04 | 2024

CIMAC Guideline

Marine-fuels containing FAME;
A guideline for shipowners & operators

CIMAC WG 7 Fuels

This publication is for guidance and gives an overview regarding the composition and properties of marine fuels containing FAME and the due diligence needed to use such fuels, onboard. Sections 5.5.2 and 5.5.5 were written in collaboration with CIMAC WG 5 Emissions. The publication and its contents have been provided for informational purposes only and is not advice on or a recommendation of any of the matters described herein. CIMAC makes no representations or warranties express or implied, regarding the accuracy, adequacy, reasonableness or completeness of the information, assumptions or analysis contained herein or in any supplemental materials, and CIMAC accepts no liability in connection therewith.

The first edition of this CIMAC Guideline / Position Paper was approved by the members of the CIMAC WG 7 “Fuels” at its meeting in April 2024.

Content

1. Introduction

Since the Paris Climate agreement in 2015, many industries have started the decarbonisation journey, with major steps taken to achieve the ambitions set out. Shipping was initially excluded from the agreement, nevertheless voluntary initiatives have been undertaken and now additional regulations have been agreed in order to reach current climate ambitions, which are to achieve net zero Greenhouse gas (GHG) emissions in 2050.

One of the most readily available ways to decarbonise shipping is the use of biomass derived fuels. The current amount of available biofuel is not sufficient to reach the targets set. It is however a first step and additional technical innovation, and investment will increase the uptake of this decarbonisation pathway. The development of biofuels is therefore ongoing, and more differentiation is expected in the biomass used, processing and resulting qualities. ISO has published a new version of the ISO 8217 Specifications of marine fuels standard and to support this transition it now allows the use of FAME up to a concentration of 100% in specific grades.

FAME has been used in road transportation for many years and vast experience is available. However, its adoption within the maritime industry requires specific attention to be given to the handling of these products. When these requirements are met the use onboard ships has been successful.

This document serves as a guideline for shipowners and operators to safely use biofuels in conjunction with the publication of ISO 8217:2024. It is mainly focused on Fatty Acid Methyl Esters (FAME) and blends with fossil fuel.[1]

2. Definitions

FAME - Fatty acid methyl ester, ester derived by transesterification or esterification process of fats and vegetable oils used as a fuel, commonly referred to as biodiesel.

Oxidation stability - Resistance of a fuel to react with oxygen, thereby changing its chemical properties.

Drop-in - A substitute fuel type or blend which can be used without changes to the engine and/or treatment systems. (e.g. as a direct replacement of)

Fossil fuel - Fossil energy sources, including oil, coal, and natural gas, being non-renewable resources that formed when prehistoric plants and animals died and were gradually buried by layers of rock.

Very Low Sulfur Fuel Oil (VLSFO) - Marine fuel with a maximum sulfur content of 0,50 % by mass

Ultra Low Sulfur Fuel Oil (ULSFO) - Marine fuel with a maximum sulfur content of 0,10 % by mass

High Sulfur Fuel Oil (HSFO) - Marine fuel with a sulfur content exceeding 0,50 % by mass

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[1] Since the use of Hydrotreated Vegetable Oil (HVO) is already allowed in earlier versions of ISO 8217 and is considered a direct drop-in fuel for gasoil, this document will not include guidelines for the use of this type of biofuel.

Bio-residual marine fuel (RF) - Blend of a fossil residual marine fuel with bio-based liquid fuel

Bio-distillate marine fuel (DF) - Blend of a fossil distillate marine fuel with bio-based liquid fuel

Synthetic hydrocarbons - Liquid hydrocarbons obtained from syngas, a mixture of carbon monoxide and hydrogen, in which the syngas was derived from gasification of solid feedstocks such as coal, or biomass, or by reforming of natural gas.

Renewable hydrocarbons - Liquid hydrocarbons produced from renewable resources, e.g. biomass

MGO - Marine Gas Oil which is predominantly a distillate marine fuel.

ISO - International Standardization Organization.

ASTM - American Society for Testing and Materials

SOLAS - International Convention for the Safety of Life at Sea

IMO - International Maritime Organization.

MEPC - Marine Environment Protection Committee

NOx - Collective term for NO and NO_2

SCIC - Singapore Chemical Industry Council

WA - Working Agreement

3. Sustainability aspects

"Biomass used in food, feed, chemical and energy markets should be produced in a sustainable way. This means that the production of biomass should follow best environmental, social, and economic practices. Areas, which are biodiverse or rich in carbon, which serve the protection of threatened or vulnerable species, or which are of other ecological or cultural importance, need to be protected and should not be degraded or destroyed for biomass production." [2]

Biofuels used should be certified to an International Sustainability Standard, which is preferably endorsed by a legislative party, via the issuing of either a Proof of Sustainability Certificate (POS) or a Sustainability Statement linked to this document.[3] Such a document warrants that the product is produced from biomass obtained in a sustainable manner. It also includes the GHG footprint from production to use.

The sustainability requirements for marine applications are under development and may differ from one geographical location and legislative body to another.

[2] International Sustainability & Carbon Certification (ISCC) Principles section 2

[3] A sustainability Statement can only be made by an independent party.

4. FAME

FAME, Fatty Acid Methyl Ester is produced from fats and oils of biogenic feedstock such as recycled/used cooking oil, plant oils (palm, rapeseed etc.) and animal fats mostly by transesterification. It is possible to produce high-quality FAME, meeting the relevant specification, regardless of the feedstock by controlling and managing the production process.

The general transesterification process is described below.

4.1 Transesterification process

Triglycerides within the biogenic feedstock are transformed into FAME, often called biodiesel, through transesterification (Figure 1). The triglycerides react with alcohol (methanol) to produce esters when using a catalyst, which is typically sodium or potassium hydroxide. The by-product is glycerol (glycerine).

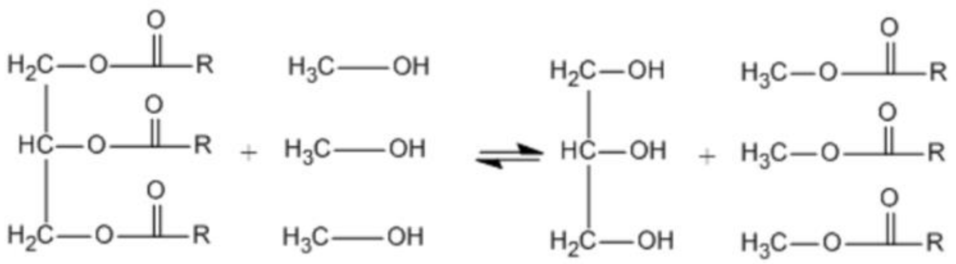


Figure 1. The transesterification process of triglyceride with methanol to glycerol and methyl esters. (*R = alkyl chain of fatty acid)*

4.2 FAME specifications

EN 14214 – is the European standard defining the quality of FAME for 100% use as a fuel in diesel engines, heating applications and as a blending component together with road diesel meeting the EN 590 road diesel standard. The EN 14214 standard is very specific on the requirements of the FAME. It describes the minimum FAME content (96,5%) and the maximum allowance for several other components related to the FAME production such as mono-, di- and triglycerides. It is the result of several years of FAME use in the European automotive sector and is still undergoing changes, tightening the requirements to ensure trouble-free use.

ASTM D6751 – is the US standard defining the quality of FAME used either as a B100 or as a blend component.

Both standards ensure the quality of FAME for automotive purposes however there are some differences in their approach, the main one being that FAME content is not defined within the ASTM D6751, where instead, section 4.1 describes the biofuel to be mono alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, without defining a testing requirement. Additionally, the cold flow properties are defined via the so-called Cold Soak Filterability test (ASTM D7501) and not by the Cold Filter Plugging Point (CFPP) included in the additional national annexes of EN 14214. Finally, the oxidation stability requirements differ in that the test stated in ASTM D6751 takes 3 hours whilst the test in EN 14214 takes 8 hours.

In general, while both serve the same purpose, the ASTM D6751 is more defined by operational requirements whereas EN14214 has more quantitative compositional requirements.

Lastly, in the EN 14214, climate grades tables are defined using the cloud point, cold filter plugging point and total monoglycerides content. The grades and their uses are defined by national standardisation bodies accounting for seasonal and regional temperature variations to avoid cold flow problems in the automotive sector. However as maritime vessels run globally around the world and FO (fuel oil) treatment systems are designed to be run in various climate conditions, climate grades tables do not apply for FAMEs used as blending components in the marine fuels.

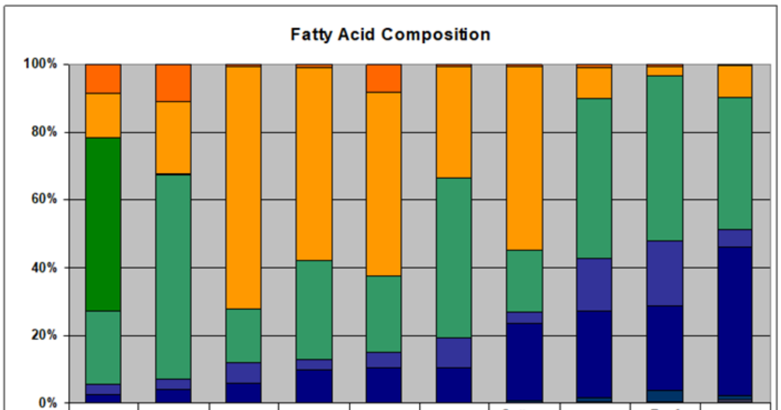
4.3 General characteristics

The composition of FAME depends on the source of the feedstock used and the extent and control of the processing, during, and after the transesterification or esterification process. The main determination of FAME quality, however, is the purification of the methyl esters upon completion of the transesterification or esterification reaction process. This will also impact the level of impurities and minor components, such as mono-, di- and triglycerides present in the finished product.

The alkyl chain length of FAME (indicated as R in Figure 1) varies from about C10 to C22. The highest proportion of sources used commercially, are from C16 to C18 chain lengths.

The main element affecting behaviour, such as cold flow properties and oxidation stability, of FAME is the amount of unsaturation (double bonds) in the chain. A mixture of fatty acids containing 0, 1, 2 and 3 or more double bonds can be present in FAME. The portion of FAME molecules with no double bonds is referred to as the saturated content.

The unsaturation level is usually indicated with a number after the carbon length e.g. C18:1 or C18(1) indicates a chain of 18 carbon atoms and one double bond present within the chain.



	Rapeseed	Canola	Sunflower	Corn	Soybean	Peanut	Cotton-seed	Lard	Beef Tallow	Palm
C18:3	8.6	11.1	0.6	1.1	8.3	0.5	0.5	1.1	0.5	0.3
C18:2	13.1	21.1	71.4	56.8	54.1	32.9	54.2	8.9	2.7	9.5
C22:1	50.9	0.5	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
C18:1	21.9	60.2	16.0	29.1	22.5	47.1	18.5	47.1	48.9	39.0
C18:0	2.8	3.1	5.9	3.1	4.7	8.9	3.1	15.8	19.2	4.9
C16:0	2.7	3.9	6.0	9.9	10.3	10.4	22.9	25.5	25.2	43.9
C14:0	0.0	0.1	0.1	0.0	0.1	0.0	0.8	1.4	3.3	1.3
C12:0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.9
C10:0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
C08:0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1

Figure 2. The distribution of carbon-chain-length between FAME produced from different feedstock / Biomass.

The higher the number of double bonds the worse the oxidation stability, two or three double bonds in the same chain will oxidise much quicker and easier than one double bond. A chain with no double bonds (saturates) has very low tendency to oxidise.

Figure 2 is an illustration of the different carbon chain lengths and the amount of saturation in various feedstocks.

For example, when we compare FAME produced from both rapeseed and peanut oil, it can be seen that rapeseed has a higher level of unsaturated carbon chains, meaning less oxidation stability.

To meet the requirements of EN 14214 or ASTM D6751, oxidation properties of FAME may need to be improved. This is achieved by treating the FAME with an antioxidant additive at the point of production since the effectiveness is much greater compared to adding it later in the supply chain. It is then considered to be part of the FAME production.

The saturated content is also linked to cold flow properties with highly saturated FAME having worse cold flow performance. Figure 3 shows the correlation between the level of saturation and the value of the cloud point (CP) and pour point (PP).

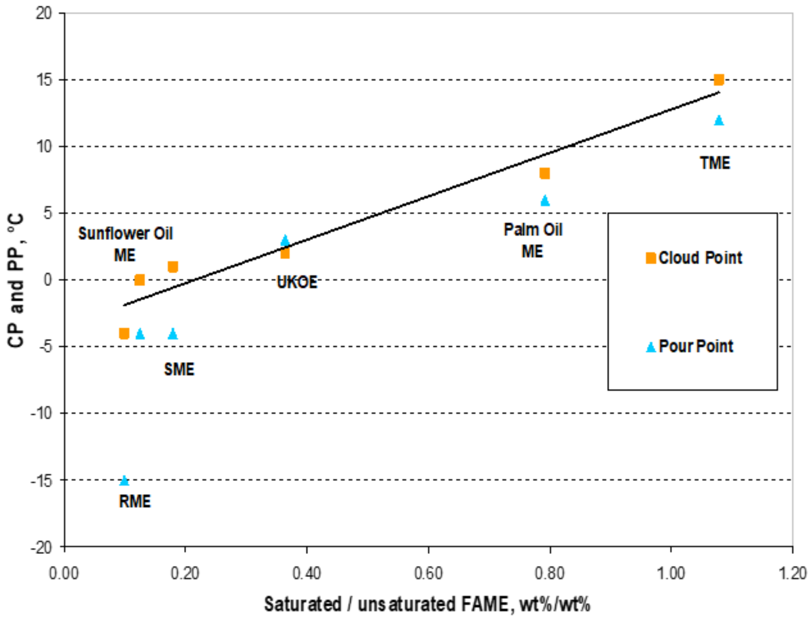


Figure 3. The correlation between saturation of a FAME with the cold flow properties, CP & PP.

As an example, comparing tallow methyl ester (TME) with rapeseed methyl ester (RME) there is a substantial difference in PP, this being 12 °C vs -15 °C, respectively.

The cold flow characteristics of FAME and FAME blends can be improved with cold flow improver additives in a similar way as distillate fossil fuels.

Another characteristic to consider, which is controlled in the EN 14214 FAME specification, is the level of impurities, like Saturated Mono Glycerides (SMG). SMG have been linked to filterability issues in automotive diesel blends and so are limited when the FAME is produced. Due to the design of FO treatment systems onboard commercial sea-going vessels, it is not expected that the marine industry will be affected by SMG content in the same manner.

Lastly, high levels of metals and salts can poison exhaust gas aftertreatment systems such as the catalyst used in Selective Catalyst Reduction (SCR) systems. Therefore, these are also limited by the FAME specification.

4.4 Specification of the finished bio-blend

The 6th edition of ISO 8217, published in 2017, defines the specifications for distillate fuels, DF grades, containing up to 7%v/v of FAME, where FAME shall meet EN 14214 or ASTM D 6751 requirements. The seventh edition of the ISO 8217 Standard, published in 2024, has been revised to accommodate the growing demand for blends containing higher volume % of FAME and inclusion of FAME into residual fuels. The FAME content is not defined and is to be agreed between buyer and seller.

When considering distillate marine fuel containing FAME, attention should be paid to the cold flow properties of the blend. Normally gasoil systems onboard seagoing vessels have limited or no heating capabilities. Therefore, it is advised to make sure that the fuel is suitable for the intended voyage and ship design. The new standard therefore includes the requirement to report Cloud Point (CP) and Cold Filter Plugging Point (CFPP) for bio-distillate marine blends.

Another important property is the oxidation stability. Oxidation stability was already included in the previous edition of the ISO 8217, however due to the inclusion of higher percentages of FAME the required testing method for DF grades is now EN15751, a rapid oxidation test method.

The Cetane Index (CI) which is used for fossil distillates does not apply to distillates containing FAME, therefore the Cetane Number (CN) has been included in the specification as a substitute.

The newest edition of the standard also accommodates bio-residual fuel blends where the final blend shall comply with the requirements as stated in Table 3 of ISO 8217. Similarly, for bio-distillates it is required that the FAME used is meeting EN 14214 or ASTM D 6751.

For residual fuels containing FAME, the final viscosity of the blend needs to be considered as the bio-component has a relatively low viscosity. Blending at high ratios with a conventional fuel oil will result in a considerably lower viscosities, therefore the grades included in Table 3 of ISO 8217 have a minimum viscosity requirement.

Previously there was no requirement to test FAME content in residual fuels streams. In the newest edition, this can either be measured by the supplier, or the blend ratio can be reported.

FAME has good combustion properties however the energy density is somewhat lower than that of fossil fuels. As such, the Lower Heating Value (LHV) has to be measured using ASTM D240 and reported when FAME is included in either distillate or residual blends.

5 Operational considerations

FAME has been used in the automotive industry since around 2004. Since then, vast experience has been gained on the production, blending and use of fuels containing FAME and specifications for FAME have been developed, such as EN 14214 and ASTM D6751. Initially there were some issues with the use in the automotive sector, primarily filter clogging due to inadequate purification of the methyl esters during production, and issues with the cold flow properties, which have mostly been resolved by updating the housekeeping rules and improvements in the FAME specifications.

Today in Europe, most automotive diesel contains FAME in some percentage due to legislative requirements.

For the maritime industry, FAME is an attractive option for immediate means to reduce its CO2 footprint. The experience gained by other industries serves as a stepping stone to facilitate easy adaptation in shipping.

When starting to use a FAME in the maritime environment additional requirements need to be taken into consideration. These include amongst others, longer storage periods, influence of (sea)water, changing ambient conditions during a voyage, material compatibility, the treatment systems onboard and the fact that the FAME can be blended with different fuel types. These factors will be addressed in the chapters below.

All industry best practices in fuel management should be applied. In fact, the same principles applied with the implementation of VLSFO's in 2020, should be applied in the use of fuels containing FAME.

Mixing/comingling of different fuel batches should be avoided.

More recently, through trials, the use of FAME blends in different ratios in both distillate and residual fuel (including 100% FAME) have been successfully demonstrated. The challenges experienced have been limited and will be further reduced significantly when the following recommendations are taken into consideration.

5.1 Preparation required before use

Prior to using FAME blends for the first time, it needs to be ensured that all systems onboard are compatible with the use of FAME, especially in reference to the sealing materials and metals in contact with the fuel (see 5.2) where the percentage of FAME needs to be considered.

Original Equipment Manufacturer (OEM) of the ship's equipment will be able to confirm compatibility of a specific piece of machinery and provide operational advice. This should include but is not limited to, main and auxiliary engine, emergency generator, filter units, separators, boilers, gaskets, and piping system materials. Normally the materials used in the high-pressure system of engines are compatible with FAME and fuels containing FAME.

FAME is a good solvent and therefore can have a negative effect on certain coatings, such as paint. Therefore, compatibility of the FAME with all coatings and paint it will be in contact with, should be a part of any evaluation.

Flag Administration and Class should be contacted, in order to be advised on any technical and statutory requirements and changes thereof in the use of biofuels.

For first-time use a risk assessment should be completed. Adequate actions to mitigate the identified potential risks need to be taken and communicated within the technical organization and shared with the vessel crew. The crew further needs to be informed and instructed in the use of FAME blends and any subsequent additional requirements.

5.2 Materials compatibility

FAME tends to react with materials more readily than diesel fuel and this may lead to material compatibility problems. FAME can damage or degrade certain plastics, elastomers, and metals.

FAME may not be compatible with materials present in the fuel system, the severity of which depends on the concentration of FAME in the fuel. Table 1 can be used when evaluating the compatibility of materials within the fuel system with FAME.

Table 1 Compatibility recommendation between materials and FAME.

Material	Recommended	Not recommended
Metals	Carbon Steel Stainless Steel Aluminium	Brass Bronze Copper Lead Tin Zinc
Elastomers	Flurocarbon Nylon Teflon Viton	Nitrile rubber Neoprene Chloroprene Natural rubber Hypalon Styrene-Butadiene rubber Butadine rubber
Polymers	Carbon filled acetal	Polyethylene Polypropylene Polyurethane Polyvinchloride
Others	Fibreglass	

Prior to use, one should check with the individual OEMs on engine and other fuel supply and treatment systems.

5.3 Storage tanks

When loading a fuel containing FAME for the first time it should be ensured that the tanks are stripped in advance.

The content of the settling and service tank(s) should be reduced to an absolute minimum, as far as is practically possible with regards to safe operations, prior to putting the batch of biofuel into use.

FAME has a tendency to disperse dirt as a result of its higher solvency power. This can lead to more frequent separator and filter cleaning, particularly at the beginning of the initial use of the fuel. It should be ensured that the tanks do not contain large portions of residues from use of previous fuel batches. No major issues have been reported from trials conducted to date, other than the earlier mentioned increased frequency of filter cleaning at the start of use, which will disappear over time.

It is important to ensure that no free water is building up over time at the bottom of storage tanks. The presence of FAME (in the fuel), in combination with free water, can have an impact on both the quality of the fuel and also on the integrity of the tank in which it is stored. Free water may lead to increased acidity and hence increased corrosion, especially in bio-distillate fuels where the presence of water can lead to microbiological growth.

Keep the tanks as full as possible when storing fuel for longer periods, as there will always be some condensation in the tanks and the less area there is for water to gather, the less water will enter the fuel.

When preparing for the use of FAME or fuels containing FAME, check the tanks for leaks from the heating coils. Also check for water intrusion from other tanks, e.g. ballast tanks and cargo tanks, or from outside via cracks in the hull.

If there is no possibility of drainage, a small separator should ideally be installed to remove the water.

Thermal and oxidation stability need to be considered when handling FAME and products containing FAME. Excessive heating should be avoided. Thermal and oxidation reactions can lead to the formation of sediments and gum-like materials causing filters to clog and can also lead to increased acidity. To avoid this from happening prolonged storage should be avoided by consuming the biofuel within a reasonable timeframe and applying the first-in – first-out (FI/FO) method. Retesting the fuel should be considered when fuel is stored for longer than six months.

FAME has a tendency to react with certain coatings such as paint. It should therefore be verified whether the tank coating, if present, is compatible with FAME. The same might apply to the seals used, for example the manhole cover gasket material, see 5.2.

FAME also has a lower calorific value compared to fossil fuel, see 5.5.1. The higher the FAME content in the blend the more fuel is required to obtain the same energy content to complete the same voyage. When using B100 FAME, this may increase to up to 13% more fuel being required. This will need to be considered when ordering fuel to avoid running short.

5.4 Fuel treatment system.

As earlier discussed, the chemical composition and profile of FAME determines parameters such as cold flow properties and oxidation stability. This in combination with the solvency power of FAME can increases the risk of the formation of sludge and more frequent need for fuel cleaning, especially when initially using the fuel and when residues from previous batches of fuel remain in the storage tanks and fuel lines. As a result, FAME and fuels containing FAME, require careful management onboard and control over the fuel cleaning and separation process.

When starting to use FAME or fuel containing FAME for the first time, dirt which has built up over a period of time in the fuel system may get dispersed into the fuel and could cause additional load on the separation process and/or cause filter clogging. It is therefore good practice to ensure there are sufficient spares to handle the potential decreased overhaul intervals and that the crew is alerted to monitor this closely. Proper fuel management, following guidelines and housekeeping is of outmost importance to minimize risk of problems.

FAME and fuel containing FAME tend to have a lower viscosity than 100% fossil residual fuels. This calls for careful temperature management across the fuel treatment system, including the separation process.

Consideration should be given to the cold flow properties of the fuel to be used. Fuel oil systems which are designed for residual fuels will have heating which can be utilized to remedy poor cold flow properties. However, distillate systems are normally designed without heating, thus closely controlling storage temperatures is impossible and understanding the impact of cold flow properties of FAME is paramount to avoid blocked fuel systems due to wax formation. This should be taken into consideration when such fuels are ordered. FAME compared to regular fossil distillates does not have a defined pour point (PP) in the FAME specification. For this reason, it is a requirement in Table 1 of ISO 8217:2024 to report PP, cold filter plugging point (CFPP) and cloud point (CP) for the finished distillate grade, including 100% FAME as a distillate. Operators are advised to have a proper evaluation of the cold flow properties (PP, CFPP and CP) and the geographical operational area of the vessel, with regards to expected ambient temperatures and impact on the fuel.

5.4.1Separator settings

When operating with Fuels containing FAME it is important to ensure that the fuel cleaning system settings match the properties of the specific fuel in use. The fuel characteristics such as density need to be considered for efficient water removal and optimal separation performance.

Variation in density of the fuel cleaned via conventional separators is managed with the gravity-disc. Prior to the start of use it needs to be ensured that the correct gravity disc is installed for the density of the fuel to be used.

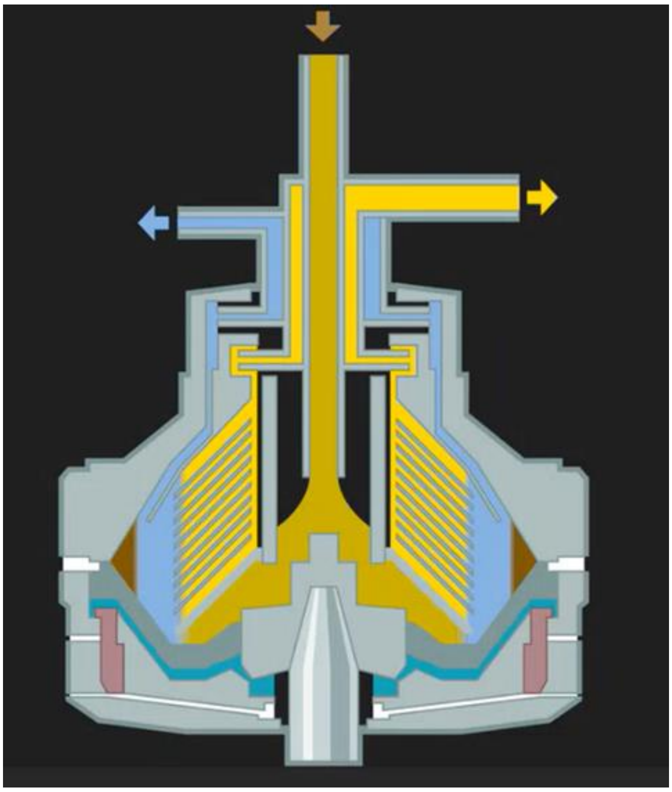


Figure 4 Illustration of a separator bowl. Fuel is cleaned and separated into a light phase, marked in yellow, and a heavy/water phase, marked in blue.

Automatic separators, such as Alfa Laval ALCAP™ systems or GEA Westfalia Unitrolplus™ systems handle density variations including densities above 991,0 kg/m^3 efficiently via automated control systems. These systems automatically control the interface between water and oil in the separator (Figure 4). For some makers, due to the inclusion of FAME, the density and the relative permittivity of the fuel may be beyond the design criteria for the software and an update may be required to ensure proper functioning. It is recommended that the OEM is consulted.

If lower densities are not properly managed, either by the installation of the correct gravity disc or automatically, the lighter fuel inside the separator may cause the interface to be in the wrong place within the separator. This will lead to poor separation since the interface between water and oil needs to be just outside of the plate package for the separator to work efficiently and effectively.

There are, however, automatic separators and operational modes which work to a slightly different principle, where the separator is working in a clarifier mode. In this instance, only the water present in the fuel to be cleaned is removed, so this potential issue does not occur.

FAME's chemical composition can attract and hold water content which, in turn increases the risk of microbiological growth. As such, microbial contamination should be avoided by minimising free water content.

Water intrusion in tanks and piping causes residue and microbial sludge build-up which may potentially clog filters, the separator disc stack (if the build-up arises inside the separator) and injectors.

Water should continuously and actively be removed from the storage system, and frequent water level checks are recommended. Note that microbes grow over time, which means that using the fuel as soon as possible is the best approach to prevent microbial issues. Again, overall housekeeping of any fuel system through ensuring clean tanks, continuous dewatering and control over the separation will allow a safe fuel cleaning process. The separator can remove the large amounts of impurities that may occur when processing fuels containing FAME if operated in accordance with the recommendations given by the OEM.

Water is often used to control the separation process, the function of which may differ between OEMs installations and sequence within the separation process. The addition of water to FAME and fuels containing FAME may lead to excessive soapy sludge formation. If these types of problems are noticed please contact your separator OEM for advice.

Some installations allow the process settings to be adjusted by selecting FAME or fuels containing FAME as a fuel in use in the control system. Another aspect that can have an impact on the separation process and water removal functionality is the higher relative permittivity of FAME compared to diesel oil or heavy fuel oil. For systems with automatic water detection, monitoring escaping water in the clean oil, this must be reflected in settings controlling the separation process, otherwise faulty alarms can occur. A small deviation in capacitance will trigger draining or discharge, but a larger deviation indicates an error and will result in an alarm. If these types of problems are noticed please contact your separator OEM for advice.

FAME has a lower chemical stability, compared to fossil fuel oil, being more prone to degrade over time and can form hydroperoxides, aldehydes, carboxylic acids, alcohols, and insoluble materials. This will affect the fuel's compatibility with metals, rubber parts and polymers and potentially corrode the fuel system components. Therefore, adhering to fuel management procedures as well as carrying out regular and thorough inspections, are recommended.

The experience from the industry with separation of FAME and fuels containing FAME has, so far been positive and poor performance of separation has been limited.

5.5 Engine

On a general note, engines are able to use FAME either as a blend component in the fuel or as a 100% drop-in fuel. From an operational perspective, provided that the seals in the engine are compatible with FAME, no major issues are to be expected. There are however some operational aspects to be considered as outlined below.

5.5.1 Combustion of FAME

The calorific value of a fuel is normally expressed as the Net Specific Energy (NSE). This value is used to plan the required amount of fuel needed for a planned voyage as discussed in chapter 5.3, further it is required to calculate the fuel efficiency of an engine and it may also be needed as an input in electronic engine control systems.

The NSE of FAME is significantly lower than traditional fossil fuels, average values of which are shown below:

- FAME 37 MJ/kg
- VLSFO 41.7 MJ/kg
- HSFO 40.3 MJ/kg
- MGO 42.7 MJ/kg

Whilst the calorific value of FAME is relatively constant the calorific value of fossil fuels varies more significantly. Figure 5 below, shows the variance observed on different batches of VLSFO to illustrate this phenomenon.

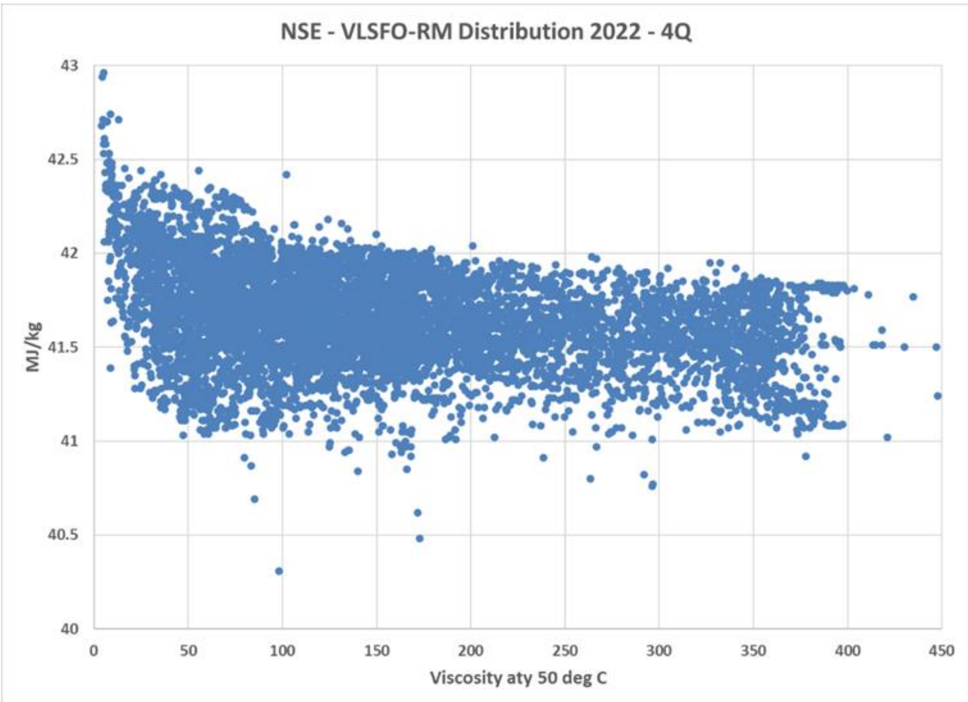


Figure 5. The variance of NSE of VLSFO.

It is common industry practice when using fossil fuels, to calculate the calorific value instead of measuring it. The energy content of fossil fuel is calculated from the certain properties of the fuel (density, water, ash, sulfur) using the equations stated in ISO 8217 (annex H: Specific Energy). The current equations for calculating NSE in ISO 8217 were developed for fossil fuels only and are not valid for FAME and blends with FAME, and therefore cannot be used in this instance. There are initiatives underway to create formulas to calculate the energy content of FAME and FAME blends but these are not finalized yet.

For an accurate determination of the NSE, ASTM D240 ("Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter") is utilised. The difference between the measured NSE and the calculated NSE in ISO 8217: 2017 can be as large as 10% (for 100% FAME). The measured NSE is the better value to be used in order to run the engine efficiently when using FAME or FAME blends, especially when optimising and monitoring the engine combustion using the (auto) tuning feature, if available in the engine control system. This is further described in section 5.5.3 engine experience.

5.5.2 SCR – TIER III aftertreatment catalyst

One option to comply with IMO Tier III requirements is the installation and use of SCR systems. IMO Tier III systems removing harmful NOx emissions from the exhaust gas by an SCR process require a catalyst for the chemical reactions. The design and the catalysts selection are based on several parameters, one of the most relevant being the type of marine fuel used. However, fuel quality varies, even within fuel specifications, and catalyst poisons as well as operating conditions will impact the catalyst lifetime.

From the automotive and heavy industrial sector, we learned that FAME, meeting the standard EN 14214 or ASTM D6751, may contain higher levels of several catalyst poisons compared to distillate fossil diesel. These include alkaline metals (e.g. Na, K), alkaline earth metals (e.g. Mg, Ca), and also elements such as phosphorus and silicon. [1] [2]

In case the SCR system is designed for non-residual fuel operation only (MGO, LNG, etc.), use of marine fuels containing FAME should be verified. As the lifetime of the catalyst may be shorter and, consequently the catalyst replacements would have to be more frequent, [3] [4] [5] it is recommended to share the FAME fuel standard and, if possible, representative fuel analyses for catalyst poisons (e.g. EN 14538, EN 16294) with the respective SCR supplier.

For SCR systems designed for residual fuel operation, which may contain some of these elements at higher levels, it is still recommended to contact your SCR supplier even though, the addition of EN 14214 or ASTM D6751 FAME to the regular fuel is not expected to have significant additional adverse impact,

In case of non-standard FAME biofuel, other bio-based fuel or recycled carbon fuels as described in Chapter 7, contacting the SCR system supplier before use of such fuels is recommended. Many suppliers have experience with various non-standard FAME biofuels and other bio-based fuels, and it has been found that some of these fuels have had a strong impact on the SCR catalyst, urging operators to contact their SCR suppliers to ensure safety of their equipment and compliance with emission regulations.

See also chapter 5.5.5 for further information on the emissions and possible effect on SCR system design.

In the event that a different catalyst would be selected to cope with FAME operation, the relevant Flag administration or on their behalf the related Classification Society, should be contacted for further consideration on possible effects on the approved NOx Technical File of the related engine.

5.5.3 Experience with two-stroke & four-stroke engines

The service experience of FAME and FAME blended with ISO 8217 compliant fuels (RM and DM-grades) on marine engines is good. There is no major difference in experience between two-stroke and four-stroke engines.

Various engine designs of two-stroke and four-stroke engines with different bore sizes have been used for the testing of FAME and blends with FAME. Vessels are mainly operating on B30 (30 % FAME + 70% VLSFO or MGO), but also on B50 up to B100.

During the last two years of use, vessel operators have generally been satisfied with the handling and operation of the engines on FAME blends, when following OEM's guidelines. The long-term impact on components is still under investigation by OEM's, however, so far no major incidents have been reported.

As mentioned earlier, FAME has a net specific energy of approximately 37 MJ/kg, which is around 10% lower than traditional marine fuels. Therefore, it is important to understand if the supply system capacity is sufficient to reach the higher load range on fuels containing FAME. This can be a challenge for the engines, which cannot automatically adjust the intended injection quantity at a given engine load to compensate for the lower calorific value of this fuel. Additionally, due to the lower calorific value, some engines may reach torque limiters due to overestimation of engine load at that actual engine speed. These effects will be most noticeable for B100 fuels.

Further, biofuels with a low calorific value and a low viscosity may be a risk factor for some of the fuel pumps and fuel injector designs.

FAME is also available for which the quality and purity is not fully in line with the EN 14214 or ASTM D6751 standard requirements. Their allowed use is evaluated on a case-by-case basis. Please see Chapter 7.

There have been instances where automotive diesel fuel was used which already contain FAME. Use of such fuels can only be permitted when the flashpoint of the blend is above the 60°C requirement as per SOLAS and Class for marine applications.

It is recommended to follow engine OEM guidelines and service letters and consult the specific OEM when needed.

In summary:

- No major handling problems or issues during fuel changeover.
- Separators have been performing satisfactorily.
- Fuel stability has been good.
- Combustion behaviour has been good.
- No reported major cylinder condition deterioration.
- Minor issues have been addressed and corrected in consultation with the OEM.

5.5.4 Lubrication

At the time of writing this document, prolonged operational experience while using FAME is limited. It is not expected that FAME will have a significant impact on the lubrication of internal combustion engines and no adverse effects have been reported.

5.5.4.1 Cylinder lubrication for two-stroke engines.

There is little difference in cylinder lubrication requirements for two-stroke engines when using fossil fuels, fuels containing FAME or 100% FAME (B100).

The recommendations should be aligned with the corresponding fossil grade when looking at the sulfur content and in line with OEM lubrication guidelines. When using FAME in a high percentage or even at 100% please be aware that the sulphur content will be very low (close to zero).

General operational recommendations

- Each OEM has their own specific lubrication recommendations, and these should be closely adhered to.
- Have a maintenance and monitoring strategy in place which should include:
    - Regular scavenge port inspections.
        - Visually check to ensure healthy cylinder condition e.g. Liners, piston, and rings have well lubricated surfaces and are in good condition.
        - Measurements, of piston ring coating thickness and ring groove clearances.
    - Drain oil sampling, analysis, and action on the result.
        - The analysis of the scrape down oil is indicative of the cylinder condition mainly through the value of the remaining base number (BN) and the iron content. The evaluation should be based on the combination of both parameters. The OEM lubrication guidelines should be consulted to ensure the engine is operating within the recommended range or whether any change to cylinder oil feed rate or type of cylinder oil used is required.
        - For applications where FAME at a high percentage or even at 100% is used, the impact on the BN of the drain oil will be much less due to the extremely low sulphur content of the FAME. The relevance of this value is therefore limited, and focus should be on the iron content.
        - For prolonged operation on FAME at a high percentage or even at 100% the OEM lubrications guidelines should be consulted as to which type of cylinder lubrication oil should be used.
- In general, a well-maintained engine will always be more efficient and better able to resist potential challenges. It is therefore important to ensure the engine is up-to date with the maintenance schedule prior starting the use of FAME.

For more detailed information please refer to:

- CIMAC Recommendation 31, the lubrication of 2-stroke Crosshead diesel engines.
- CIMAC Guideline, The causes of scuffing and actions to prevent scuffing in two-stroke engines

- CIMAC Guideline, On the Lubrication of Reciprocating Gas Engines
- CIMAC Guideline, Used engine oil analysis

5.5.4.2 System lubrication oil for two-stroke engines

A potential problem may be contamination of the system oil with fuel containing FAME. However, it is likely this will be to a lesser extent than for four-stroke application. Please see 5.5.4.3 for additional information.

It is recommended to monitor lube oil quality on a regular basis to avoid impact of the biofuel contaminating the system lubrication oil.

5.5.4.3 Lubrication for four-stroke engines

For 4-stroke applications the same lubricant is used for both cylinder and system lubrication. A potential contamination of the lubricant with fuel is therefore more likely.

In general, a contamination of the lubricant with a fuel is an issue. When lubricant is contaminated with fossil fuel this is normally detected via a decrease in the flashpoint. When FAME is used as a fuel, contamination can only be detected via a drop in viscosity, as the flashpoint of FAME is already high. A relatively high level of contamination will be required to register this decrease in viscosity. Ideally the contamination of the lubricant with FAME should be detected by testing for the presence of FAME. Unfortunately, there is currently no standardised test method to quantify FAME within a lubricant.

Biofuels can have a higher evaporation temperature than conventional diesel fuels, so those will accumulate within the lube oil.

Ingress of FAME to the engine lube oil could result in reduced oxidation stability, increased water retention and effect metals used in bearing materials.

It is recommended to monitor lube oil quality on a regular basis to avoid impact of biofuel contaminating the system lubrication oil.

5.5.5 NOx emissions / Black carbon

Depending on the composition of the biofuel, combustion properties are affected. For FAME, the higher fuel-bound oxygen content can increase NOx emissions [6]. Some studies indicate the boundaries of the NOx technical code are still respected, provided the engine is operating within the approved bounds of the NOx Technical File. [7] [8] [9] [10] IMO published a unified interpretation (UI) no. 13 "Application of regulation 18.3 for biofuel and synthetic fuel" in MEPC.1/Circ.795/Rev. 6 and revised as .7 and .8, allowing operators to use biofuels like e.g. FAME in their vessels, without having to undertake the NOx emission assessment if there are no changes to NOx critical components or settings outside of those as given by that engine's approved Technical File. This UI is applicable for all emission Tiers, and thus also covers also "NOx reducing devices", e.g. SCR and Exhaust Gas Recirculating (EGR).

Possible changes in engine emissions due to the use of biofuels may need to be considered for the NOx reducing device process equipment. With correctly designed SCR equipment (reagent pumps, air compressors, SCR reactor with elements) or EGR equipment the set NOx emission limit will be fulfilled. In order to avoid any misleading results during spot checks – if required by MEPC.291(71), the "SCR guidelines", paragraph 3.2.8.2 – for NOx reducing devices without NOx sensors-based operation it is advisable to use fuels similar to the fuels as used during test bed certification also for on-board confirmation testing.

Summaries of research studies generally indicate reductions of Black Carbon (BC) emissions when using FAME, though the extent seems to depend on the specific engine design such as bore, stroke, engine speed, Brake Mean Effective Pressure (BMEP) and possibly other parameters, not overlooking the maintenance condition and/or the loading of the engine itself [8] [11] [12].

Also, for non-standardized FAME biofuels or other biofuel types including blends, BC reductions have been reported from test beds, but more operational experience in the field is needed for further statements [9] [10].

6 ISO 8217 Bio-distillate & bio-residual marine fuel

Finished marine fuels containing bio products can be tested and evaluated in a similar manner as fossil marine fuels. Inclusion of FAME will change the properties of the final product depending on the blend ratio. For example, FAME exhibits a lower viscosity, density and heating value compared to fossil fuels.

This chapter will discuss the difference in typical characteristics between marine fuel grades, the test methods which can be applied, potential complementary test methods and the use of additives.

6.1 Characteristics of the finished products (ISO)

Table 2 compares the typical range of physical properties of marine residual fuels, distillates, bio-blends and 100% FAME. It is impossible to narrow this range at this point in time. For biofuels it will depend on the blend ratio with FAME and the fossil components used. It is therefore important that the characteristics of the bio blend are known prior to the start of use, enabling the onboard treatment systems to be adjusted accordingly. The adjustment will predominantly revolve around applying the right temperature settings (see 5.4).

Table 2. Table of typical physical properties of different fuels.

		Fossil fuel			Biofuel		
		HSFO	VLSFO	DMA	RF	DF	FAME
FAME content					1 - 99%	1 - 99%	100%
Viscosity	cSt	380 - 500	20 - 180	2 - 4	2 - 380	2 - 4	max 5
Density	kg/m3	930 - 1010	840 - 1010	max 890	860 - 1010	860 - 900	860 - 900
Sulfur	%m/m	2,60	0,46	0,0010 - 1,00	0,0010 - 3,50	0,0010 - 1,00	max 0,0010
Net energy content	MJ/kg	40	41	42	41 - 37	42 - 37	37
FAME content	%m/m	max 0,5	max 0,5	max 0,5	1 - 99	1 - 99	min 96,5
MCR	%m/m	10 -20	3 - 10	max 0,3	3 - 20	max 0,3	NA
Ash (# sulfated ash)	%m/m	0,07 - 0,15	0,07 - 0,15	0,01	0,01 - 0,15	max 0,01	max 0,02 #)
PP	°C	max 30	max 30	(-6) - 6	max 30	(-6) - 6	NA
Water	%v/v	0,5	0,5	Clear & Bright	0,5	max 500 ppm	max 500 ppm
Acid number	mgKOH/g	max 2,5	max 2,5	max 0,5	max 2,5	max 0,5	max 0,5

Figure 6 shows examples of the physical appearance of the different fuels.

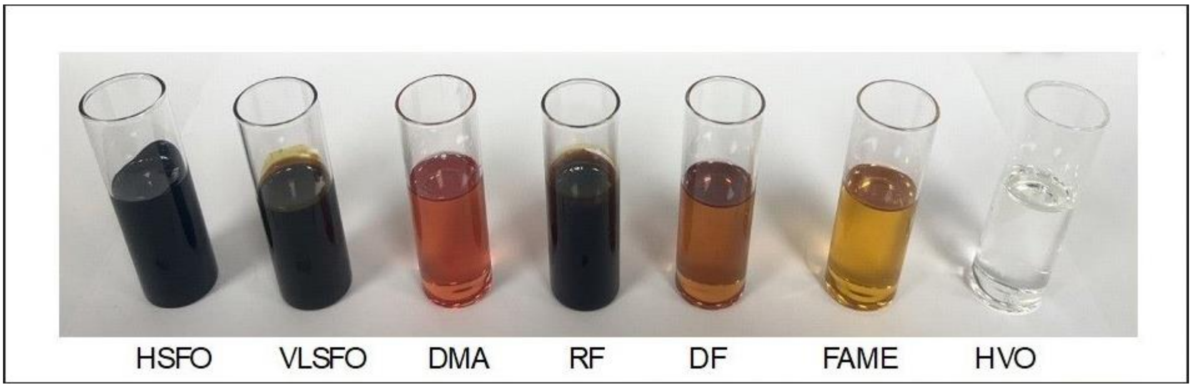


Figure 6. Examples of the physical appearance of the different fuels.

6.2 ISO 8217 Methods & additional tests

6.2.1 ISO 8217 Analysis methods

Analysis of marine fuel containing FAME should be completed in accordance with the relevant table of the most recent version of ISO 8217. It must be noted however, that at the time of publication, not all tests listed in ISO 8217 include FAME in the scope of the method. Whilst the impact of FAME is expected to be limited, the precision statement may not be applicable. Relevant ISO related test methods should be consulted for further guidance.

Below follows a description of the properties measured when performing an ISO 8217 test slate, which have additional relevance when FAME is included.

6.2.1.1 FAME content

Since FAME has been included in some of the grades in ISO 8217:2024 the percentage of FAME is of interest to the user. Whilst there is the possibility for suppliers to report FAME content based on the blend ratio, there are several methods available to determine the FAME content. The fuel type and the availability of the test equipment will determine which method is most suitable. Please note that some methods determine the FAME content on a mass basis and some on a volume basis. These are not easily interchangeable.

The two reasons for determining the FAME content are:

i) For bio-distillate and bio-residual fuels, to verify that the renewable content is in line with the FAME content of the biofuel purchased and as indicated on a proof of sustainability (PoS) document or the supplier declaration.

ii) For distillate and residual fuels, to ensure the FAME content does not exceed de-minimis levels.

Please note that there will most likely be a difference in FAME content result between the reported value on the PoS and the value when the fuel is tested. This is due to the fact that the initial FAME blended in the fuel has a variable ester content (minimum 96.5% if ordered in accordance with EN14214). Further there may be a difference in the method used on the pure FAME and for the blended biofuel which will have an influence on the result. Lastly, there may be some restrictions with each individual method which are further described below.

Therefore, a lower or higher measured ester content on the fuel received compared to the PoS does not automatically mean that a lower or higher amount of sustainable material has been received. Nevertheless, the reported measured content should be in line with the expected value.

ASTM D7963

This is a rapid screening test which uses Fourier Transform Infrared (FTIR) spectroscopy. It is the only method for determining ester content of all grades included within ISO 8217:2024 as it is the only method which can be used to measure FAME below 0.5 mass % (de-minimis level) for both distillate and residual grades. This test differs from other FTIR methods in that a preparation stage is completed whereby the fuel is filtered through a disposable sorbent cartridge which is used to strip the ester from the fuel, improving the accuracy of the method.

Accuracy: The accuracy of the test result relies on the molecular mass of FAME species ranging from C16 to C18. However, the presence of other FAME species with varying molecular masses could impact the accuracy of the results.

Interferences: The flow analysis by FTIR allows for the elimination of potential interferences by considering their relative retardance times through the sorbent along with their absorbance at particular wavelengths.

EN 14078

This method also uses FTIR but is only suitable for distillate fuels containing FAME between 0.05 volume % and 50 volume %. The method is split into three procedures depending upon the FAME content:

Method A may be used for distillate fuels containing FAME between 0.05 to 3 volume %.

Method B may be used for distillate fuels containing FAME between 3 to 20 volume %.

Method C may be used for distillate fuels containing FAME between 20 to 50 volume %.

Accuracy: This method identifies all FAME components by measuring the C=O IR absorption at approximately 1745 cm^{-1} and molecules within the C8 to C22 range. The accuracy of the measured results relies on aligning the molecular weights between the FAME used for calibration and the FAME in the analyzed sample. The presence of FAME with a lower average chain length, calibrated using FAME of longer average chain length, will lead to notable overestimation, and vice versa.

Interferences: Referring to Annex A2, further investigation is required to ascertain the impact on FAME measurement using this test method when esters besides methyl ester calibration standards are incorporated into the calibration models.

ASTM D7371

This method utilises FTIR but is only suitable for distillate fuels containing FAME in the range of 1.00 to 20 volume % so cannot be used to determine either de-minimis level of FAME or the FAME content for biofuel grades above B20.

Interferences: Other esters such as fatty acid ethyl esters (FAEE) have not been used for calibration material. Additional work is necessary to determine the effect on the measurement of FAME by this test method when esters other than methyl ester calibration standards are added to the calibration models.

IP 631

This test method is similar to ASTM D7963 in that a preparatory stage using sorbent cartridges is used prior to FTIR.

6.2.1.2 ASTM D240 (heat of combustion)

As explained in section 5.5, the specific energy calculations contained within ISO 8217 using the measured values for Sulphur, density, water, and ash, are unsuitable for marine fuels containing FAME. Instead, the heat of combustion can be measured using ASTM D240 to provide accurate combustion values.

This method involves burning a weighed sample of the test fuel in an oxygen bomb calorimeter under controlled conditions.

ASTM D240 is utilised for fuels consisting only of carbon, hydrogen, nitrogen, oxygen and sulphur so it is suitable for both distillate and residual fuel containing FAME as well as B100.

Gross heat of combustion

The gross heat of combustion (at constant volume) is calculated using the measured temperature rise (corrected), the measured energy (MJ/°C), and relevant thermochemical corrections, one of which allows for the correction for the heat of formation of sulphuric acid. To apply this correction, the mass percent of Sulphur within the sample must be known.

Net heat of combustion

The net heat of combustion is subsequently calculated using the gross heat of combustion at constant volume (MJ/kg) and the mass percent of hydrogen in the sample which is determined using a suitable method, typically ASTM D5291 or ASTM D1018.

The net heat of combustion is the value mostly used for subsequent calculations like specific fuel oil consumption (SFoC).

6.2.1.3 Stability

6.2.1.3.1 Stability of FAME and distillate fuels containing FAME

Oxidation stability

The standard method for testing the inherent stability of distillate fuel is ISO 12205. However, this method is only suitable for middle-distillate petroleum fuels. Distillate fuel containing greater than 2% v/v FAME shall have oxidation stability measured using EN15751.

EN15751

EN15751 is the reference method when testing the oxidation stability of FAME used as a marine fuel and distillate fuel containing FAME. Commercially, this method is often referred to as the modified Rancimat test.

This method involves passing purified air through a sample heated to 110°C. Any volatile components formed during the process are transferred with the air into a flask containing distilled or demineralised water. The change in conductivity (due to the dissociation of carboxylic acids) is measured and a plot of conductivity versus time is produced. The output from this test is an induction period which is the time measured between the start of the test and the rapid increase in the formation of oxidation products.

Oxidation stability cannot be measured on residual fuels containing FAME as the induction period cannot be determined. Instead of a typical ‘S’ shaped conductivity curve with a discernible inflexion point, a gradual, almost linear, increase in conductivity is observed throughout the duration of the test.

Total sediment

When testing the DFB grade of bio distillate, and the appearance is not clear and bright, oxidation stability as described above cannot be measured. Instead, the total sediment by hot filtration shall be determined by method ISO 10307-1. However, this test method does not include FAME in the scope which may affect the precision statements.

6.2.1.3.2 Stability of residual fuels containing FAME

Residual fuels containing FAME may have the potential to precipitate asphaltenic sludge similarly to typical residual marine fuel, therefore the Total Sediment tests remain applicable. However, these test methods do not include FAME in the scope which may affect the precision statements.

Potential Total Sediment (TSP) - ISO 10307 – 2 (Procedure A)

TSP is the total sediment after ageing a sample of residual fuel for 24h at 100°C under prescribed conditions, i.e. the amount of sediment after stressing the fuel through heating.

This method is expected to show the maximum amount of sediment that is likely to form when applying thermal stress.

Accelerated Total Sediment (TSA) - ISO 10307 – 2 (Procedure B)

TSA is the total sediment after dilution of a sample of residual fuel with a paraffinic solvent (hexadecane) under carefully controlled conditions, followed by storage for 1h at 100°C i.e. the amount of sediment after stressing the fuel chemically and storage at 100°C for 1 hr.

This method is expected to show the maximum amount of sediment that is likely to form when applying a combination of chemical and thermal stress.

Existent Total Sediment (TSE) - ISO 10307 – 1

TSE measures the amount of sediment present in a fuel at a particular moment by filtration and weighing the amount of sediment on the filter. TSE includes inorganic sediment as well as organic sediment such as precipitated asphaltenes and waxes.

The relationship between Total Sediment Accelerated (TSA) and Total Sediment Potential (TSP) for residual fuels containing FAME has yet to be determined. As such, both methods shall be completed in addition to Total Sediment by Hot Filtration (TSE). TSP remains the reference method in cases of dispute.

For more general information on the interpretation of sediment results see CIMAC guideline 03/2024, Overview and interpretation of total sediment test results in the context of ISO 8217:2024.

6.2.1.4 Cetane

Cetane number (CN) : ISO 5165 is a measure of the compression ignition behaviour of a distillate fuel. Cetane number is measured in a Cooperative Fuel Research (CFR) engine by ISO 5165. Cetane engines are no longer widely available across the industry, and the test is considered as expensive and time consuming. Alternative tests (see below) are available which give sufficient warranty on the combustion behaviour however in case of dispute this will be the referee method.

Cetane index (CI): ISO 4264 is a calculation/equation based on four measured fuel properties [Density, 10%, 50% and 90% distillation points] and is often referred to as the "4 point cetane index". When this equation was developed, cetane number and cetane index had an approximately 1:1

correlation. Today, in case of addition of FAME, the ignition quality as predicted by CI will be lower. However, the CN may be met in these cases, meaning that if CI is met for distillates including FAME, no ignition issues are to be expected.

Derived Cetane Number (DCN) and Indicated Cetane Number (ICN) test methods have been developed over the last 20 years. There are a number of DCN / ICN test methods: ASTM D 6890/EN 15195/IP498 (DCN), ASTM D7668/EN 16715/IP615 (DCN)) and ASTM D8183/EN 17155/IP617 (ICN). These DCN / ICN test methods are correlated back to cetane number obtained via the use of the cetane engine. These tests are more practical and more widely available. The scope of these test methods includes various levels of FAME, and precisions should be verified for each specific test.

Cetane additives can be added to distilllate fuels. Such additives can increase the cetane number of the fuel but do not affect the cetane index of the fuel. It can therefore be said that the cetane index approximates the 'natural' cetane of a fuel.

In summary:

- CN, DCN or ICN give similar results for all distillate fuels
- CI may under predict the CN/DCN/ICN if the fuel contains cetane improver additives or FAME.

6.2.1.5 Cold flow properties

Having information pertaining to the cold flow characteristics of the fuel will assist in the onboard handling of it, particularly in respect to storage, pumpability and filterability. There are three cold flow parameters detailed in ISO 8217 as described below, however for residual fuels it is only possible to measure pour point. Additional cold flow tests, not contained within ISO 8217, but suitable for residual fuel, can be considered and are detailed in section 6.2.2.

Cloud Point (CP): ISO 3015

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 scope of ISO 3015:2019 includes up to 30% (V/V) FAME. The nature of this test requires the fuel to be clear and bright. Other methods are available for determining the wax appearance temperature (WAT) of opaque fuels like marine residual fuels.

Cold Filter Plugging Point (CFPP): EN 116, EN 16329, (IP 309 or IP 612)

The cold filter plugging point is the lowest temperature at which a set volume of fuel, drawn by vacuum through a standardised filter (45 micron), within a specified time (60 sec), still continues to flow. The methods indicated are both automated and include FAME and bio distillate blends within the scope. These methods are not suitable for residual fuels due to their higher viscosity and dark colour.

This method has been developed for the automotive industry and indicates the lowest temperature at which a fuel can be used in the fuel system without any filter clogging problems. In marine the conditions and filters used are different. Nevertheless, the result of this test gives the user relevant information on the usability of a certain distillate fuel.

Pour Point (PP): ISO 3016

The reported pour point is the lowest temperature at which the fuel will continue to flow. Below this temperature the fuel is no longer fluid and cannot be pumped. This method can be utilised for both distillate and residual fuels. FAME and fuel containing FAME, is not included within the scope of the method however the method is expected to give reliable results.

6.2.2 Non-ISO 8217 additional tests

Incorporating FAME will affect certain properties of the final blend, such as viscosity and density. When considering using FAME and FAME blends there are also other properties which can provide additional information to assist with the proper fuel handling onboard. As such, consideration can be given to the use of additional and non-routine tests as detailed below. This is specifically applicable for users with limited experience on the use of FAME and FAME blends.

Results obtained from the tests described below should be considered as informative rather than normative.

NOTE: Some of the additional tests are also described in WA 2:2022 (Workshop Agreement: Specification for Marine Biofuel), written following a workshop organized by the SCIC (Singapore Chemical Industry Council). ISBN 978-981-5073-48-5.

6.2.2.1 Additional stability testing

Below is a list of available methods, not included in ISO 8217, which can be considered if more in-depth insights are required. Their suitability in the presence of FAME has yet to be determined.

Test method	Reference
Spot test	ASTM D4740
S-value	ASTM D7157
P-value	ASTM D7112
P-ratio	ASTM D7060
Toluene Equivalent (TE)	N/A
Xylene Equivalent (XE)	N/A
Bureau of Mines Correlation Index (BMCI)	N/A
Separability Number	ASTM D7061

6.2.2.2 Cold flow properties

Due to the nature of residual marine fuel, the precipitation of wax cannot be detected visually using the standard method for determination of cloud point. Alternative methods to measure the wax appearance temperature (WAT) have been developed. The same methods can also be used to measure the wax disappearance temperature (WDT). WDT is the temperature at which all precipitated wax has solubilised. The WDT will be higher than the WAT as additional energy is required to solubilise the wax deposits.

Wax Appearance Temperature (WAT): ASTM D8420

This method detects the wax appearance temperature using optical light scattering detection. The scope of this method incorporates all marine fuel types including FAME. However, ASTM D8420:2021 is only applicable for WAT up to 75°C.

Alternative in-house methods are available typically using either Differential Scanning Calorimetry (DSC) or Cross Polar Microscopy (CPM).

Wax Disappearance Temperature (WDT): ASTM D8420

The methods detailed for WAT may also be used to determine the wax disappearance temperature (WDT).

The relevance of the information obtained from these additional tests is depending on the practical application. Residual fuels are used in heated systems and have a relatively high viscosity, therefore flow properties are normally not an issue. When the viscosity of the fuel is low and the melting point of the heaviest waxes is relatively high, this could cause separation and filter issues. This is rare and in this situation the temperature should be raised to above the WDT while passing through the settling tank to service system maintaining sufficient viscosity for injection.

ASTM D8420 does not quantify the amount of wax, nor determines the size of the crystals formed, so it is possible to have a high WAT & WDT, but this will not necessarily result in operational issues.

6.2.2.3 Corrosion

FAME has the potential to break down to its corresponding fatty acids. It also has the potential to oxidize to form peroxides. To evaluate the corrosive properties of marine fuel containing FAME on copper and steel, copper strip corrosion and steel strip corrosion tests may be performed. These tests may be considered when the fuel is to be stored for long periods of time or when new FAME streams are being assessed.

Copper strip corrosion

EN ISO 2160 is included in EN 14214 which is the standard that applies to fatty acid methyl esters (FAME) for use in diesel engines and heating applications. A polished copper strip is immersed in the test fluid at an elevated temperature for a length of time. Any tarnishing at the end of the test is assessed against the table in the standard and rated. A result of either 1a or 1b passes the test.

Alternative methods are available including ASTM D130.

Steel strip corrosion ASTM D665 (Proc. A)

This method may be useful as an additional test when new bio streams are assessed.

A steel rod is immersed in the test fluid containing water at an elevated temperature for a period of time. The steel rod is assessed for signs of rusting.

The result for steel strip corrosion test should be negative i.e. no visible corrosion.

6.2.2.4 Bacteria & yeast

"Due to its chemical structure, FAME and diesel blends are more susceptible to biological attack by micro-organisms. Microbiological activity in B100 is about twice that in diesel fuel and the activity is even higher in FAME blends [13]*. Aerobic micro-organisms that consume hydrocarbons, such as fungi, bacteria, and yeast, usually grow at the interface between fuel and water in tanks and vessels* [14]*. Anaerobic species can actively grow on tank surfaces and can contribute to metal corrosion because they often chemically reduce sulphur, forming sulphur acids. Proper control of water and sediments is therefore essential for preventing microbiological problems. This can be achieved by a combination of periodic sampling and testing of storage tanks and immediate removal of any water or sediment that is present. The sampling frequency may vary depending on local conditions"* [4]

IP 385 or ASTM D6974 can be utilised for low viscosity marine fuel containing FAME.

"If microbiological growth remains unnoticed, it will eventually cause fouling and filter plugging. Field problems have been reported that have been associated with fungal growth in service station filters. Removal of water, sediment, and contaminated product as well as a shock treatment with biocides is recommended in such circumstances." [5]

So far, this phenomenon has not been detected with bio-residual fuels. Nevertheless, dip-slides suitable for use with marine fuel can be used for monitoring purposes.

6.2.2.5 Deleterious materials

As stated in ISO 8217, marine fuel should not contain any deleterious materials; these are, any components which causes harm or damage to the onboard machinery. Annex B of the ISO 8217 gives more context.

It is difficult to determine which chemical components and their concentration in marine fuel that can be considered as harmful. It is the combination between the fuel oil and the manner in which it is handled which determines if operational issues will be experienced or not. If handled properly and specification parameters are met, but still issues are experienced, the fuel is potentially not meeting the requirements of ISO 8217 and may contain deleterious materials.

The use of fatty acid methyl ester (FAME), compliant with EN 14214 or ASTM D6751 either as a fuel or as blend stock, should not be considered as a source of contamination. This can be assessed by requesting the COQ of this particular FAME used by the supplier in the fuel production.

In case more information is needed on fuels or blend components, test methodologies are available to potentially identify individual chemical components. These include Fourier Transform Infra-Red

[4] CONCAWE report no. 9/09
[5] CONCAWE report no. 9/09

(FTIR), direct injection Gas Chromatography – Mass Spectrometry (GC-MS) and GC-MS completed either on a particular distillation cut or on a polar extract of the fuel. These are investigative methods and are not standardised and mostly propriety in-house methods.

ASTM D7845 is a standardised GC-MS method for the detection of a range of contaminants observed within marine fuels. At the time of publication, this standard does not contain components typically associated with FAME waste stream products or any other biological feedstocks. Regardless the same applies as stated above, it is difficult to determine what chemical component and at what concentration in marine fuel can be considered as harmful.

Even when FAME is used as a blend component and meets the chosen FAME specification, the chance for a potential contamination via the residual or distillate fossil portion still remains. Whilst instances of contaminated fuel are few and far between, they do occur. In cases where a fuel has met the ISO 8217 specification and potential onboard handling errors have been ruled out, but operational problems still occur, investigating the possibility of chemical contamination should be considered.

6.3 Additives

Additives are used during the FAME production to meet certain specification requirements in EN 14214 or ASTM D6751. In general, the use of additives in finished biofuels and blends is not required. There are products available for finished fuels (including Fossil Fuels) which might improve handling, and/or combustion properties. Below are a few examples of such additives used.

6.3.1 Biocides

FAME's chemical composition can attract water and hold higher water content which in turn increases the risk of microbiological growth. Good housekeeping is very important to prevent bacterial growth and resulting sludge in storage tanks. Biocides can be used when bacterial growth has occurred in cases where housekeeping has not been sufficient.

Bacterial and Fungal growth issues are mostly expected when FAME is used neat or blended in a distillate marine fuel. For bio-residual fuels, it is expected that this problem is much less likely to occur.

Preventing bacterial growth with biocides is possible but carries the risk to select resistance microbes that may be more difficult to eliminate if they grow out of control.

Shock treatment works as a possible measure where housekeeping was not sufficient in combination with water and sediment removal (as recommended in CONCAWE report no. 9/09); however, in the more severe cases the biocide will not be capable of eliminating the biomass formed by the microbiological activity and manual removal would be required.

6.3.2 Oxidation stability and sludge control,

FAME contains unsaturated chains that can react or be oxidised to form gums that can adversely impact storage and fuel supply systems. Antioxidants are commonly used in FAME to stabilise them and 1000 ppm Butylated hydroxytoluene (BHT) equivalent is recommended in EN14214 to prevent oxidation. When the fuel is stored for long periods of time, the antioxidant is consumed and may need to be topped up onboard the vessel. Dosage should be determined after consultation with an additive supplier.

Dispersant can also be used to help keep the gums/sediments into solutions and prevent deposits.

Oxidation stability and sludging issues are mostly expected when FAME is used neat or blended in a distillate marine fuel. For bio-residual fuels it is expected that this problem is much less likely to occur.

6.3.3 Cold flow

FAME cold flow performance varies a lot depending on the feedstock used for its production. (See Chapter 4.3, Figure 2) Cold flow performance of the final fuel may be impacted by FAME addition. This is most relevant when FAME is blended with a distillate fuel due to the absence of heating.

Cold flow additives are effective in FAME and FAME blends to achieve the required performance.

It is recommended to add these types of additives prior to bunkering, because once the waxes have formed, they can only be dissolved via heating.

In case mitigation is needed to improve the cold flow properties, for example when planning to sail into colder climates than initially intended, and no heating is available, additives may be a solution and can be added onboard. However, this can only be done prior to entering any cold area, under strict conditions and after consultation with the additive supplier. The type of additive and manner of application is critical and if not done correctly may make the situation worse.

For more information please see: 01 2015 CIMAC Guidelines Cold Flow properties of marine fuel oils.

7 Bio- & recycled carbon fuels not meeting ISO 8217

7.1 FAME not meeting EN 14214 or ASTM D6751

If it is considered to use FAME not meeting the EN 14214 or ASTM D6751, an evaluation should be made to determine how these products differ from the FAME reference specification (EN 14214 or ASTM D6751). This can be used as the basis for a risk assessment prior the use of such a product.

Consideration may be given to include some additional trials/tests prior to putting such a grade/blend into use on board a ship (See Chapter 5.1).

Approval from the appropriate authorities (Flag & Classification) may be required. Guidance from OEM’s should be sought.

The better aligned with the FAME reference specifications, the lower the risk that the product will prove unsuitable for purpose and successful implementation is more likely.

It is anticipated that a marine specific FAME specification will be developed to increase the availability of FAME products for the marine industry.

7.2 Other bio based- / recycled carbon products.

Currently there is a lot of R&D work being performed on alternative bio- and recycled carbon-streams. It is important to realize that there are many unknowns. Chemical behaviour and impact on the machinery is hard to predict. Consideration should be given to the fact that these types of products are not widely applied in similar applications and the composition varies.

Even when properties are within Table 1,2,3 or 4 of ISO 8217, it will not warrant safe use of such products.

For a fuel to meet ISO 8217, the standard needs to be met in its entirety and there is no provision for these new streams.

Examples of products which need consultation and possibly consensus of the OEM and Class include:

- Distillation bottoms from FAME production.
- Pyrolysis oils
- Cashew Nut Shell Liquid (CNSL)
- Products derived from lignocellulosic biomass
- Straight/unprocessed waste and residue fats and oils.

When considering using a new fuel in this category, comprehensive testing procedures and potential ship trials are required to ensure that there is no harm to personnel, machinery and environment, and regulatory requirements are met. Additional and alternative testing to judge quality, consistency and usability going forward is highly advisable.

Consultation and involvement of the OEM and Class should be sought to provide additional support and guidance.

A full risk assessment will be required and means of mitigation present onboard during trials.

Once trouble free use of a product is established, continuous care and attention should be given for a prolonged period of time during use of these products.

When an alternative biomass-based product is used, the requirements as stated in this document should be adhered to as far as possible.

Ultimately, it will be up to the industry to establish if these products will be fit-for-purpose.

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