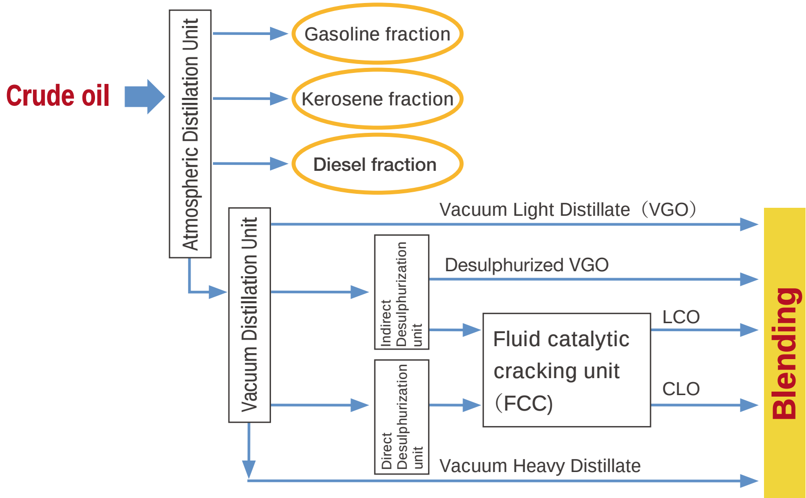
Unit (ADU) to distill it into light fractions. The residual oil then goes through a Vacuum Distillation Unit (VDU) under vacuum (31-38 kPa) and is fractionated into a light fraction (350°C to 550°C at equivalent atmospheric pressure) and a heavy fraction (550°C or higher at equivalent atmospheric pressure).

The light fraction sulphur content is reduced through an Indirect Desulphurization Unit, and then desulphurized Vacuum Gas Oils (VGO) are converted through a Fluid Catalytic Cracking Unit (FCCU) into higher-value gasoline and middle distillates such as light cycle oil (LCO) and clarified oil (CLO).

《Blending process of compliant fuel oil》

For consistent supply and cost effectiveness, residual oil with a sulphur content of 0.50% or less is commonplace.



VGO：Blendstock with good ignition quality, not directly blended with bunker heavy oil, and used as a raw oil for cracking unit (VGO：Vacuum Gas Oil)

LCO (Light Cycle oil)
CLO (Clarified Oil) ：Low sulphur blendstock, low kinematic viscosity

Figure 5-3 Manufacturing process at a typical petroleum refinery

According to current oil refinery technology, there are said to be five production methods of compliant fuel oil:

① **Blending of various low-sulphur blendstocks which have been produced at the refinery,**

② **Desulphurization of residual oil from high sulphur crude oil,**

③ **Blending of light oil and high-sulphur heavy oil (e.g., crude oil from the Gulf of Mexico, see Figure 5-4),**

④ **Use of MGO (Marine Gas Oil, lighter distillate oil) or MDO (Marine Diesel Oil, blend of distillates and heavy oil but with very low content)**

⑤ **Use of low-sulphur crude oil residue (e.g., crude oil from the North Sea oilfields, see Figure 5-4).**

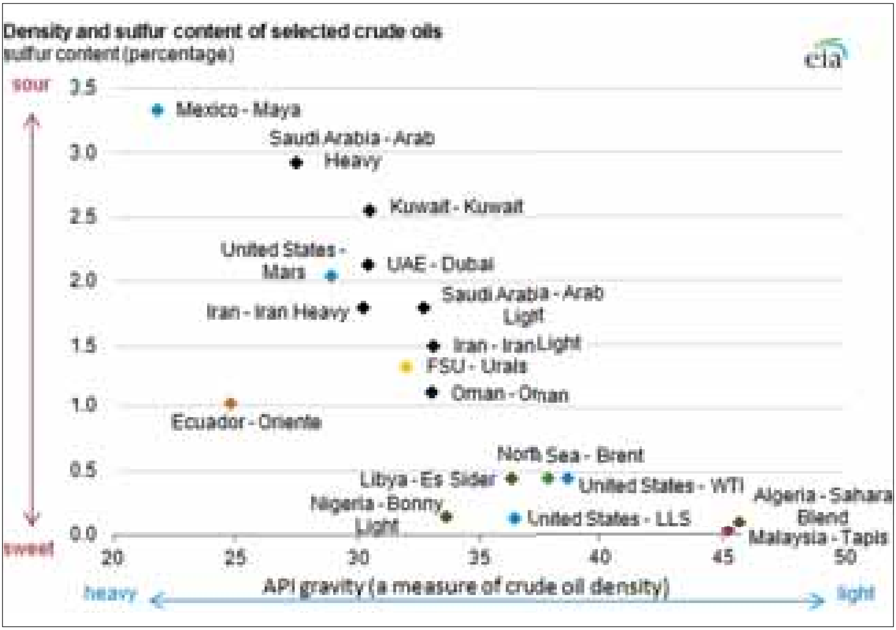


Figure 5-4 Density and sulphur contentof selected crude oils

Figure 5-4 shows sulphur content by crude oil production area. Low sulphur oil is essential as a blendstock for compliant fuel oil. Due to financial considerations, it is not possible to supply a sufficient amount of compliant fuel oil using only distillate oil and desulphurised residual oil. The above mentioned production method ① is the most promising way to secure a stable supply of compliant fuel oil.

In order to keep the sulphur content of compliant fuel below the new 0.50% sulphur limit, it is necessary to blend various blendstocks together. This leads to an increase of various fuel oil properties other than sulphur content when compared to conventional fuel oils for open sea areas outside ECAs (HSHFO: High Sulphur Heavy Fuel Oil with sulphur content of less than 3.5%).

① **Use various low-sulphur blendstocks other than light distillate oils which have been obtained by repeatedly refining, distilling, fractionating, and cracking from crude oil.**

② **Since crude oil properties vary depending on the region of production (see Figure 5-4) and each refinery's capabilities, the ratio of blendstocks in compliant fuel oil may vary widely from region to region when compared to conventional fuel oil.**

5−2 Precautions and countermeasures for safe usage of 2020 IMO compliant fuel oil

Safe use of VLSFO requires an essential understanding of the various properties found in blendstocks (‘VLSFO’ Very Low Sulphur Fuel Oil: fuel oil compliant with 0.50% sulphur limit required in open sea areas outside of ECAs. It is further sub-classified into VLSFO-RM (Residual Marine Fuels) and VLSFO-DM (Distillate Marine Fuels) depending on the production process. Hereinafter, the compliant VLSFO-RM is referred to as VLSFO)

Safe use of VLSFO requires essential awareness of the following 5 properties:

① Compatibility
② Low viscosity
③ Cold flow properties
④ Cat-fines
⑤ Ignition and combustion quality

Using the points outlined in 'Problems of conventional High-Sulphur Heavy Fuel Oil (HSHFO) and Distillate Marine Fuels (MDO: marine diesel oil & MGO: marine gas oil', and based on previous experience and knowledge of fuel oil properties, this chapter aims to identify the various 'precautions' and 'countermeasures' required for each property. Please also refer to "Loss Prevention Bulletin Vol.30, Bunkers – Quantity and Quality Disputes" to review fuel quality fundamentals.

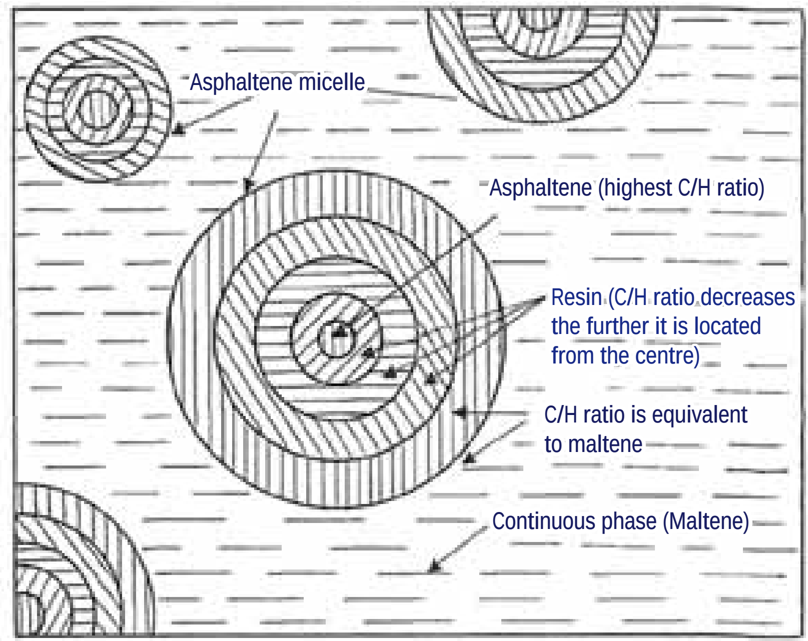
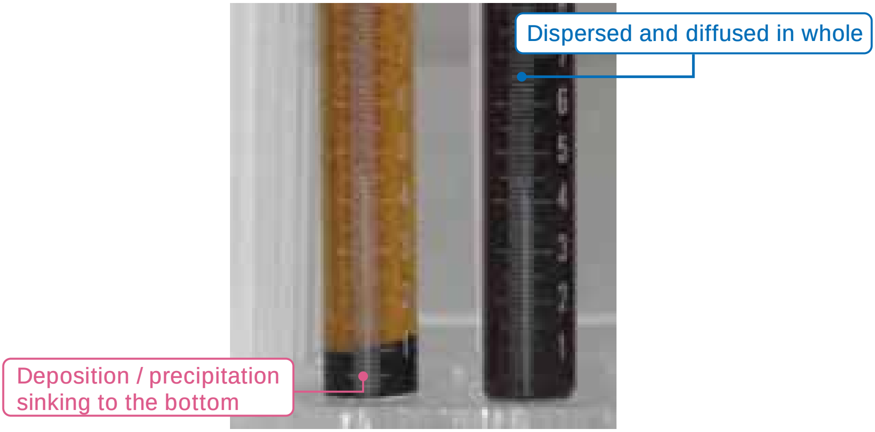


Figure 5-5 Structure of asphaltene micelle

5-2-1 ① Compatibility

When two different fuel oils are mixed, the stability of that fuel will decline, and asphaltene sludge and/or other substances contained in either of the original fuel oils may deposit/precipitate. The capacity of fuel oil to resist this deposition/precipitation is generally referred to as fuel compatibility.



Photograph 5-6 Deposition/precipitation

Photograph: ClassNK Guidance

Depositing and precipitating Sludge

Asphaltene in heavy fuel oil forms stable micelle structures in maltene, as shown in Figure 5-5. They are dispersed and remain in a suspended state (colloidal) and do not deposit/precipitate.

However, when the fuel is mixed with other fuel oils, or undergoes thermal shock or when the fuel is oxidized, the micelle structure becomes unstable and the colloidal state is lost. Asphaltene will then start to aggregate, and its particles grow in size. It is finally deposited/precipitated as asphaltene sludge (See Photograph 5-6).

Generally, when a fuel containing a large amount of aromatic hydrocarbon is mixed with another fuel containing a large amount of paraffinic hydrocarbon, maltene containing the asphaltene reaches a point of discontinuity and asphaltene begins to aggregate.

Potential issues and countermeasures for machinery/plant systems affected by fuel oil sludge

Table 5-7 shows a summary of compatibility issues and countermeasures.

Machinery/plant system issues in the engine room

Please see the Fuel oil piping system (1) in Figure 5-8 and sludge deposition and precipitation in Photographs 5-9 and 10.

1 Asphaltene sludge deposition clogs pipes and prevents the transferal of fuel oil.

Reason: Fuel oils are a mixture of different compositions and this leads to deposition of asphaltene in the following areas:

① In the hull storage tank when bunkering.

② In either the settling tank/service tank or piping when the crew switch fuel oil used for onboard machinery to a compatible oil.

2 Low fuel oil supply, or in the worst case scenario, main engine shut down (loss of propulsion), or generator shut down (loss of power)

Reason: The strainer on the fuel oil supply pipeline clogs with sludge in the following situations:

① When asphaltene sludge deposition generated in the hull tank is transferred.

② When fuel oils of different composition are mixed in the piping.

3 During the discharge of sludge, the oil purifier may be damaged or abnormal vibrations may occur in the case of any imbalance in the purifier's rotation unit.

Reason: Accumulation of sludge on the separating disc in the rotating bowl of the oil purifier which may occur in the following situation: When filters in the fuel oil supply pipeline become clogged, sludge spreads throughout the entire fuel oil supply system. At the same time, asphaltene sludge deposition increases in the oil purifier.

Countermeasures

The following countermeasures are required:

Caution : Do not mix fuel oil in the hull storage tank or pipeline, or at the very least keep the mixing ratio as low as possible.

1 The following measures should be adopted to avoid any adverse effect on shipping operations:

① Do not change oil in areas of high operational risk such as congested sea areas.

② Keep the duration of fuel oil mixing to a minimum. Change fuel oil after a calculated estimation of fuel consumption in the main engine.

2 The following measures should be adopted in the event of sludge accumulation:

① Add sludge dispersants or solubilizers to the hull storage tanks.

② Clean strainers frequently.

③ Regarding oil purifier operating management, reduce the flow rate of oil purifiers, shorten interval of sludge discharge, raise oil treatment temperature, and reduce overhaul interval of the separating disc for inspections and maintenance.

3 In case of emergency, it is advisable to keep a reserve stock of sludge dispersant on board.

Table 5-7 Compatibility issues and countermeasures

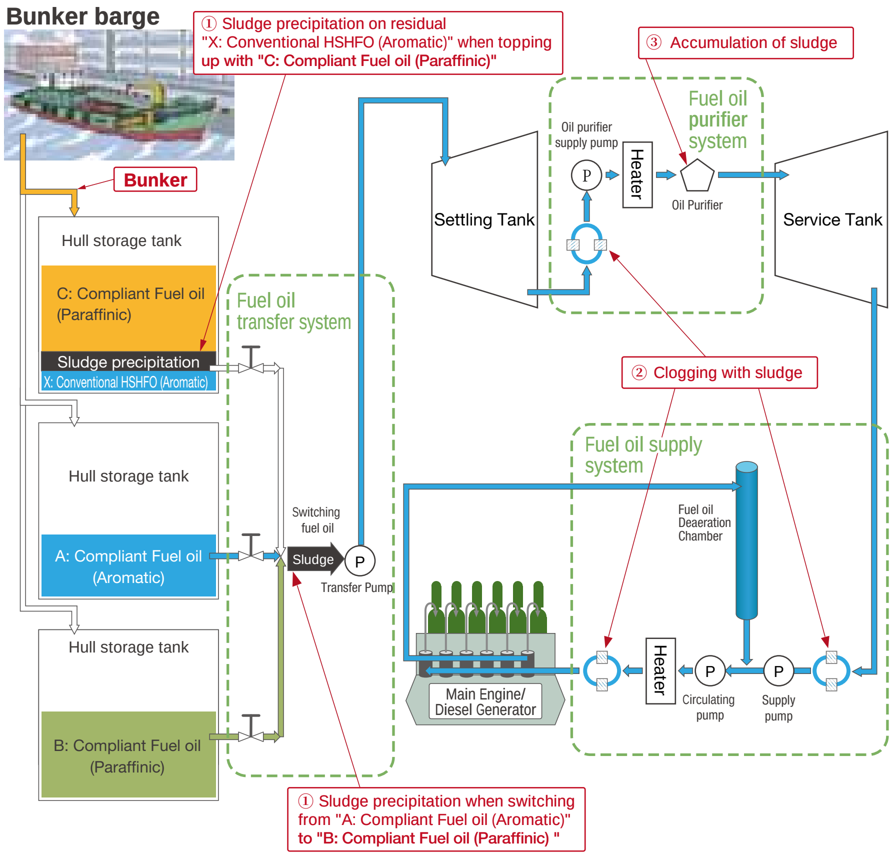


Figure 5-8 Fuel oil piping system (1)

Photograph 5-9 Sludge deposition and precipitation within the rotating bowl of the oil purifier

Source: Guide for use of 2020 SOx regulation compliant fuel oils
(Maritime Bureau of the Ministry of Land, Infrastructure, Transport and Tourism)

Courtesy of Nippon Kaiji Kentei Kyokai

Photograph 5-10 Sludge deposition and precipitation in fuel oil filters

Photograph: ClassNK Guidance

5-2-2 ② Low viscosity

In order to produce VLSFO compliant fuel oil with a sulphur content of 0.50% or less, the blending ratio of the following low sulphur blendstocks will rise above that of conventional fuel oil (HSHFO):

(1) Desulphurized Vacuum Gas Oils (vacuum residue which has passed through an Indirect Desulphurization Unit)

(2) LCO (Light Cycle Oil) and CLO (Clarified Oil)

Cracking reaction in the desulphurization units and cracking units will cause blendstock viscosity to be reduced.

Therefore, the viscosity of the blendstocks mentioned above is much lower than that of conventional blendstocks which have not passed through direct desulphurization (Vacuum Heavy Distillate) and been blended with conventional heavy fuel oil (HSHFO). The viscosity of VLSFO supplied from 2020 is lower than that of conventional fuel oil (HSHFO).

According to two research reports “Assessment of Fuel Oil Availability - final report, MEPC70/5/3 and MEPC 70/INF.6." (see right side Photograph) presented at the 70th Marine Environment Protection Committee IMO, held in 2016, the future of marine fuel oils was described as follows: "Low Sulphur crude oil is available in certain regions such as the North Sea Oil Fields. However, it is also envisaged that a VLSFO compliant fuel oil, mainly composed of atmospheric residue or vacuum residue, can be produced and supplied and which is broadly similar to conventional HSHFO fuel oil. Sulphur content of residues exceeding 0.5% can be adjusted when necessary by blending with an appropriate amount of low sulphur heavy oil or distillate oil. In some regions such as the North Sea oil field where low sulphur crude oil is available, it is also predicted that compliant fuel oil VLSFO which mainly is composed of atmospheric residue or vacuum residue can be produced and supplied, similar to conventional fuel oil HSHFO. And if the sulphur content of residue is higher than 0.5%, the appropriate amount of low sulphur heavy oil or distillate oil will be blended to adjust it as necessary. This will bring VLSFO viscosity to an equivalent level as that of current HSHFO."

Potential issues and countermeasures for machinery/plant systems affected by low viscosity oil

Table 5-11 shows a summary of issues and countermeasures.

Machinery and plant system issues in the engine room

Refer to images of damaged parts in Photographs 5-12,13 and 14

1 Diesel engine

① Sticking of the fuel injection pump (due to decreased lubricity), failure to start-up, and difficulty in increasing rotation speed (load) due to increased

leakage of the internal sliding parts.
(As reported in the "Summary of damage" published in the ClassNK Technical Review (Kaishi) (No312, No316): following enactment in 2015 of SOx regulations which restrict the sulphur content in fuel oils in overseas SOx Emission Control Areas, some Class NK registered ships reported damage to fuel injection devices).

② Difficulty in increasing rotation speed (load) because of an insufficient fuel supply from the fuel supply pump (due to decreased kinematic viscosity). Internal leakage from the clearance between the rotating body and the casing occurs, and the fuel supply is insufficient.

③ Low-temperature corrosion of fuel valves and related components. (This occurs when the fuel injection valve on engines using heated HSHFO is cooled excessively. This often happens in 4-stroke engines).

2 Fuel supply pump / Fuel transfer pump / Oil purifier supply pump

① Sticking, gear wear, reduction of bearing life (due to decreased lubricity).

② Insufficient fuel oil supply (due to leakage of the sliding parts inside the pump, and decreased kinematic viscosity).

③ Leakage from pump seal (due to decreased kinematic viscosity).

Countermeasures

The following countermeasures are required:

It is essential to comply with the manufacturer's manuals and instructions for safe use of ECA (Emission Control Areas) compliant fuel oil, even when using VLSFO.

1 Confirmation of engine and fuel pump specifications before use of compliant fuel.

① Measures to be implemented when replacing or modifying machinery:

1) When the minimum viscosity of the fuel in use is lower than 20 cSt @50℃ at the engine inlet, it is necessary to install a fuel oil cooler in front of the inlet to ensure the manufacturer's recommended viscosity.

2) For fuel supply pumps, if the minimum viscosity of the VLSFO in use is not within the manufacturer's recommended range of viscosity, the following countermeasures should be implemented:

(a) Use a fuel supply pump with specifications compatible with low viscosity.

(b) Replace the pump seal.

(c) Install a fuel oil cooler (viscosity can be adjusted provided it is done upstream from the supply pump).

② Overhauls and maintenance
Some VLSFOs have a high kinematic viscosity and a large amount of residue. The clearance between the sliding parts of the fuel supply pump and the fuel injection system can increase due to wear.
If the kinematic viscosity of fuel oil is significantly lower than that which has just recently been used, it is necessary to carry out an overhaul before use.

2 Countermeasures at sea

① Kinematic viscosity varies greatly with changes in temperature. Make sure to maintain thorough control of fuel oil temperature.
When there is no risk of wax precipitation (see next section) at the pour point, cease steam tracing and avoid raising the temperature of the fuel oil as much as possible.

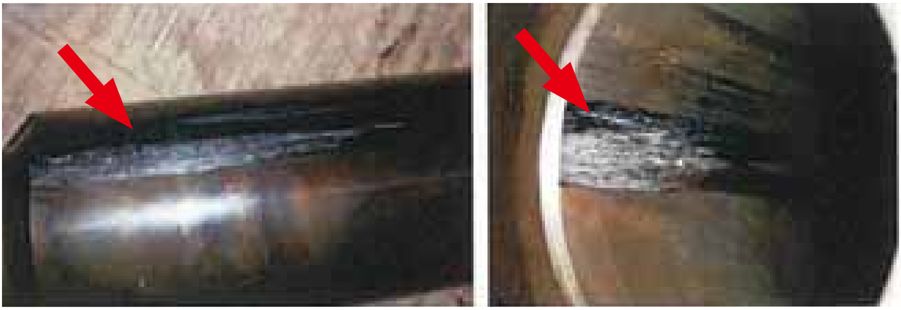
② Monitor fuel oil temperature so that viscosity remains within the recommended range of the manufacturer.
Kinematic viscosity can be controlled if the fuel oil is 100 cSt @50℃ or higher. However, if kinematic viscosity is low, crew should be aware that it may be difficult to adjust onboard by steam heating.

③ For fuel oils with low kinematic viscosity 20cSt @50℃ or less that are prone to wax at a high pour point, there is a risk of wax formation when adjusting kinematic viscosity by cooling. Be aware that there is a narrow temperature range of acceptable cooling to adjust kinematic viscosity.

④ Where there is concern about the lubricity of VLSFO, a lubricity improver should be added to the fuel oil.
(Lubricity improvers should be added to the fuel tank in advance.)

⑤ It is recommended to keep a reserve of lubricity improvers onboard.

Table 5-11 Low viscosity issues and countermeasures



Photograph 5-12　Scratches on the plunger and barrel of the fuel injection pump

Photograph: ClassNK Guidance

Photograph 5-13　Abnormal wear of plunger and barrel in the fuel injection pump

Photograph: ClassNK Guidance

Photograph 5-14　Scratches on the fuel injection valve

Photograph: ClassNK Guidance

Importance of viscosity control

Manufacturers provide a recommended kinematic viscosity of fuel oil at the engine inlet, and to ensure safe and efficient operation of the engine, the fuel oil supply pipeline is equipped with an onboard viscosity control device (see table 5-11). Precautions for the handling of fuel oil are also explained in the manufacturer's instruction manual. Each manufacturer has a recommended range of approximately between 2 cSt and 20 cSt.

As shown in Figure 5-15, kinematic viscosity is inversely proportional to increases in fuel oil temperature. Conventional fuel oil (HSHFO) has a relatively high viscosity of 180cSt@50□ or 380cSt@50□, and so a virtually consistent quality could be obtained. Adjusting it to fall within the recommended viscosity range was therefore just a matter of steam heating. However, after 2020, trade of VLSFO with a wider range of kinematic viscosity is expected. When kinematic viscosity is lower than recommended levels, it will be necessary for crew to increase viscosity by cooling. Moreover, regarding oil purifiers, from the viewpoint of economy and safe operation, the manufacturer recommends that optimum viscosity be set at, for example, 24cSt for the treatment oil. So, crewmembers must take care to set the treatment (feeding) temperature of the oil purifier to its relative (corresponding) temperature.

It is therefore essential for crew members to familiarize themselves with the manufacturer's instruction manual and to take appropriate measures to manage fuel oil viscosity.

The role of the Engineer

Consider:
M/E inlet viscosity Manufacturer's
recommended viscosity Corresponding
temperature Steam **Heating Valve aperture**
THEN
Monitor, think, analyse, judge and act!

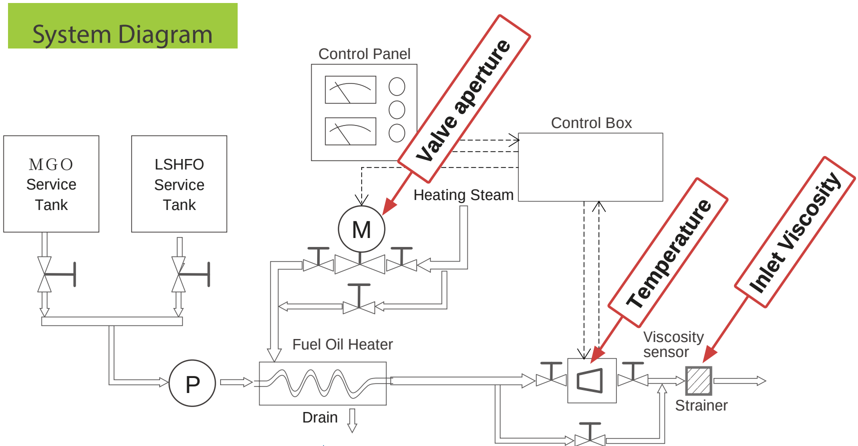
Understand the technology
Viscosity Controller

Check ⇒ System Diagram

Understand the science
Viscosity Characteristics of HFO

Check ⇒ Diagram

System Diagram



Low kinematic viscosity: Beware! It may require cooling.

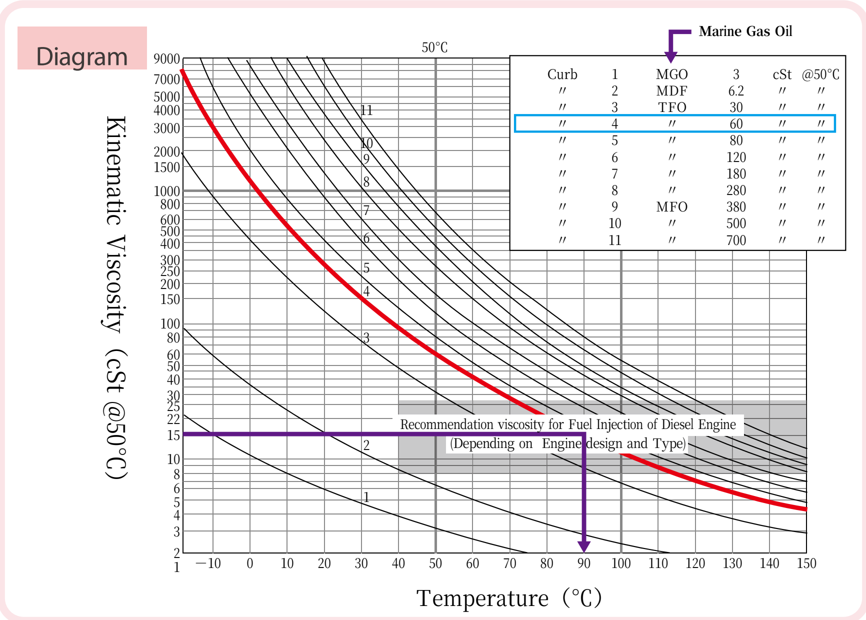
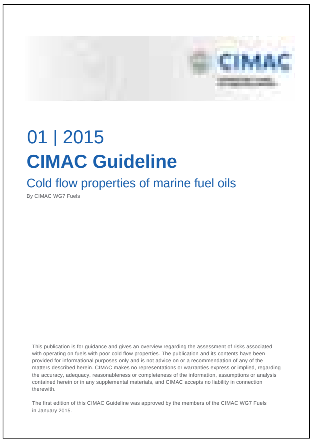


Figure 5-15 Viscosity controller

5-2-3 ③ Cold flow properties

Cold flow properties indicate the lowest temperature at which fuel can continue to flow when it is cooled. The Pour Point (PP) is the temperature below which the fuel loses its flow characteristics.

During the process of wax crystal formation as fuel begins to cool, Cloud Point (CP) is the temperature at which wax crystals start to grow and visibly form in the fuel. Crystal size is still small, and transparent fuel becomes cloudy. Cold Filter Plugging Point (CFPP) is the lowest temperature at which these crystals



01 | 2015
CIMAC Guideline
Cold flow properties of marine fuel oils
By CIMAC WG7 Fuels

This publication is for guidance and gives an overview regarding the assessment of risks associated with operating on fuels with poor cold flow properties. 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 was approved by the members of the CIMAC WG7 Fuels in January 2015.

Figure 5-16
01| 2015 CIMAC Guideline Cold flow properties of marine fuel oils

grow into larger plate shapes and begin to plug the filter. Pour Point (PP) is the lowest temperature at which the crystals in the fuel grow even larger to the extent that the entire fuel oil becomes gelled and loses its ability to flow (see Photographs 5-17 and Figure 5-18).

According to “01 | 2015 CIMAC Guideline, Cold flow properties of marine fuel oils “ issued by CIMAC (The International Council on Combustion Engines), the temperature difference between each of the above stages will be between 2 and 5 □ for untreated fuels. In order to ensure efficient management of fuel fluidity at low temperature, the crew should endeavour to maintain a temperature of at least 10°C higher than the Pour Point. From a practical point of view, fuel with a low pour point is preferable.

Photograph 5-17 Wax formation process

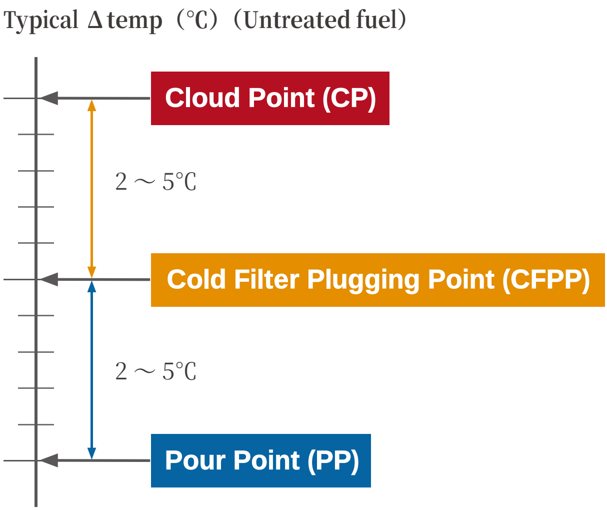


Figure 5-18 Definition of cold flow properties

Potential issues and countermeasures for machinery/plant systems affected by cold flow properties

Table 5-19 shows a summary of issues and countermeasures.

Machinery and plant system issues in the engine room

See“ Fuel oil piping system (2) ”in Figure 5-21 and wax crystal formation images in Photographs 5-20, 22, and 23.

1 Inability to transfer fuel oil from hull storage tank by fuel oil transfer pump.

Reason : Fuel oil temperature has fallen below the pour point (PP) in the hull storage tank, and the entire fuel oil gels, losing its flowability. It is impossible to transfer from the hull storage tank to the settling tank in the engine room.

2 Low fuel oil supply, or in the worst case scenario, main engine shut down (loss of propulsion), or generator shut down (loss of power).

Reason : Wax crystals can form and clog the strainer in the fuel oil supply pipeline under the following conditions:
Even if fuel oil temperature exceeds PP, if it falls below CFPP, wax crystals can form in larger plate-shapes. In this instance, any wax formed in the hull storage tank will be transferred and lead to potential clogging of filters in the fuel supply pipeline (Cold Filter Plugging Point (CFPP): please see Photographs 5-17 and18).

3 Poor sludge treatment.

When discharging sludge, any imbalance of the oil purifier can lead to abnormal vibrations and may damage the purifier.

Reason : When fuel oil containing wax crystal formations passes through the oil purifier, the following occurs:

① Wax adheres to the separating disc and reduces the separation efficiency.

② Wax accumulates on the separating disc in the rotating bowl of the oil purifier.

Countermeasures

The following countermeasures are required:

Caution : Maintain, or if necessary, heat the fuel oil temperature to at least 10℃ above the cold filter plugging point (CFPP+10℃).

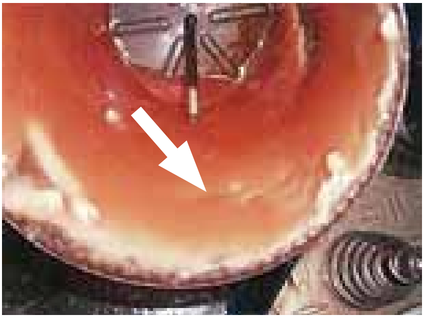
1 When using fuel oil without a heating device, ensure that the operating environment (*) is PP+10 ℃ or above, taking into consideration the navigation route and season.
When fuel oil cannot be used, employ wax suppresants to control wax formation.
* Operating environment: Conditions which affect fuel oil management include: seawater temperature, surrounding temperature of pipeline, engine room temperature, and ambient temperature.

2 If wax crystals frequently form on the strainer in front of the purifier, make the following changes to the oil purifier operating settings: reduce the flow rate of oil purifiers, shorten interval of sludge discharge, raise oil treatment temperature, and reduce overhaul interval of the separating disc for inspections and maintenance. If necessary, clean the strainer more frequently than usual.

3 In case of emergency, it is advisable to keep a reserve stock of additives to mitigate any wax crystal formation on board.

4 When the kinematic viscosity of fuel oil is low (less than 20 cSt @ 50 °C), heating is basically unnecessary. However, if the pour point is high, fuel oil requires appropriate heating. Be aware though that careful fuel oil management is required since the range of acceptable temperature variation is narrow.

Table 5-19 Cold flow property issues and countermeasures



Filter blocked due to wax deposit

Source:01 2015 CIMAC Guideline

Source: Guide for use of 2020 SOx regulation compliant fuel oils (Maritime Bureau of the Ministry of Land, Infrastructure, Transport and Tourism)

Photograph: ClassNK Guidance

Photograph 5-20 Wax crystal formation in fuel oil

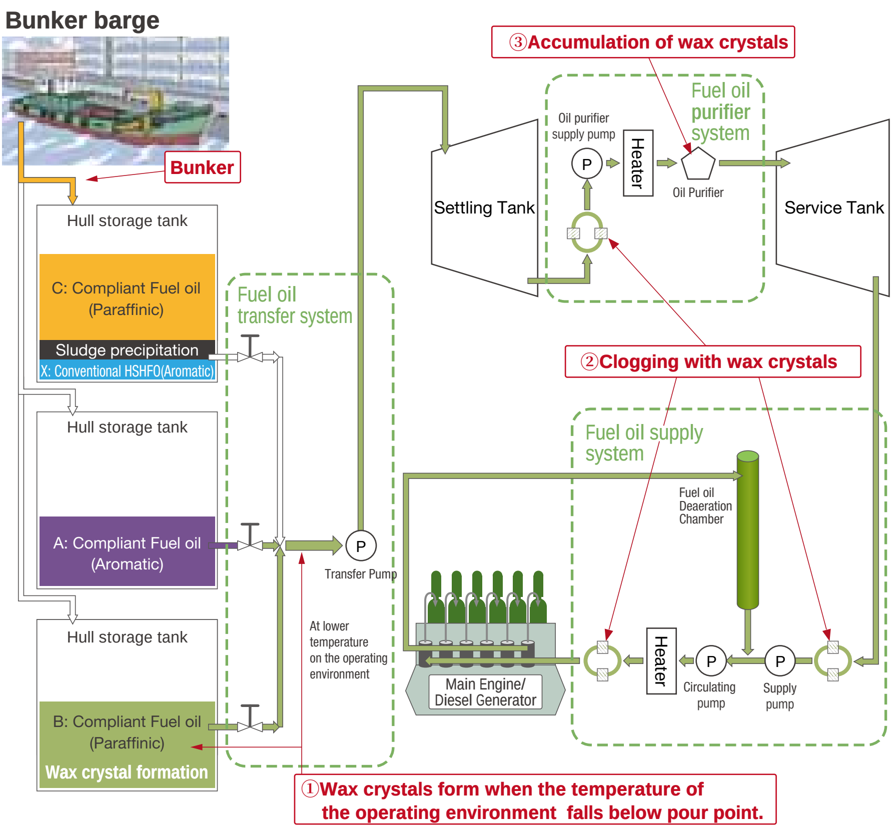
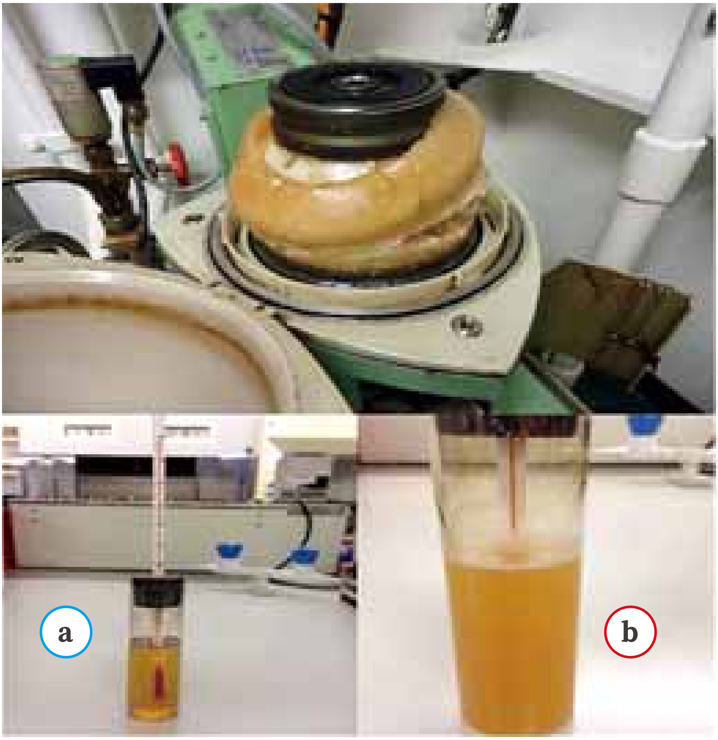


Figure 5-21 Fuel oil piping system (2)


Photograph 5-22 Wax crystal formation in the fuel oil tank



(a) Clear sample at 28°C (b) Wax crystals formed at 24°C

Photograph 5-23 Wax crystal formation in the diesel oil purifier where the distillate fuel temperature is below the CFPP of fuel in the oil purifier

5-2-4 ④ Cat-fines (FCC catalyst particles)

Cat-fines originate from catalyst particles used in the fluid catalytic cracking (FCC) process. During the FCC process, these catalyst particles break up into smaller particles and remain in the fuel oil as cat-fines. They are very hard particles composed of alumina (Al_2O_3) and silica (SiO_2).

The catalyst particles are continuously used and recycled during the FCC process. However, some of the cat-fines catalyst particles still remain in the low sulphur blendstocks (CLO: Clarified Oil). The presence of cat-fines is evaluated according to the total amount of aluminum (Al) + silicon (Si) content.

Potential issues and countermeasures for machinery/plant systems affected by Cat-fines

Table 5-24 shows a summary of issues and countermeasures

Machinery and plant system issues in the engine room

Cat-fines problems (Photograph 5-25) have also occurred on ships using conventional oil in the past. VLSFO which is rich in CLO has an Al and Si content approaching the upper limits specified in the international standard "ISO 8217:2017 Petroleum products– Fuels (class F)– Specifications of Marine Fuels". When using such VLSFO, any cat-fines which have not been properly removed onboard from fuel oil will enter into the engines and machinery. As a result, if the particle mass of cat fines is large and their diameter outstrips oil film thickness, engines and equipment may be damaged, especially sliding parts, such as the fuel injection valve or piston ring (refer to Figure 5-26, and Photograph 5-27). Potential problems include:

(1) Sticking and wear of fuel injection parts / Sticking, wear and nozzle hole defects of the fuel injection valve

(2) Excessive wear and breaking of piston ring / Excessive wear of piston ring groove

(3) Excessive wear and scuffing of cylinder liner

(4) Excessive wear, scuffing and excessive leakage of the piston rod and gland packing

(5) Wear and blow-by in valve seat on exhaust valve

(6) Damage to exhaust gas passage on T/C nozzle and turbine blade

Countermeasures

The oil purifier uses centrifugal force to separate the different densities of fuel oil and cat-fines/sludge. If the Al+Si content of fuel oil falls within the value specified by ISO 8217 ISO, it is possible to reduce Al+Si content, before the engine inlet, to the engine manufacturer's recommended value. To this end, it is necessary for the crew to conduct pre-treatment in the settling tank, and ensure proper function of the oil purifier by carrying out the necessary repairs, inspections and maintenance.
The following countermeasures are required:

Caution : Ensure the proper operation of the oil purifier and conduct appropriate pre-treatment of VLSFO in the settling tank as follows:

1 In order to maintain and improve the separation efficiency of the oil purifier, operation settings should include maintenance of an appropriate oil treatment temperature, and reduction of the flow rate to just a little more than expected fuel consumption. Use of two or more oil purifiers in parallel operation can increase purification efficiency.

2 Whenever bunkering, confirm that oil purifiers are functioning correctly by regularly taking fuel oil samples to a laboratory in order to have Al + Si content measured. Samples should be taken from (i) ship manifold (inlet of hull storage tank), (ii) before and after the oil purifier, and (iii) at the engine inlet.

3 It is important to keep the fuel oil level of the settling tank within an appropriate range.

4 Drain water and sludge from the settling tank should be removed because cat-fines deposited in the settling tank are also removed.

5 When cat-fines are captured by emulsified matter, apparent specific gravity is reduced, and this means a reduction of removal efficiency at the oil purifier during the pre-treatment process. To prevent this, the water content of fuel oil should be removed as much as possible and emulsification preserved. The following methods are effective:

① Prevent the mixing of water with fuel oil.

② Heat the fuel oil settling tank (around 70℃), allow sufficient settling by gravity, and enhance separation of water content.

③ Be careful not to stir fuel oil upstream of the oil purifier.

6 Backwash oil from the automatic backwash secondary filter should be consumed outside the diesel engine and not returned to the settling tank.

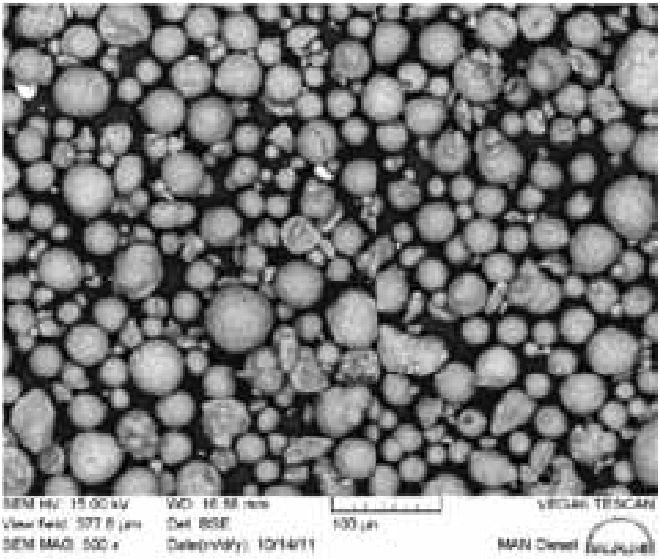
7 Operate the filter in front of the engine inlet in accordance with the engine manufacturer's operating manual. Pay particular attention to the following:

① In principle, use the automatic backwashing filter side.

② Ensure that the fine filter in front of the engine inlet and the by-pass filter are of the same mesh size. Inspect and maintain the fine filter regularly to ensure it is not perforated.

③ Fine filter cleaning schedules should be logged daily. If cleaning frequency increases, be sure to improve the fuel separation efficiency of the oil purifier (refer to the countermeasures for compatibility and cold flow properties).

Table 5-24 Cat-fines issues and countermeasures



Photograph 5-25 Cat-fines particles

“Cat-fines particles vary in size and shape”

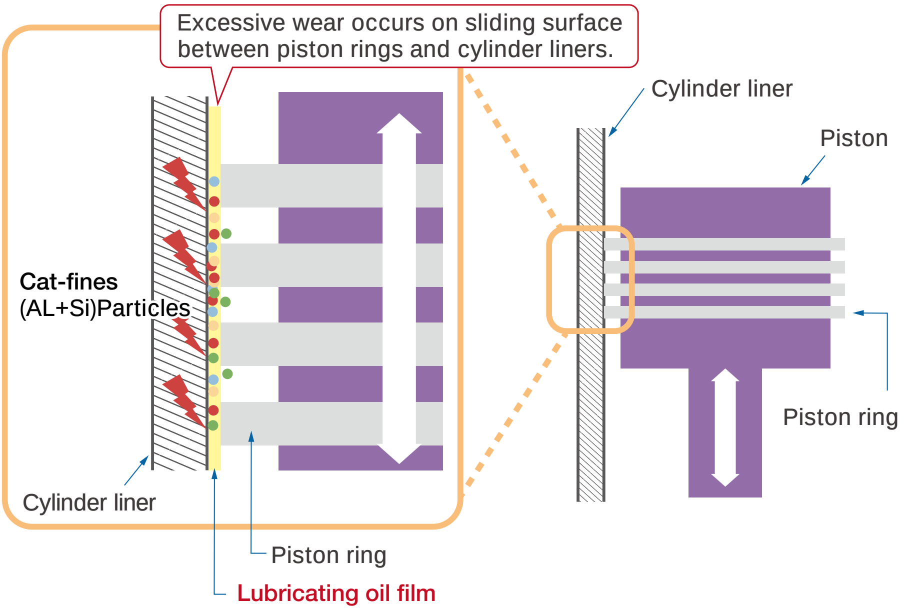
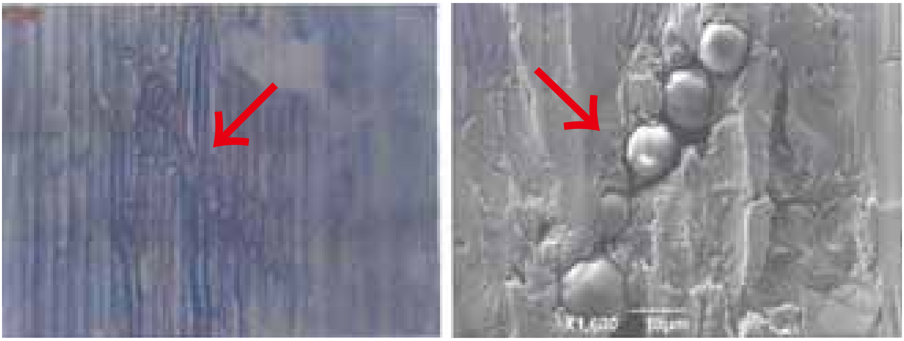


Figure 5-26　Cylinder abrasion by cat-fines

(a) Cat-fines embedded in the cylinder and trace of abrasive wear

(b) Cat-fines embedded in the piston ring



Photograph: ClassNK Guidance

Photograph 5-27 Cat-fines embedded in the piston ring and cylinder liner

5-2-5 ⑤ Ignition and combustion quality

Ignition quality

“Ignitability” here is divided into two stages: ignition and combustion quality. Ignition quality reflects the degree of ease with which a fuel self-ignites. It is generally expressed as the time taken from the initial injection of fuel oil into the combustion chamber to ignition (i.e., ignition delay).

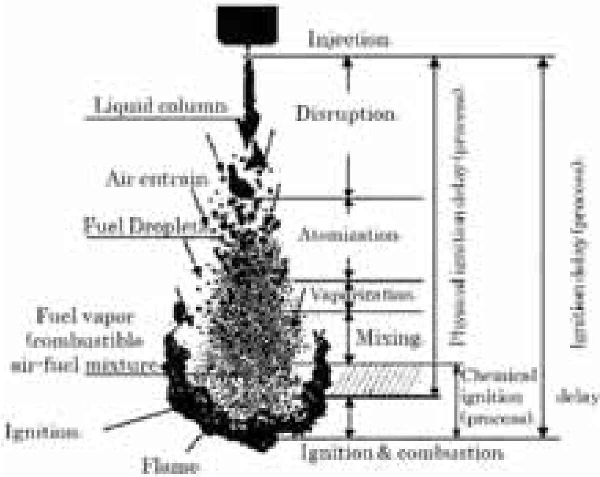


Figure: ClassNK Guidance

Figure 5-28 Behavior of diesel spray

Figure 5-28 shows the length of ignition delay for diesel spray. Ignition delay can be further subdivided into two stages: physical and chemical processes. The process of physical ignition delay begins with fuel oil being injected into a high-pressure environment from the fine tips of the fuel injection valve whereupon it spreads and atomizes. The atomized oil droplets then draw heat from the surroundings, and as surface evaporation progresses an air-fuel mixture of fuel vapor and air is formed.

The process of chemical ignition delay begins at the point where the air-fuel ratio (air mass/fuel mass) of combustible air-fuel mixture approaches the stoichiometric air-fuel ratio. Chemical ignition delay depends mainly on the ignition quality inherent in the fuel components.

Since both the cetane number and cetane index are not applicable to marine heavy fuel oil, CCAI (Calculated Carbon Aromaticity Index) is used as the indicator of ignitability. CCAI (Calculated Carbon Aromaticity Index) was developed as an indicator for the practical evaluation of the ignition quality of residual oil in the 1980s. It is an empirical index simply calculated from the oil density and viscosity. The higher the CCAI, the higher the aromaticity is, and consequently the poorer the ignition quality.

The guidelines set forth in “ISO 8217:2017 Petroleum products — Fuels (class F) — Specifications of marine fuels” specify the upper limit value of CCAI for RM (residual oil) grade. The CCAI was developed based on the two following assumptions: “(1) the ignition delay of fuel correlates to the carbon aromaticity of that fuel” and “(2) there is a correlation between carbon aromaticity and viscosity/density.” From 2020 various low sulphur blendstocks will be increasingly blended with VLSFO meaning that the correlation between CCAI and actual ignition delay will be less than before.

For the time being, the following formula should be used:

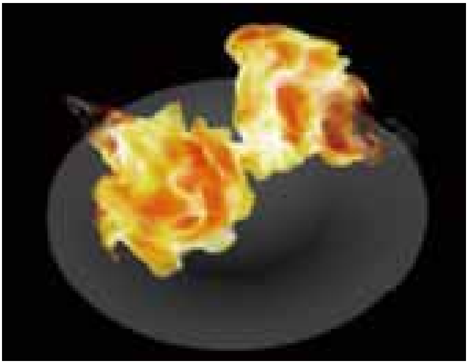
$$CCAI = \rho_{15} - 81 - 141 \cdot \log_{10}[\log_{10}(v + 0.85)] - 483 \cdot \log_{10}\frac{T + 273}{323}$$

ρ_{15} : density @ 15℃ , kg/m^3

v : kinetic viscosity @ T℃, cSt

Combustion

Whereas the term "ignition" refers to the start of combustion, the term 'combustion' refers to the latter half of the combustion process. It represents the extended combustion period, the flame length, and the proportion of unburned components such as black smoke and deposits in the combustion chamber.



Photograph 5-29 Ignition and combustion

Potential issues and countermeasures for machinery/plant systems affected by Ignition and combustion

Table 5-30 shows a summary of issues.

Machinery and plant system issues in the engine room

Compared to conventional fuel oil (HSHFO), VLSFO is blended with higher levels of LCO and CLO which can inhibit ignitability and flammability.
LCO, mainly composed of 2-ring aromatics, particularly affects the ignition quality of fuel oil.
CLO, mainly composed of 4 or more ring polycyclic aromatics, particularly affects the combustion quality of fuel oil.

1 Typical damage on a low speed 2-stroke diesel engine

① Excessive wear and breaking of piston ring.

② Excessive wear and scuffing of cylinder liner.

③ Excessive wear of piston rod/stuffing box packing and excessive