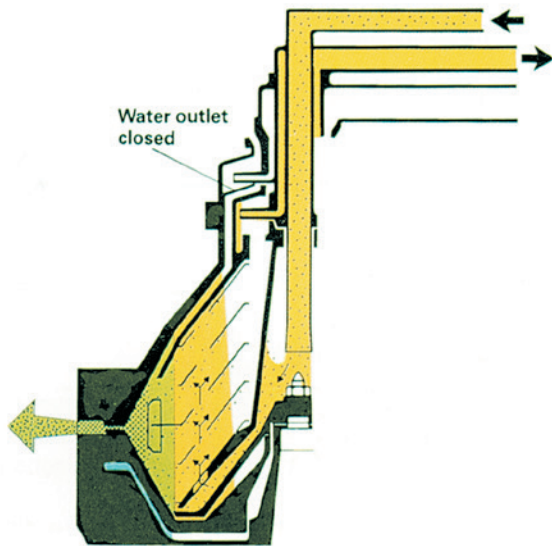
For fuel oils with a viscosity above $180 \text{ mm}^2/\text{s}$ at 50°C , it is recommended that the highest possible temperature (98°C) be maintained. The fuel oil has to remain in the centrifuge bowl for as long as possible by adjusting the flow rates through the centrifuge so that it corresponds to the amount of fuel required by the engine.

If the interface is in an incorrect position (see Figure 3), the oil to be cleaned will pass through only the lower part of the disc stack, since the upper part is blocked with water.



(Source: Alfa Laval)

Figure 3: Incorrect interface position



(Source: Alfa Laval)

Figure 4: Conventional clarifier

Thus, separation is inefficient because only part of the disc stack is being used.

To ensure optimal cleaning of a fuel oil, a second separator can be used in series operation, for example, a purifier followed by a clarifier. The density limit of 991 kg/m^3 is not applicable to clarifier operation, but the combined system of purifier and clarifier in series remains restricted to a maximum density of 991 kg/m^3 at 15°C . Heavy movements of the vessel can stir up dirt, water and sludge that have accumulated over time on the bottom of the bunker and settling tanks. Efficient purification is not always possible when separators have been put in a parallel purifying function.

In a conventional clarifier (see Figure 4), the water outlet is closed off and the separated water can only be discharged with the sludge through the sludge ports at the bowl periphery. A sludge discharge causes turbulence in the bowl and leads to less efficient separation. Consequently, the water handling capability of a conventional clarifier is insufficient for the cleaning of fuel oil if the fuel oil has a significant amount of water. (The prior use of a purifier with its continuous water removal is mandatory.)

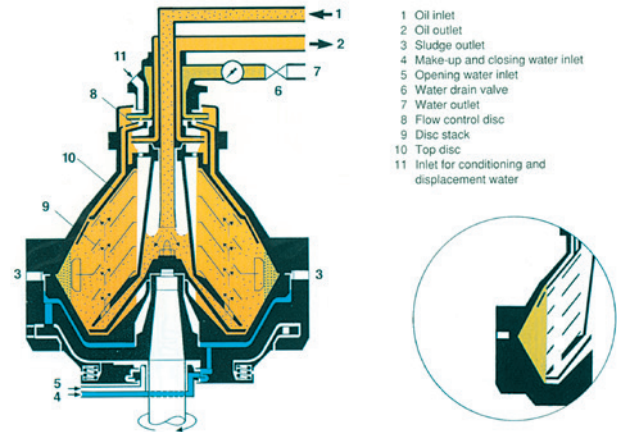
4b. Advanced computer driven fuel cleaning systems

Example: ALCAP

Fuel oils with densities above 991 kg/m^3 at 15°C are available on the market and can be purified, for example, with the ALCAP system, which allows fuel oil densities up to 1010 kg/m^3 at 15°C . Fuel oil is continuously fed to the separator. The oil flow is not interrupted when sludge is discharged.

The ALCAP basically operates as a clarifier. Clean oil is continuously discharged from the clean oil outlet. Separated sludge and water accumulate at the periphery of the bowl. Sludge (and water) is discharged after a pre-set time. If separated water approaches the disc stack

(before the pre-set time interval between two sludge discharges is reached), some droplets of water start to escape with the cleaned oil. A water transducer, installed in the clean oil outlet, immediately senses the small increase of the water content in the clean oil. A signal from the water transducer is transmitted to a control unit and changes in water content are measured.

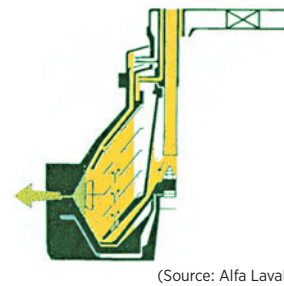


(Source: Alfa Laval)

Figure 5: ALCAP separator

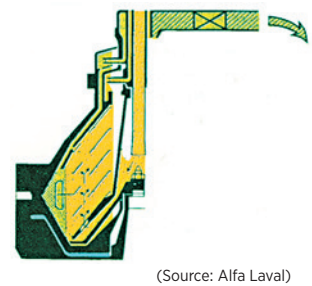
Increased water content in the cleaned oil is the sign of reduced separation efficiency for not only water, but for the removal of solid particles, as well. When the water content in the cleaned oil reaches the pre-set trigger point, the control unit will initiate an automatic discharge of the water that has accumulated in the bowl through the water drain valve.

In summary, water is discharged either with the sludge at the periphery of the bowl (Figure 6a): separated water does not reach the disc stack in the pre-set time between sludge discharges, or through the water drain valve (Figure 6b): separated water reaches the disc stack before the pre-set time between sludge discharges.



(Source: Alfa Laval)

Figure 6a: Discharge of separated water through sludge outlet



(Source: Alfa Laval)

Figure 6b: Discharge of separated water through water drain valve

5. Fuel oil stability, compatibility, stability reserve

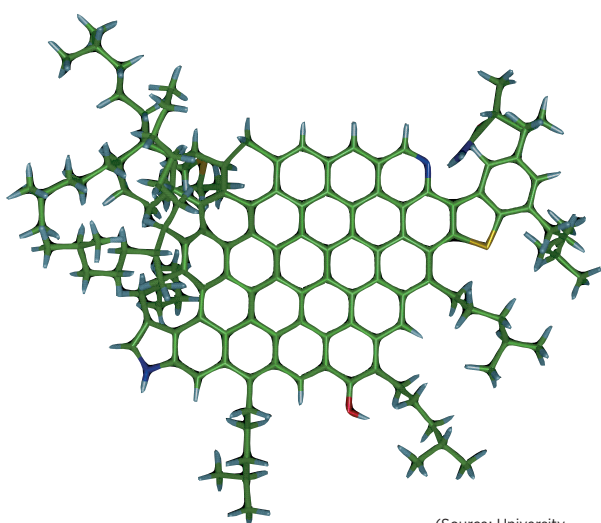
The stability of a residual fuel is defined by its resistance to precipitate asphaltenic sludge despite being subjected to forces, such as thermal and aging stresses, while handled and stored under normal operating conditions.

Compatibility is defined as the ability of two or more fuels to be commingled at a defined ratio without evidence of material separation, e.g., sludge formation.

Stability reserve is defined as the ability of an oil to maintain asphaltenes colloiddally dispersed and to prevent flocculation of the asphaltenes.

Total sediment aged is an important specification for heavy fuels. Currently, nearly all heavy fuel is marketed with the stability guarantee of maximum total sediment aged (ISO 10307-2) 0.10%. Stratification in heavy fuel oil tanks is minimal when this specification is met.

The reason for the specification requirement is the presence of asphaltenes in the fuel. Asphaltenes are present in crude oil, and are defined as the fraction insoluble in n-heptane, but soluble in toluene. Their concentration in the crude oil is dependent on the crude oil origin itself. Asphaltenes are the highest molecular weight molecules in the crude, and contain all of the organically bound vanadium and most of the nickel found in the crude. They also contain a relatively high percentage of sulphur and nitrogen. Their hydrogen content (and hence, combustion characteristics) can be quite different from one crude to another. Asphaltenes have a predominantly aromatic structure and the C and H atoms are combined in ring structures as illustrated in Figure 7.



(Source: University Illinois-Chicago, TRL)

Figure 7: Asphaltene molecule

Asphaltenes are polar molecules, kept in colloidal suspension³ by their outer molecular structure. Thermally cracked asphaltene molecules have lost part of their outer structure (depending on the severity of the thermal cracking process), and even visbreaking, which is a relatively soft thermal cracking process, affects this outer

³ Colloidal suspension: a suspension in which gravitational forces are negligible.

molecular structure. If too much is removed, part of the asphaltenes can start agglomerating and will no longer be kept in suspension in the fuel matrix; sludge will be formed. It is the responsibility of the supplier to formulate the fuel blend in such a way that the fuel is stable and the fuel's stability reserve sufficient.

A change in the fuel matrix composition (e.g., a stable visbroken fuel blended to obtain a lower viscosity) can also affect the stability of the asphaltenes. This means that viscosity reduction of a visbroken fuel with a paraffinic-type cutterstock can make the fuel unstable. When this happens, the two fuels are said to be incompatible.

Two residual fuels with diverse compositions (for example, one an atmospheric fuel from paraffinic crude, and the other from a relatively severe visbreaker operation) can also be incompatible with each other.

When storing fuel, the potential of compatibility problems between two different residual fuels should be kept in mind.

High sulfur fuels are predominantly aromatic in nature and viscosity and density are the primary blending target for these fuels, resulting in these characteristics to be at a relatively constant level within the same fuel grade. Recently, more stringent sulphur restrictions changed the primary blending target to sulphur content. This has resulted in a wider variability in fuel blend formulations and their characteristics. This created some concern in the industry ahead of 1 January 2020. Therefore, a study (Concawe Report 11/19) was undertaken to evaluate the stability and the compatibility between marine fuels. This study showed that some fuels might exhibit a TSA well within the 0.10 mass % but when using the referee method (TSP), may exhibit a TSP exceeding 0.10 mass %. To ensure that the total sediment aged limit as specified in ISO 8217:2017, Table 2 has been met, it is recommended to use the referee test.

CIMAC, the International Council on Combustion Engines, has published a guideline on marine fuel handling in connection to stability and compatibility. This guideline aims to provide a practical and working understanding of the definition of stability and compatibility of marine fuel oils and how these two specific fuel properties may be best managed in the supply chain and on-board ships. It compliments and expands on the information given in ISO/PAS 23263:2019.

6. Commingling of fuels

Indiscriminate commingling of fuels can lead to stability problems of the final fuel due to incompatibility of the fuels used as blend components. Eventual problems/damages arising from the commingling of fuels are the responsibility of the individual who made the decision to commingle the fuels. Fuel suppliers guarantee the stability of the fuel they deliver, but cannot be held responsible for compatibility problems with another fuel.

Rules, in descending order of safety:

- Segregate and do not commingle different bunker stems.
- If commingling is unavoidable, check the compatibility of the fuels in advance, and make a final decision based on the test result.
- If a compatibility check is not possible (one component unavailable at the moment the decision has to be made), reduce the amount of one fuel to a minimum before adding the second fuel.

Note: Generally, fuels of the same viscosity grade with similar densities will be compatible.

The Joint Industry Guidance on the supply and use of 0.50% sulphur marine fuel, published in 2019, provides additional information and guidance on avoiding incompatibility issues and minimizing the risks of commingling potentially incompatible fuels.

7. Microbiological contamination

Plugging of filters on gasoil and marine distillate fuel feed lines can be caused by microbiological contamination (bacteria, fungi and yeast).

Microbiological contamination can always occur, especially if temperature conditions are favorable (between 15 and 40°C, for the most common types), and if non-dissolved water is present in the fuel.

Ideal conditions for microbiological contamination can occur in tropical and sub-tropical regions due to high air humidity combined with a high ambient temperature.

To avoid contamination, VOS, the Dutch organization that supervises the quality of gasoil delivered in the Netherlands, offers these points:

- Good water-housekeeping is essential.
- No water = no bacterial contamination.
- Fuel-producing companies, dealers, and end-users have a common responsibility: bacterial contamination can occur in each link of the chain.
- Slime, sludge, corrosion in filters, tanks and lines can be indicative for bacterial contamination.
- Consequences of bacterial contamination are filthy fuel systems, plugged fuel filters and erratic engine operation.
- What the end-user can do:
 - Make sure no water enters the gasoil
 - Check filters
 - Check bunker and day tank for water
 - Whenever necessary, drain tanks. Secure permanent connection devices at the fuel receiving site

- Have de-aerating openings which can be closed (to prevent waves entering the bunker tank)

On-site macroscopic (visual) examination offers a first screening between the contaminated and non-contaminated tanks. Possible microbiological contamination indicators are:

- Gasoil is hazy and/or contains suspended fluffy material
- Emulsion or a slimy interface layer between water and gasoil
- A turbid, badly smelling water bottom, with sludge-like deposits

Bacteria and fungi are the most important agents of microbiological contamination (yeast normally only occurs as co-contaminant). All are living cells, which multiply through cell division.

The prime contamination of fuel is almost always by aerobic bacteria and/or by fungi. Both use the n-paraffin fraction of the fuel as nutrient. Aerobic bacteria need oxygen for their metabolism and evolve at the interface between the water and the gasoil; fungi (aerobic) also attach themselves to the tank wall. When oxygen is no longer present, anaerobic bacteria start to develop. The anaerobic metabolism process generates hydrogen sulphide. Besides being a very dangerous toxin, hydrogen sulphide can also cause severe corrosion.

Anaerobic microbiological contamination should be avoided at all costs. Keep close control on the presence of microbiological contaminants in the entire fuel system, from manufacturing to end use. In regions with moderate climatic conditions, efficient water draining is often sufficient to avoid exponential growth; in sub-tropical and tropical climates, the continuous use of a biocide is often the only way to avoid problems. Biocides are also used worldwide to combat “imported” microbiological problems. Commercially available biocides have been developed to eliminate the total microbiological contamination (bacteria, fungi and yeast). There are two different types of biocides: water soluble and oil soluble. To eliminate microbiological contamination in fuel tanks, water soluble biocides are generally the most cost-effective. The treat rate can differ according to the type and severity of the contamination (and the amount of non-removable water). Water drained from tanks after a biocide treatment cannot be sent directly to a biological water purification system; the biocide has to be deactivated first.

8. Biofuels

Over the last decades, environmental concerns have resulted in both a voluntary and mandatory use of biodiesel in road diesel for passenger cars and heavy duty vehicles. Also in the marine industry, blends of

bio-derived fuels with petroleum products or bio-derived fuels are considered as potential alternative energy source as they are renewable and may result in reduction of Green House Gases (GHG) and SO_x emissions.

Biodiesel refers to esters derived from vegetable oils (e.g., palm oil, soybean oil, rapeseed oil), animal fats (e.g., tallow oil) and waste material and is often referred to as Fatty Acid Methyl Esters (FAME). The variety of different FAME products has resulted in the development of FAME specifications EN 14214 and ASTM D6751.

The practice of blending FAME in other distillate fuels makes it almost inevitable that some distillate fuels supplied in the marine market contain FAME. Because of little experience with respect to storage, handling, and treatment in a marine environment, ISO 8217:2010 took a precautionary approach and limited the FAME content in marine fuels to a *de minimis* level, which in the case of the distillate fuels (DMX, DMA, DMZ and DMB when bright and clear) was to be taken as not exceeding approximately 0.1 volume % (determined according EN 14078).

In the meantime, more experience and information on the use of distillate fuels containing biodiesel onboard ships has become available. Therefore, ISO 8217:2017 introduced additional distillate grades (DF) allowing up to 7.0 volume % FAME and has retained *de minimis* levels of FAME for DMA, DMZ, DMB and all RM grades, though *de minimis* is now taken to be a level of approximately 0.5 v %. DMX shall be free of FAME.

For residual fuels, detection of FAME is most likely the result of refinery processes or blending in a distillate cutterstock containing FAME.

Adequate controls should be in place so that fuels as delivered are compliant with the requirements of Clause 5 of the International Standard ISO 8217:2017.

Although FAME has environmental benefits, good ignition and lubricity properties, potential complications can arise in a marine environment with respect to storage, handling of distillate fuels containing FAME, such as:

- Tendency to oxidation and long-term storage issues
- Affinity to water and thereto linked risk of microbial growth
- Degraded low-temperature flow properties
- Deposition of FAME-related material on filter elements and other exposed surfaces.

CIMAC (the International Council on Combustion engines) has developed guidelines on managing distillate marine fuels containing up to 7.0 volume % FAME. Driven by the GHG reduction potential, experience is being built by the shipping sector on the use of residual fuel oil blends containing higher percentages of FAME.

9. Chemical fuel treatment

Residual fuel oils today are still an unprocessed product and as bunkered are not fit for purpose without proper treatment (settling, centrifuging, filtration) to remove or reduce contaminants that can be present in the fuel oil, such as water and catfines. Blending of marine fuel oils has become more complicated over the years as they can contain a heavier fraction of crude oil after most valuable products have been extracted, requiring aromatic cutterstocks to keep heavy aromatic molecules such as asphaltenes in solution. On the other hand, lower maximum S limits introduced on 1 January 2020 often require more paraffinic product streams to be used.

Whereas in automotive applications it is common practice to add fuel additives to distillate fuels to enhance performance aspects, and biocides are commonly used in marine distillate fuels to combat microbiological contaminations, the application of residual fuel additives in the marine and power generation sectors to improve combustion or provide other benefits is not yet widespread.

There is, however, no such single miracle product that can prevent or cure any fuel-related problem — the choice of additive should be discussed with the additive supplier as it really depends on the job to be done and can potentially be harmful if not carefully evaluated. Using residual fuel oil additives should not, however, be considered as a replacement for the onboard cleaning of the fuel oil.

The main types of residual fuel additives in the marine and power generation markets are:

- pre-combustion conditioning treatment additives (e.g., demulsifiers, dispersants, stabilizers)
- combustion improvers
- ash modifiers

The combustion phase is one of the areas where marine residual fuel oil additives can be used to advantage. A combustion improver can be organic or can include an organo-metallic compound, containing iron or other metals. The use of an iron-based component as an oxidation catalyst to accelerate the main combustion and enhance complete combustion of residual fuel oils is a proven technology.

The introduction of lower maximum sulphur limits and the variability in fuel blend formulations has increased the interest in additives to maintain the stability of VLSFOs and to minimize the risk for asphaltenes sedimentation in the event commingling of fuels is unavoidable.

Appendices

Appendix I: Crude oil refining

The purpose of crude oil refining is to convert crude and other feedstocks into saleable products. The desired products are mainly gasoline, kerosene, jet fuel, gasoil and diesel.

In order to obtain these products, crude oil is first separated into fractions by distillation, then the different fractions are further processed in order to obtain the desired characteristics and optimum yield.

The different processes used in a modern refinery are:

1. Crude oil desalting

Water and inorganic salts are removed in an electrostatic field. The main purpose of crude oil desalting is to protect the refining process units against corrosion.

2. Atmospheric distillation

Crude oil is a product with a very wide boiling range. In an atmospheric distillation column the fractions boiling below 360°C are distilled off under reflux, and, according to boiling range, recovered as naphtha, kerosene, and gasoil type stocks. Atmospheric distillation is limited to a maximum temperature of 360°C, because otherwise coking would start to occur, which is not desirable at this stage of crude oil refining.

3. Vacuum distillation

To distill off a heavier cut without exceeding the 360°C temperature limit, a second distillation is done under reduced pressure: the vacuum distillation. The distillate fraction of the vacuum distillation unit is the feedstock for a catalytic cracking unit.

4. Catalytic cracking (for example, fluidized bed catalytic cracking)

The main feedstock for a catalytic cracker is vacuum gasoil. The cracking operation breaks large molecules into smaller, lighter molecules. The process runs at high temperatures, and in the presence of the appropriate catalyst (crystalline aluminum silicate).

Atmospheric residue, with a low metal and MCR content, can also be used as catalytic cracker feed, necessitating an adjustment of the catalyst type.

The main purpose of a catalytic cracker is to produce light hydrocarbon fractions, which will increase the refinery gasoline yield.

Additional streams coming from the catalytic cracker are light cycle oil (increases the gasoil pool) and heavy cycle oil (base stock for carbon black manufacturing). Both streams are also used in heavy fuel oil blending.

5. Catalytic hydrocracking

Some refineries use catalytic hydrocracking as a supplementary operation to catalytic cracking. Catalytic hydrocracking is similar to catalytic cracking because it uses a catalyst, but the reactions take place under a high pressure of hydrogen. Hydrocracking further upgrades heavy aromatic stocks to gasoline, jet fuel and gasoil material. The heaviest aromatic fractions of a cat cracker and vacuum gasoil (VGO) are the normal feedstocks for a hydrocracker. Hydrocracking requires a very high investment, but makes the refinery yield pattern nearly independent from the crude oil feed.

6. Visbreaking

The feedstock of a visbreaker is the bottom product of the vacuum unit, which has an extremely high viscosity. In order to reduce that viscosity and to produce a marketable product, a relatively mild thermal cracking operation is performed. The amount of cracking is limited by the overruling requirement to safeguard the heavy fuel stability. The light product yield of the visbreaker (around 20%) increases the blendstock pool for gasoil.

7. Coking (delayed coking, fluid coking, flexicoking)

Coking is a very severe thermal cracking process, and completely destroys the residual fuel fraction. The yield of a coker unit is lighter-range boiling material, which ultimately goes to the blending pool for the lighter products, and coke, which is essentially solid carbon with varying amounts of impurities. The heavier distillate fraction of a coker can be used as feedstock for a hydrocracker (see item 5).

More processes are required before the end products leave a refinery. Most processes are designed to meet the technical requirements of the end products, others are needed to meet environmental limits (mainly sulphur reduction, both in the end products and in the refinery emissions).

8. Catalytic reforming and isomerization

Both processes are catalytic reforming, and are intended to upgrade low-octane naphtha fractions of the crude distillation unit into high octane components for gasoline production. The type of catalyst and the operating conditions determine if the reforming is mainly to iso-paraffins or to aromatics. The terminology “reforming” is generally used for the change to aromatics, while the change to iso-paraffins is referred to as “isomerization”. Isomerization is normally done on a lighter fraction (C5/C6), while reforming is done on the heavy naphtha fraction (C7 and heavier, up to 150°C).

9. Alkylation

This is another process intended to increase the yield of valuable gasoline blend components. Alkylation is a catalyst-steered combination reaction of low molecular weight olefins with an iso-paraffin to form higher molecular weight iso-paraffins. The feed to the alkylation unit is C3, C4 and sometimes also C5 olefins from the catalytic cracker unit and iso-butane.

10. Hydrotreating

The hydrotreating process uses hydrogen in the presence of catalyst to remove impurities from product streams, replacing these impurities by hydrogen. When hydrotreating is used to remove sulphur to meet the very low sulphur limits in the specifications of gasoline and gasoil, it is called hydro-desulphurization. The process is generally used on kerosene and gasoil fractions. Residual hydro-desulphurization is also a process, and is feasible, but not economical.

11. Merox

A merox unit is used on naphtha and kerosene streams. It is a catalytic process which is not intended to remove the sulphur from the stream, but to convert mercaptan sulphur molecules (corrosive and obnoxious smelling) into disulphide type molecules.

12. Sulphur recovery

As a result of the removal of sulphur from the refinery streams by hydrotreating, and the generation of hydrogen sulphide during cracking and coking, refinery gases contain a very high concentration of hydrogen sulphide. The simple solution to eliminate the highly toxic hydrogen sulphide is to burn it, but this then generates SO₂, which contributes to acidification problems. In order to safeguard the environment, the hydrogen sulphide is converted in refineries to elemental sulphur. This is typically accomplished by extracting the hydrogen sulphide from the refinery gas by a chemical solvent, for example, an aqueous amine solution. The rich solution is then preheated and stripped by steam. The Claus process consists of the partial combustion of the hydrogen sulphide rich gas stream (sufficient air is

introduced to combust 1/3 of the H₂S to SO₂). This SO₂ then reacts (under influence of a catalyst) with H₂S in the order of one SO₂ for two H₂S, and thus provides elemental sulphur. The tail gas of the Claus unit is still rich in SO₂, and environmental legislation can require the further clean-up of this tail gas.

Appendix II: Reproducibility (R) of marine fuel test methods

Acid number, mg KOH/g

ASTM D664

Method: inflection, volume of solvent: 60 ml:

$$R = 0.4022x^{0.8199}$$

Method: buffer, volume of solvent 60 ml:

$$R = 0.5542x^{0.9758}$$

Method: inflection, volume of solvent: 125 ml:

$$R = 0.2188x^{1.0431}$$

Method: buffer, volume of solvent 125 ml:

$$R = 0.3160x^{1.0513}$$

Where x is the average of the results being compared

Ash, mass %

ISO 6245

For ash content between 0.001 and 0.079 wt %:

$$R = 0.005$$

For ash content between 0.080 and 0.180 wt %:

$$R = 0.024$$

Ca, Zn, P, mg/kg

1. Ca

$$\text{IP 501 (ICP)} R = 0.6440x^{0.65}$$

$$\text{IP 470 (AAS)} R = 1.139x^{0.8}$$

Where x is the average of the results (mg/kg) being compared

2. Zn

$$\text{IP 501 (ICP)} R = 0.5082x^{0.7}$$

$$\text{IP 470 (AAS)} R = 0.580x^{0.75}$$

Where x is the average of the results (mg/kg) being compared

3. P

$$\text{IP 501 (ICP)} R = 1.2765x^{0.55}$$

$$\text{IP 500 (UV)} R = 1.2103x^{0.4}$$

Where x is the average of the results (mg/kg) being compared

Cat fines Al+Si, mg/kg

1. ISO 10478, IP 501

ICP detection:

$$\text{Al: } R = 0.337x$$

$$\text{Si: } R = 0.332x$$

Where x is the average of the results (mg/kg) being compared

2. IP 470

AAS detection:

$$\text{Al: } R = 0.789x^{0.67}$$

$$\text{Si: } R = 1.388x^{0.67}$$

Where x is the average of the results (mg/kg) being compared

CCAI (Calculated Carbon Aromaticity Index)

Precision (R) depends on the precision (R) of the density and viscosity of the residual fuel oil that enter into the calculation.

Cetane index (4 variable equation)

ISO 4264

Precision depends on the precision of the original density and distillation recovery temperature calculations.

Cloud Point, °C

ISO 3015

For distillate fractions: $R = 4^{\circ}\text{C}$

Density at 15°C, kg/m³

1. ISO 3675

For transparent, non viscous products:
 $R = 1.2 \text{ kg/m}^3$ or 0.0012 kg/l
 For opaque products: $R = 1.5 \text{ kg/m}^3$ or 0.0015 kg/l

2. ISO 12185

For transparent middle distillates:
 $R = 0.5 \text{ kg/m}^3$ or 0.0005 kg/l
 For crude oils and other petroleum products:
 $R = 1.5 \text{ kg/m}^3$ or 0.0015 kg/l

FAME, volume %

IP 579

Procedure A: approx. 0.05–3 volume %:
 $R = 0.0499x + 0.0231$
 Procedure B: approx. 3–20 volume %:
 $R = 0.0793x - 0.0413$
 Procedure C: approx. 20–50 volume %:
 $R = 0.0632x - 0.0036$
 Where x is the average of the results being compared

ASTM D7963

$R = 0.1465x$
 Where x is the average of the results being compared

Flash point, P.M., closed tester

ISO 2719

Procedure A (distillate fuels): $R = 0.071x$
 Where x is the average of the results (°C) being compared
 Procedure B (residual fuel oils): 6°C

H₂S, mg/kg

IP 570

Procedure A
 Distillate and residual fuels: $R = 0.4459x^{0.55}$
 Procedure B
 Residual fuels: $R = 0.5232x^{0.6}$
 Distillate fuels: $R = 0.2389x^{0.7}$
 Where x is the average of the results being compared

Kinematic viscosity, mm²/s

ISO 3104

Heavy fuels: Manual viscometers at 50°C:
 $R = 0.08461x$
 Distillate fuels: Manual viscometers at 40°C:
 $R = 0.0082(x + 1)$
 Biofuel blends: Manual viscometers at 40°C:
 $R = 0,006133(x + 1.5)$

Biofuel blends: Automated viscometers at 40°C:

$R = 0,02092$

Where x is the average of the results being compared

Lubricity, μm

ISO 12156-1

Method A (digital camera): $R = 80$

Method B (visual observation): $R = 90$

Micro carbon residue, mass %

ISO 10370

$R = X^{2/3} \times 0.2451$

Where X is the average of the results being compared

Micro carbon residue, on 10 % volume distillation residue, mass %

ISO 10370

$R = X^{0.5} \times 0.2125$

Where X is the average of the results being compared

Oxidation stability, g/m³

ISO 12205

$R = 10.6 (x/10)^{0.25}$

Where x is the average of the results being compared

Pour Point, °C

ISO 3016

$R = 6.6^{\circ}\text{C}$

Sodium, mg/kg

1. IP 501 (ICP)

$R = 1.0667x^{0.55}$

2. IP 470 (AAS)

$R = 1.303x^{0.6}$

Where x is the average of the results being compared

Sulphur, mass %

1. ISO 8754

For values $> 0.05 \text{ m/m } \%$ and $\leq 5.00 \text{ m/m } \%$:

$R = 0.0812(x + 0.15)$

for values $\geq 0.03 \text{ m/m } \%$ and $\leq 0.05 \text{ m/m } \%$:

$R = 0.1781(x + 0.05)$

Where x is the mean sulphur content

2. ISO 14596

For sulphur content in the range 0.0300–0.0499

m/m %: $R = 0.005$

For sulphur content in the range 0.05–0.0999 m/m

%: $R = 0.01$

For sulphur content in the range 0.10–0.99 m/m

%: $R = 0.02$

For sulphur content in the range 1.00–2.50 m/m

%: $R = 0.04$

Total sediment aged, mass %

ISO 10307-2

Heavy fuels: $R = 0.294 \sqrt{x}$

Distillate fuels containing heavy components:

$R = 0.174 \sqrt{x}$

Where x is the average of the test results in % (m/m)

Total sediment by hot filtration, mass %

ISO 10307-1

Heavy fuels: $R = 0.294 \sqrt{x}$

Distillate fuels containing heavy components:

$R = 0.174 \sqrt{x}$

Where x is the average of the test results in % (m/m)

Vanadium, mg/kg

1. ISO 14597

The method is applicable to products having V content in the range of 5–1000 mg/kg, although reproducibility data have only been determined up to 100 mg/kg for V.

For V content between 5–30 mg/kg:

$R = 5 \text{ mg/kg}$

For V content between 31–100 mg/kg:

$R = 10 \text{ mg/kg}$

2. IP 501

$R = 1.6799x^{0.6}$

Where x is the average of the results (mg/kg) being compared

3. IP 470

$R = 3.26x^{0.5}$

Where x is the average of the results (mg/kg) being compared

Water, volume %

1. ISO 3733

Water collected between 0.0 and 1.0 ml:

$R = 0.2 \text{ ml}$

Water collected between 1.1 and 25 ml:

$R = 0.2 \text{ ml}$ or 10% of mean, whichever is greater

2. ISO 12937

$R = X0.06877$

Where x is the average of the results being compared



Appendix III: Gas turbine fuel requirements

Most heavy-duty gas turbines operate on natural gas and distillate fuels. Gas turbines operating on natural gas require minimum fuel treatment. Distillate fuels, immediately after refining, have no or extremely low contamination levels of water, solids and trace metals. Contamination (mainly by water) during transport cannot be excluded, and centrifuging is the best method for the removal of water and solids. Sodium salts are very detrimental for gas turbines, and seawater contamination must be completely removed.

Gas turbine manufacturers have also developed efficient technologies for gas turbine operation with ash forming fuels (for example, heavy fuels), as a cost-effective option instead of gasoil for sites where natural gas will not be available in the foreseeable future.

The use of heavy fuels requires that attention be paid to two types of potential hot path corrosion:

- Sulphidation corrosion, caused by alkaline sulphates (mainly Na_2SO_4)
- Vanadic corrosion, caused by low melting vanadium oxides (V_2O_5)

Sulphidation corrosion is avoided by removing the sodium and potassium from the fuel by stringent water washing up to the level $\text{Na} + \text{K} < 1 \text{ mg/kg}$. Vanadic corrosion is counteracted by the addition of magnesium additives to the fuel from the moment $\text{V} > 0.5 \text{ mg/kg}$. The complex oxides between Mg and V which are then formed, are no longer corrosive (traditionally, a m/m ratio Mg/V of three is adhered to).

Heavy-duty gas turbines have been operating satisfactorily on ash-forming fuels since the mid-1980s. It is clear that the need to use magnesium-based additives to combat vanadic corrosion imposes a technical and economical upper limit on the vanadium content of the fuel.

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