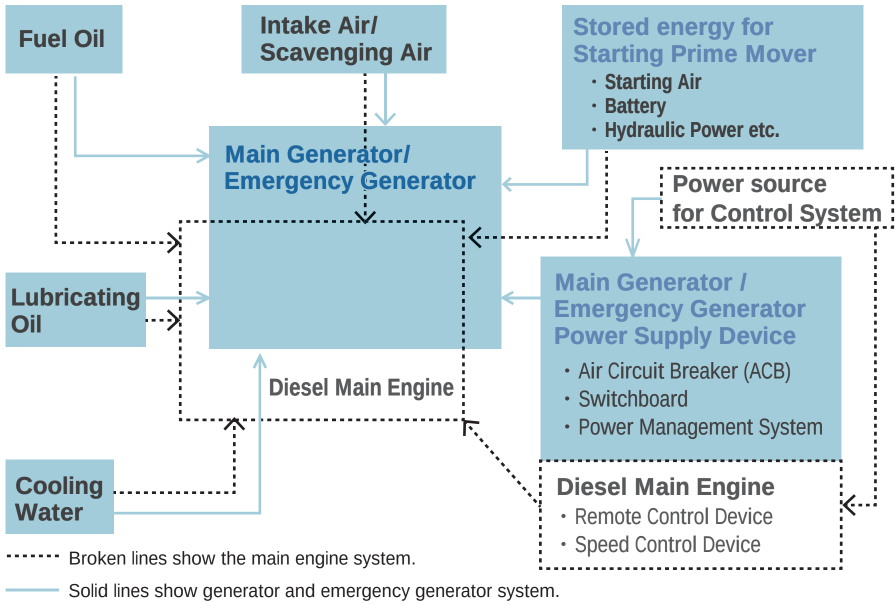


Figure 3-8 Basic configuration diagram of diesel engine system

Assuming that fuel oil supplies, lubricating oil, cooling water, intake air/scavenging air, a control device, a power supply device, or a power source for a control system is disrupted, in such a case, a diesel engine such as the main engine, diesel generators, and an emergency generator cannot operate in good order as designed. As a result, loss of propulsion or loss of power will take place. Figure 3-8 shows a basic configuration diagram of a diesel engine system.

3-3-2 Analysis of loss of propulsion

It is necessary to analyze and understand the causes behind a loss of propulsion in order to consider an appropriate response. Figure 3-9 is a diagram that breaks down the problems into elements and shows us a causal relationship among the main causes, their factors, and their elements in a step by step format. This style of visual representation is known as the Fishbone analysis.

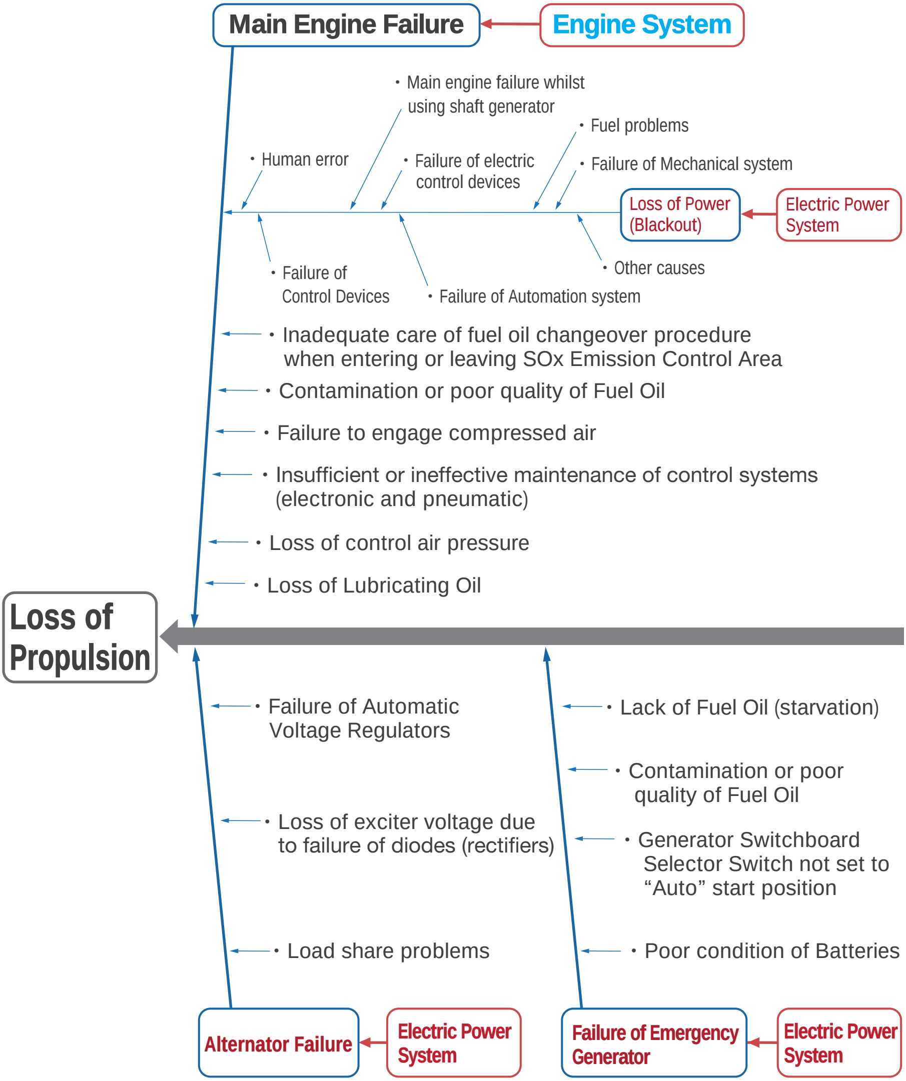


Figure 3-9 Overview of loss of propulsion and power: Fishbone analysis

As can be seen above, engine crewmembers need to manage the fuel oil, lubricating oil, cooling water, intake air/scavenging air, control devices, power supply devices, power sources, and so on, in order to maintain main engine propulsion. Furthermore, as described in the Japan Transport Safety Board's investigation reports, we must take extreme care and understand that the failure of the electric power system deeply affects the maintenance of propulsion. Therefore, it is recommended that the company and the ship review power supply system maintenance planning and an emergency response procedure to maintain the reliable operation of the main engine.

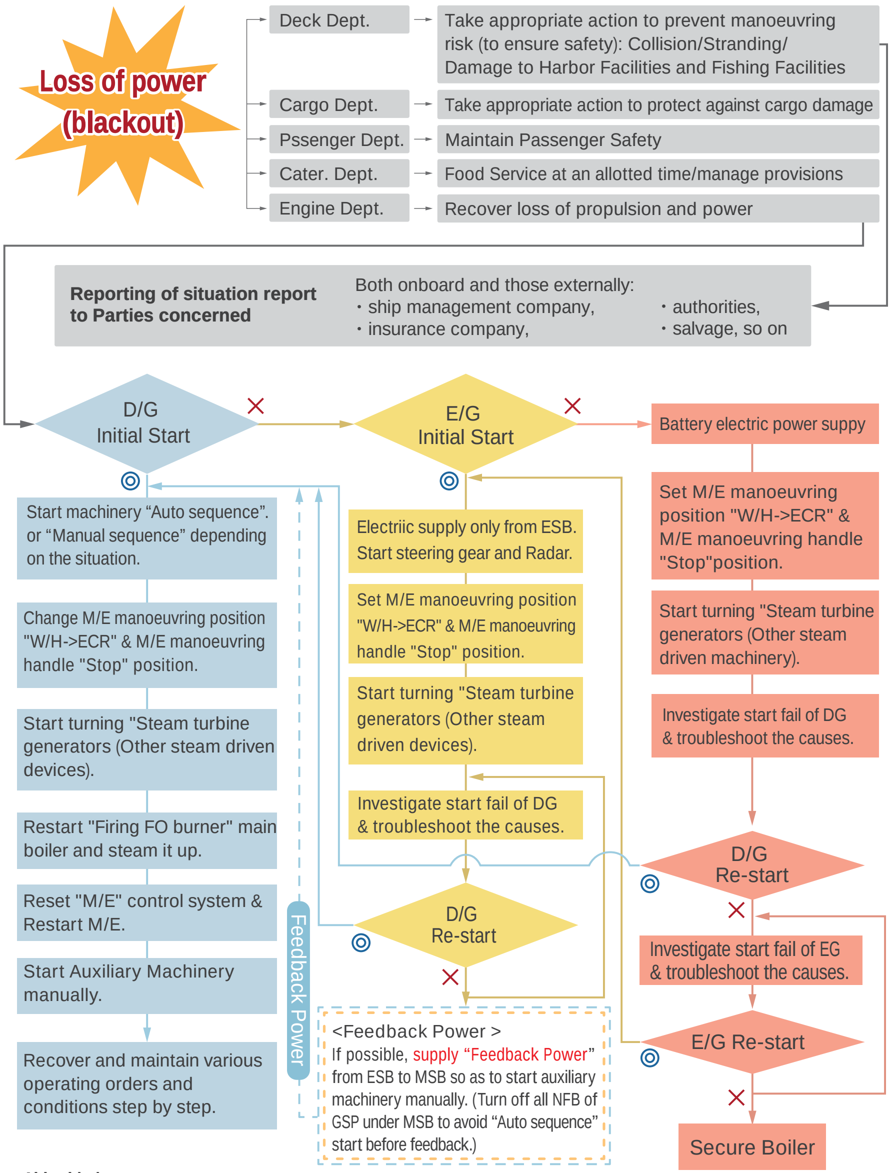
3-3-3 Emergency response when loss of power occurs (blackout)

Loss of power affects the various operations in the engine room and the entire ship. So, engine crewmembers need to take this into account and understand & respond with a recovery procedure.

It is necessary to work on an emergency response and recovery operation together with the cooperation of the entire team on board: not only the engine department alone but also the deck department, the cargo department, the passenger department, the catering department, and so on. See Figure 3-10 " Recovery flowchart for loss of power (Blackout) (Diesel Engine Plant System)".

In particular, close information sharing is required between the deck department and the engine department that is directly involved in the ship manoeuvring operation. The crewmembers need to understand that the procedure will differ depending on each power supply pattern, such as (a) successful start of diesel generator, (b) successful start of emergency generator only, and (c) only battery.

Furthermore, it is necessary to take action appropriately in accordance with the procedures specified in the SMS (Safety Management System).



Abbrebiations

M/E: Main Engine D/G: Deisel Generator E/G: Emergency Generator MSB: Main Switch Board
ESB: Emergency Switch Board W/H: Wheel House ECR: Engine Control Room FO: Fuel Oil Dept.: Department
NFB: No Fuse Breaker ◎: Yes ×: No

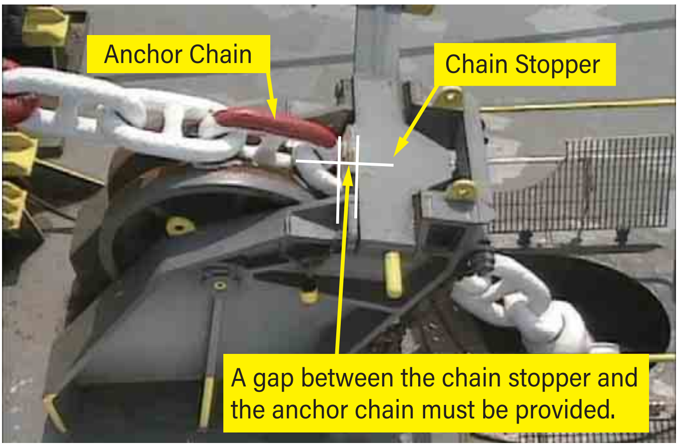
Figure 3-10 Recovery flowchart for loss of power (Blackout) (Diesel Engine Plant System)

Furthermore, it is also important that the crewmembers properly utilize the checklist, and confirm everything on it using the pointing and calling method to prevent the overlooking of a work procedure. Please refer to "Reference Material 06: Emergency response checklist immediately after loss of propulsion and loss of power" (Page 125).

Please confirm your department's appropriate response.

1 | Recovery work in the Deck department = Control action for voyage risk (collision, stranding, etc.)

The first action of manoeuvring in the wheelhouse is to grasp the circumstances surrounding the ship and to appropriately take collision avoidance actions. The next thing the officer on watch needs to do is to issue safety notifications to surrounding areas by VHF and report the situation to the Maritime Safety Authority and the company. Furthermore, in the case of loss of propulsion and loss of power in coastal waters, it is necessary to consider dropping an emergency anchor as appropriate.



Photograph 3-11 Chain stopper

DVD "Ship Handling in Restricted Waters- Anchoring-", Japan Captains' Association

In particular, there are set precautions that need to be taken regarding emergency anchoring. Normally, the anchor chain is stopped using the windlass brake. The anchor must always be securely held by the force of the brake, and a gap between the chain stopper and the anchor chain must be provided, so that the chain stopper and the anchor chain do not come into contact, as shown in Photograph 3-11. If the anchor chain slips and comes into contact with the stopper, the stopper cannot be removed. In case of loss of power, the ship will not be able to operate the windlass and hence be unable to drop an emergency anchor.

Therefore, the chief officer and technical superintendent must observe and inspect the gap as mentioned above as an important item to be confirmed for Chief Officer's on-deck rounds and the Superintendent's ship visit.

2 | Recovery work in the Engine department

1) Report to the Master

The Chief Engineer should precisely identify the power supply source at that time from and distribution destination as shown in Table 3-12 "Recovery procedures for engine department (Diesel engine plant system)", and report this so that the Master can get a complete picture of the current situation, when first reporting the loss of power to the ship and the company.

Furthermore, it is easy to clarify and understand the relationship between the power supply source and the power supply destination using the "Schematic diagram of the power supply system," as shown in Figure 3-13 as a supportive aid.

Recovery procedures for the engine department

(1) Report power supply source and its destination

① Diesel generator:
Nautical instruments, communication equipment, lighting, Main engine (high power device), auxiliary machinery (boiler), fire pump, etc.

② Emergency generator:
Nautical instruments, lighting, emergency fire pumps, etc.

③ Battery only:
DC 24V control system power source, radio communication devices, etc.

(2) Recovery work

① Initial response:
Keep calm, check the current situation, share information with Wheel House.

② Second:
Pay attention to heated steam drain returning to the drain tank.

③ Sequentially:
Work on fixing the causes and restart the engine plant system simultaneously.

1) Change the manoeuvring position "W/H->ECR" of the main engine's remote control system, and set the maneuvering handle to the "Stop" position.
2) Start turning steam turbine driven machinery such as steam turbine generators if necessary.
3) Confirm that the emergency generator started and that ACB closed automatically.
4) Confirm the direct cause.
Check whether each ACB can close in order to restart the generators.
5) Automatically or manually start the standby generator and close its ACB. Alternatively, restart the generator that was running and re-close ACB.
6) Pay attention to the electric load. Start important auxiliary machinery with "Auto sequence," or "Manual sequence "depending on the situation.
7) Start up other auxiliary machinery.
8) Restart the main engine and check that each operation is fully functional step by step.
9) Investigate the root cause and establish preventive countermeasures.

Table 3-12 Recovery procedures for engine department (Diesel engine plant system)

〈 Schematic diagram of power supply system 〉

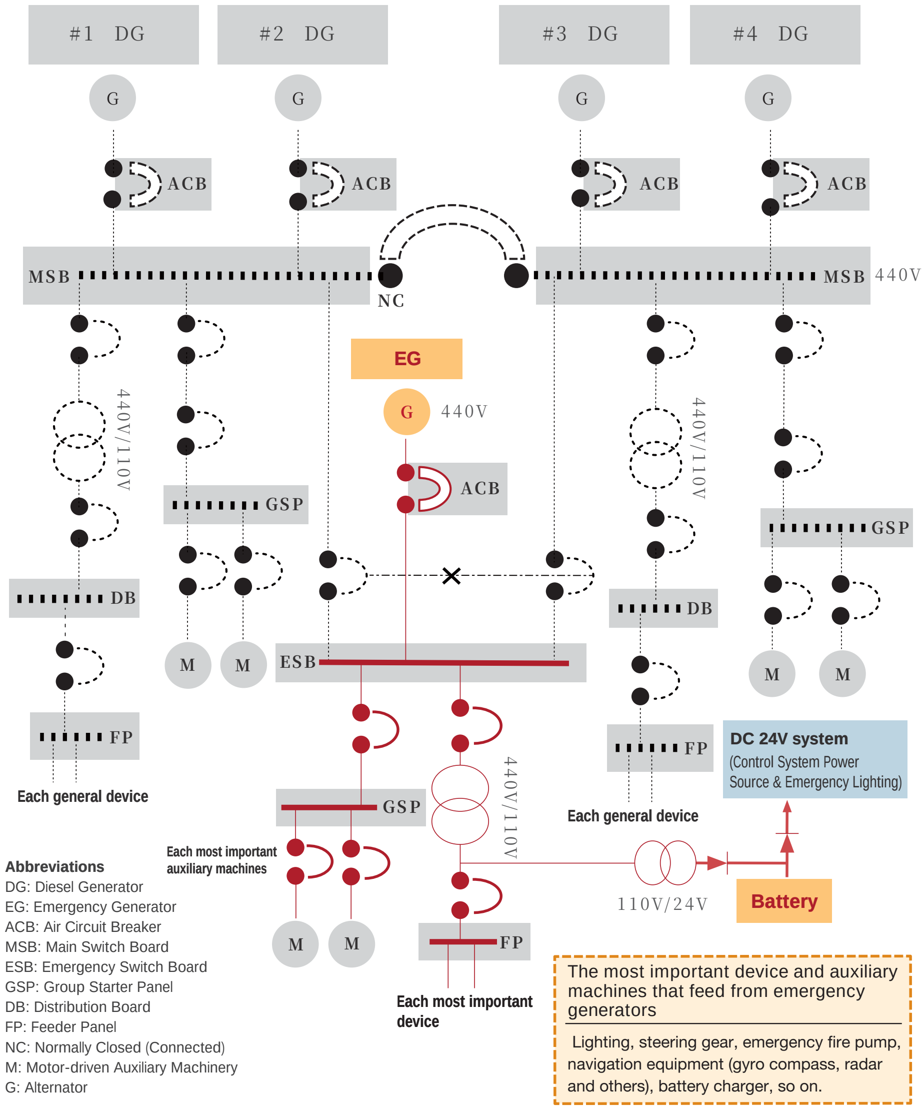


Figure 3-13 Schematic diagram of power supply system

Figure 3-14 shows the recovery work cycle. Recovery work in the engine department consists of repeating the following: “investigating causes in the engine room”, “establishing common understanding and recognition of the situation”, “repairing damage”, “trialing a test run for restart”, “understanding the stoppage/failure”, and “investigating causes”. If the recovery work is deemed to take a long time, from the perspective of fatigue, the Chief Engineer may need to consider shifting from an all-out staffing arrangement to the mobilization of a split work rotation with a second shift or a third shift and arrange for shore support if necessary.

〈 **Recovery work cycle** 〉

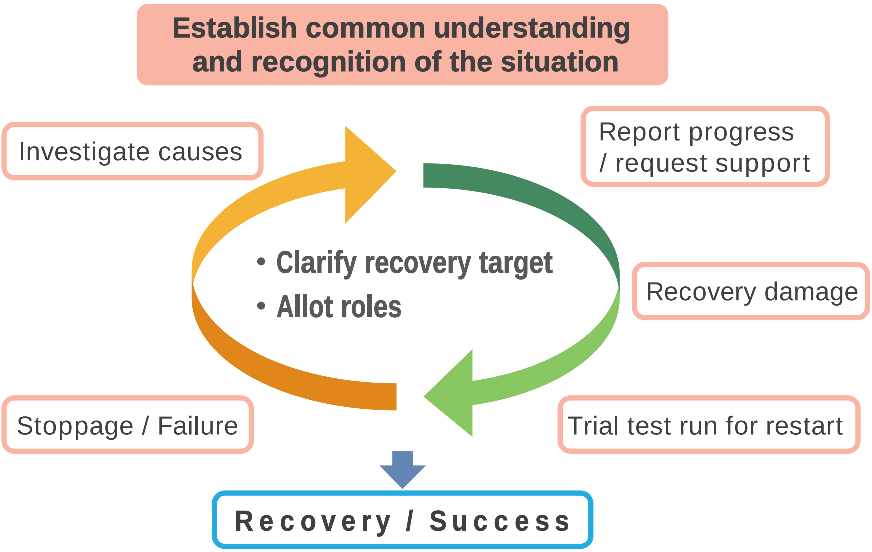


Figure 3-14 Recovery work cycle

2) Precautions for recovery work

Regarding “②Second” in “(2) Recovery work” shown in Table 3-12, even if the boiler or pump is stopped due to loss of power, the liquid (steam) may flow downstream (low pressure) due to its physical properties. Therefore please pay close attention to the water level and temperature in the atmospheric drain tank.

Regarding the recovery response pattern, in Figure “3-10 Recovery flowchart for loss of power (Blackout) (Diesel Engine Plant System)”, “**blue**” represents the successful start of the diesel generator, “yellow” is the successful start of the emergency generator only, and “**red**” is battery only. The recovery procedure differs depending on the circumstances of each power supply source.

Especially when it takes a considerable amount of time to restart the diesel generator, if the ship is equipped with a switching system that allows feedback power supply from the emergency generator to the main switchboard, the ship may take advantage of it.
However, caution must be exercised when using the feedback power supply, if engine crewmembers do not have such dry docking experience, they will be unfamiliar with the operation of switching from the emergency switchboard to the main switchboard using the feedback power supply, which may lead to an insufficient emergency response. Therefore, it is recommended that the engine department carry out onboard training of the feedback power supply system when time permits, along with opportunities such as any drills necessary for an emergency response and start-up test/load test run of the emergency generator.

3) Elimination of causes

Table 3-15 shows the typical causes behind the failure of an engine system and electrical power system. Past cases from the current ship and from other similar ships will be indispensable in investigating any future cause and help build countermeasures. Engine department crewmembers must utilize such information to promptly establish the abnormality and eliminate causes during the recovery process.

Engine System

(1) Engine failure

① Diesel Generator

(a) Fuel issue
- Blocked strainer
- Blocked fuel oil supply system because of Vapor Lock

(b) Overspeed trip
- Malfunction of speed sensor

(c) Trip due to Loss of Lubricating Oil Pressure
- Blocked strainer
- Malfunction of a Pressure switch

(d) Trip due to Overtemperature of Cooling fresh water
- Malfunction of a Temperature control valve or a thermocouple sensor

② Steam turbine generator

(a) Excessive shaft vibration, movement of shaft position, High exhaust pressure, Overspeed, Loss of Lubricating Oil Pressure, etc.

Electric Power System

(2) Electrical failure

① Air Circuit Breaker (ACB: Circuit breaker between generator and bus)
- Over current
- Under voltage
- Reverse power trip
- Mechanical defect

② Switchboard bus
- Voltage: Over or under
- Frequency: Over or under

③ Control power supply
- Voltage drop
- Fuse blown, etc.

Past Cases

(3) Check and study "Analysis and Lessons learned" of past accident cases encountered.

Table 3-15 Possible loss of power causes

4) Daily operation management as preventive measures

The Chief Engineer needs to encourage crewmembers in the engine department to carry out the management of preventive measures on a daily basis, as shown in Table 3-16, in order to ensure safe and secure operation management.

In particular, it is recommended that crewmembers satisfy the following minimum requirements.

① With reference to the countermeasures of cleaning a strainer in Accident 5 shown in Table: Reference 11 “Reference Material 05: The investigation reports of the Japan Transport Safety Board; cases of loss of power”, crewmembers must never carry out maintenance of equipment on a fuel oil supply pipeline during manoeuvring standby station.

② Engine crewmembers must secure adequate electrical capacity available before starting large electric motors such as bow thrusters.

This is because the starting current of electric motors may be several times the full amount of an “on load” current.

Furthermore, regarding engine operation management and emergency generator management, assuming that the standby generating machinery cannot be started, the engine department must regularly carry out a start-up test/load test run of the standby diesel generators and emergency generator.

Daily operation management for preventive measures

(1) During manoeuvring operation on standby

① Engine crewmembers must not carry out cleaning and maintenance of strainers or fuel supply systems.

② The watchkeeping engineers must monitor the starting air pressure. The deck department's bridge team must know the limitations of starting air availability and operate the main engine appropriately. (12 times for Single screw ships: Class Rule).

③ Engine crewmembers must switch power supply from shaft generators to Diesel generators well before entering restricted waters and well before initiating a critical manoeuvring operation. They must follow the manufacturer's guidelines.

④ The ship must test the astern operation of the main engine prior to boarding of pilot and before approaching berth.

⑤ Engine crewmembers must establish that there is sufficient electrical capacity available before starting up the lateral thrusters, mooring machinery, or other heavy load equipment. They must pay special attention to the simultaneous starting of large electric motors that will lead to a large power surge and risk of overload.

⑥ The ship must test the lateral thrusters and mooring machinery well in advance of entering restricted waters and starting critical manoeuvring operations.

⑦ The ship runs two (or more) generators in parallel because Engine crewmembers must ensure sufficient power availability even if one of them stops or trips.

(2) Sharing of power load and related training

All watchkeeping engineers must have training in manually operating load share, putting generators on board, and taking generators off board.

(3) Engine operation management

① All engineers must be fully familiar with all engine room systems and their pipelines.

- They must know how to isolate one cylinder of the main engine when it fails so that the main engine can at least continue running until repair has been completed.
- They must know all operation methods of the Main engine plant system.

② Engine crewmembers must know the cause of power loss and take preventive measures.

- Fuel pressure control valve condition, a clogging strainer, damage to fuel supply piping, a lack of cooling water supply, etc.

③ Engine department must regularly carry out a start-up test/load test run of the standby diesel generators under the following conditions.

- Weekly start-up test runs: prior to port arrival and narrow channel entry.
- Load test: supply heavy fuel oil, and regular loads, for 30 minutes.

(4) Planned Maintenance System (PMS)

The ship carries out repair/inspection/maintenance regularly.

(5) Fuel oil management

① Engine crewmembers must strictly ensure that the fuel oil viscosity and temperature control devices work accurately.

② They must drain water regularly from fuel oil tanks because they must prevent water build-up and carryover in the fuel and lower the risk of bacterial contamination/microbial infestation.

(6) Emergency response

Engine Department must make manuals/procedures/checklists/work instructions for emergency responses such as "standby machinery failing to start".

- Engine Department must regularly conduct "Loss of Propulsion" and "Loss of Power" drills by carrying out simulations of the situations on board.

- Additionally, they need to study and include them in the procedure for supplying power via the feedback method from the emergency switchboard to the main switchboard.

(7) Emergency generator management

① Engine Crewmembers must disconnect the battery charger from the mains when carrying out weekly tests for emergency generator with a battery charger.

② Engine department must also regularly carry out start-up tests/load test runs on the emergency generator under the following conditions.

- Start-up test run: weekly.
- Load test: supplying on load as close to the maximum capacity as possible, for 30 minutes.
- The Marine Safety Agency of the UK recommends weekly tests in the Marine Guidance Note (MGN) 52, 1998.

(8) Others and incident investigations

① Properly trained personnel must investigate any loss of propulsion or loss of power and determine the root cause.

② After analysing the incident and specifying the countermeasures, the ship must work on them effectively by comprehensively evaluating and prioritizing depending on their level of importance.

Table 3-16 Daily operation management for preventive measures

3-4 Summary

According to the accident investigation report of the Maritime Safety Authorities, the following points of caution are often introduced because accidents, such as loss of propulsion and loss of power, have occurred in the world.

(1) What daily operation management of preventive measures are required onboard?

(2) How effective is the sharing of information and collaboration among related parties when a recovery operation is to be carried out together as one team on board, following the occurrence of an accident?

(3) How should the engine department establish causes, eliminate them, and work on recovery procedures, taking into account other departments' work?

While these may be understood in theory, in practice it is difficult for many to take immediate action appropriately right after a marine casualty has occurred.
Therefore, parties concerned need to prepare measures on a regular basis that deal with both the soft aspects and hard aspects of engine room management in preparation for an actual situation. It is recommended that crewmembers properly prepare and repeat practical training onboard. Please refer to "Reference Material 07: How to prevent panic" (Page 127).

Chapter 4 Prepare for Bunker Trouble (Engine accident due to poor fuel oil quality)

When engine troubles occur due to the properties of fuel oil, the causal relationship between the cause and the result becomes a moot point when it comes to claims. The ship summarizes the facts recognized as phenomena related to troubles in chronological order and prepares a statement of facts. Its purpose is to explain the situation surrounding the trouble and where the problems lie to relevant parties such as charterers. Furthermore, the ship also needs to thoroughly collect supporting documentation simultaneously.

For continued safe operation, it is essential to secure fuel oil of stable quality. However, the ship sometimes faces bunker trouble (engine accidents caused by bunkering fuel oil). Therefore, in order to take precautions against bunker trouble, it is also necessary to reconfirm the preventive measures that engine crew members must adhere to daily and be well versed in methods for preserving evidence, a must when it comes to bunker trouble.

4-1 Importance of preserving evidence in time of bunker trouble

In 2018, hundreds of accidents related to severe technical problems and mechanical damage on ships due to contaminated fuel oils delivered in the Houston (USA) area and Caribbean ports such as Panama occurred.

HFO separator after one hour of operation
: blocked by heavy, hard sludge

HFO separator damaged gear due to overload caused by heavy sludge

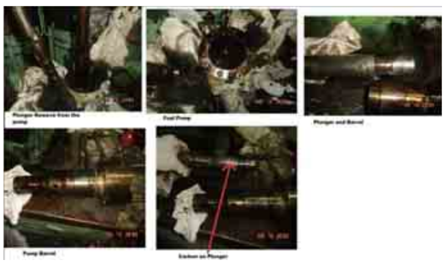
Fuel injection pump :
the plunger was found completely seized in the barrel

Fuel booster plunger stuck in the barrel

Photograph 4-1 (a) An INTERTANKO Critical Review（An INTERTANKO Critical Review）

Sludge particles

HFO separator :
completely blocked by heavy, hard sludge



Fuel filter: visible heavy sludge,
which blocked the filter completely

Photograph 4-1 (b) An INTERTANKO Critical Review（An INTERTANKO Critical Review）

The statement that the international association of independent tanker owners (INTERTANKO) issued concerning issues that the industry needs to be aware of includes Photographs 4-1 (a) and (b).
Typical situations related to engine accidents are as follows.

① The fuel injection pump's plunger was seized due to chemical contaminants, which made the main engine and generator inoperable.

② The oil purifier became blocked due to the accumulation of a large amount of sludge, thus becoming inoperable.

When an engine accident occurs on board, engine crewmembers rush to respond to the recovery on site. So evidence of bunker trouble is prone to being misplaced or even lost. However, it is difficult to establish a causal relationship if there is insufficient evidence in the subsequent stakeholder dispute. Focusing on the seriousness of the accident, Law Offices of Toda & Co. (experts in various shipping cases) proposed the following issues and countermeasures to legally resolve an engine accident caused by bunkering fuel oil.

1.Issues:

① When the ship (shipowner) disputes the claim caused by poor quality bunkering fuel oil, the background of repair/inspection/maintenance, machinery operation, defective design, and so on is also an issue to be disputed. Since it is difficult to establish a causal relationship, the timing of fuel oil switching, the history of abnormal occurrence, and the preservation of evidence are extremely important.

② On the other hand, unfortunately, in quite a few cases, engine crewmembers always give the highest priority to inspection/repair/maintenance work on board, so they are prone to overlook the following:

a) The poor handling of damaged parts and extracted fuel oil/sludge etc.

b) The disposal of a piece of important evidence in error.

c) To put off reporting on the facts surrounding bunker trouble until later.

As a result, this only increases the risk of evidence getting misplaced or lost.

③ There have been many cases whereby evidence on board has been misplaced or lost. (Engine crewmembers are likely to discard sludge and replaced parts during onboard work.)

Point **When engine crewmembers concentrate on their daily onboard work, they are prone to forget many record-keeping tasks. As a countermeasure, if they become accustomed to recording, including date and time, work details, confirmation, and repair/inspection/maintenance, they can safeguard themselves.**

2.Countermeasures:

① To be able to take appropriate measures (following "3.Guidelines for the preservation of evidence:") in the event of an accident, the ship management company must provide regular guidance to engine crewmembers based on the importance of preserving evidence.

Point **Repeated "training".**

② When there is a problem reported from a ship, the ship management company must promptly contact the charterer to cooperate with protesting against the fuel oil supplier.

Point **Based on the designated response flow, parties perform "Report, Inform, and Consult".**

Photograph 4-2(a) Bunkering work: Sounding tank level

Photograph 4-2(b) Bunkering work: Calculating tank volume

3.Guidelines for the preservation of evidence:

Table 4-3 shows the steps for countermeasures in order to preserve evidence.

Procedure for preservation of evidence

(1) Preservation of evidence to be carried out by ship/ship management company (owner)

① Engine crewmembers must precisely record and retain Tank Sounding Records, the Oil Record Book, and the Engine Log Book in case the ship needs to ascertain if/when it started using suspect bunker oil.

② Engine crewmembers must take photographs of unusual sludge with Date/Time taken, and securely retain them.

③ Engine crewmembers must take photographs of damaged parts with Date/Time taken, and securely retain them.

④ Engine crewmembers must report in detail on Engine trouble and the sequence of events that led to it.
They must also report any trouble and how it was handled to the ship management company. This goes especially for HFO.

⑤ The owner/ship management company must prepare the Crewmembers ' Statement
(This must include succinct details about the process leading up to the use of suspect bunker oil, damage status, and how to respond to trouble.)

⑥ Engine crewmembers and ship management company must check the accuracy of the records of the Bunker Delivery Note (BDN) every time
(to especially, check the serial number of sample bottles and the remarks.
Some supply barges try to avoid taking a bunker sample at the vessel's manifold.)
・Remarks must include the following

information:

・Where to take samples: from manifold?
・How to take samples: by way of continuous drips?
・How to witness sampling: attend bunker delivery?

※ 1 If there are inaccuracies or a lack of information in the BDN, correct it and record the remarks into the BDN.
In case the crewmembers fail to correct the records in the BDN, please immediately prepare the crewmembers ' statement for future reference.

※ 2 In case of inconsistency between the serial number of the sample bottle and the record in the BDN, the sample's testing result may not be trusted or ruled out due to it not being representative. In such a case, collect/keep the materials to prove that it is representative, such as Landing Pass, Fuel Information Sheet of the bottle, Fuel analysis report, etc.

⑦ Engine crewmembers are to safely retain the sample bottle after having taken a sample of bunker.
They must also take/safely retain a sample bottle of suspect bunker oil in the fuel tank before de-bunkering operation.
(Please pay attention not to take a biased sample when taking the sample.)

(2) Preservation of evidence to be carried out by the owner (ship management company) and charterer

⑤ The owner/ship management company must prepare the Crewmembers ' Statement as an official document. (same as above (1) ⑤)
(This must include succinct details about the process leading up to the use of suspect bunker oil, damage status, and how to respond to trouble.)

⑧ The owner (ship management company) and charterer must consider carrying out detailed testing such as GC-MS analysis as soon as possible. (CG-MS: Gas Chromatography-Mass Spectrometry)
(If necessary, they may consider a metallurgical analysis, too.)

(a) The detailed testing shall be carried out jointly by an independent and neutral laboratory with the attendance of surveyors appointed by multiple parties.

(b) Please arrange a joint survey for the testing.

(c) Before testing, please inform the parties, including Suppliers of the detailed information.

(Regarding the collection of the damaged parts, sludge, and the de-bunkered oil, it is desirable to appoint each party's surveyor to attend.)

(3) Preservation of evidence to be carried out by the charterer

⑨ The owner (ship management company) needs the Charterer's full cooperation and support to immediately collect information relating to the Supply chain (Who is the seller of the physical supplier? Who is the refinery?, etc.) of suspect bunker oil.

*3 Since it is difficult for the ship management company (owner) to pursue the supply chain where the real fuel supplier procured the fuel oil from, we recommend the ship management company (owner) ask of the Charterer's investigative cooperation to enable early settlement.

Table 4-3 Procedure for preservation of evidence

4-2 Summary

Fuel oil is supplied from the charterer to the owner (the ship) under the charter party. Safe navigation will always be guided by mutual trust which must be kept under the promise of “Quality of Fuel Oil: the fuel oil shall not include that which jeopardizes the safety of the ship or that which adversely affects the performance of the machinery”, Regulation 18 of Annex VI of “The International Convention for the Prevention of Pollution from Ships (MARPOL)”.

Example of records related to safety management and repair/inspection/maintenance

(1) Entries in Engine Log Book, and record books, etc.

(2) Maintenance of documents and files in accordance with the SMS manual

(3) Storage of replaced damaged parts as evidence

(4) Monitoring records of machinery status related to running hours

(5) Records of damaged machinery, operating and running history, lubricant management history, planned maintenance system (PMS) documents, and inspection/repair/maintenance records

(6) Ship-shore communication records (FAX, e-mail, etc.) about onboard work management concerns

(7) Memorandums of onboard discussions between the ship (Master & Chief Engineer) and the shoreside (person in charge at the company)

Table 4-4

On the other hand, it is difficult for insurance companies to confirm the accident's history and details even if insurance companies try to handle the claim unless records such as the repair/inspection/maintenance shown in Table 4-4 are retained on the ship. Please understand that the daily onboard work records are always important pieces of evidence or records.

Chapter 5 IMO 2020 compliant fuel oil

In order to prevent any adverse effects on human health and air pollution caused by ship exhaust gas, worldwide controls were put in place to reduce the emission of Sulphur Oxides (SOx) and Particulate Matter (PM) from ships in accordance with Regulation14, Annex VI of the "International Convention for the Prevention of Pollution from Ships (MARPOL)".

Since January 1st, 2020, sulphur concentrations of any fuel oil used onboard have been curtailed from 3.50% m/m to the current requirement of 0.50% m/m in open sea areas outside Emission Control Areas (ECAs).

This chapter explains the precautions that crew members need to be aware of when handling low sulphur compliant fuel oil with a 0.5% m/m sulphur limit.

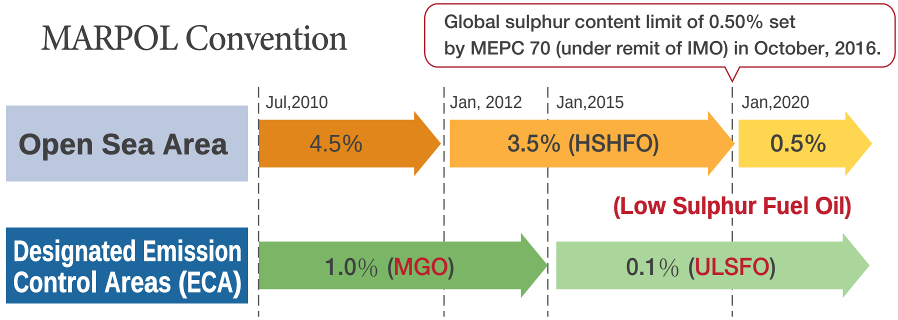
Marine sulphur Emission Control Areas

International Marine Organization Emission Control Areas

European Union Sulfur Directive

Chinese Emission Control Areas

Figure 5-1 Marine sulphur Emission Control Areas



Abbreviations HSHFO: High Sulphur Heavy Fuel Oil, MGO: Marine Gas Oil, ULSFO: Ultra-Low Sulphur Fuel Oil

Figure 5-2 Timeline of sulphur emission restrictions, prescribed under Annex VI of the MARPOL Convention (under remit of IMO)

5-1 IMO 2020 compliant fuel oil concerns

Nippon Kaiji Kyokai (ClassNK) summarized the concerns about IMO 2020 compliant fuel oil in its publication the “March 2019, ClassNK Guidance for onboard use of Compliant Fuel Oil with Sox regulation from 2020”, at its technical seminar held in June 2019.

This document is an amalgamation of material and guidelines mainly taken from this seminar, and additional reference material taken from a variety of other technical documents from the marine shipping industry.

5-1-1 Production of marine fuel oils

Figure 5-3 shows the manufacturing process at a typical petroleum refinery, and the blending process required to produce marine fuel oils.

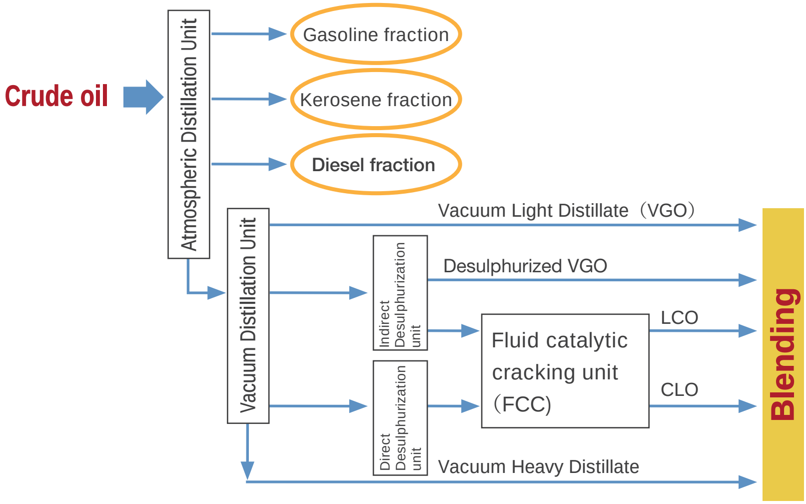
Crude oil is heated to 350°C or below and passed through an Atmospheric Distillation

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).**

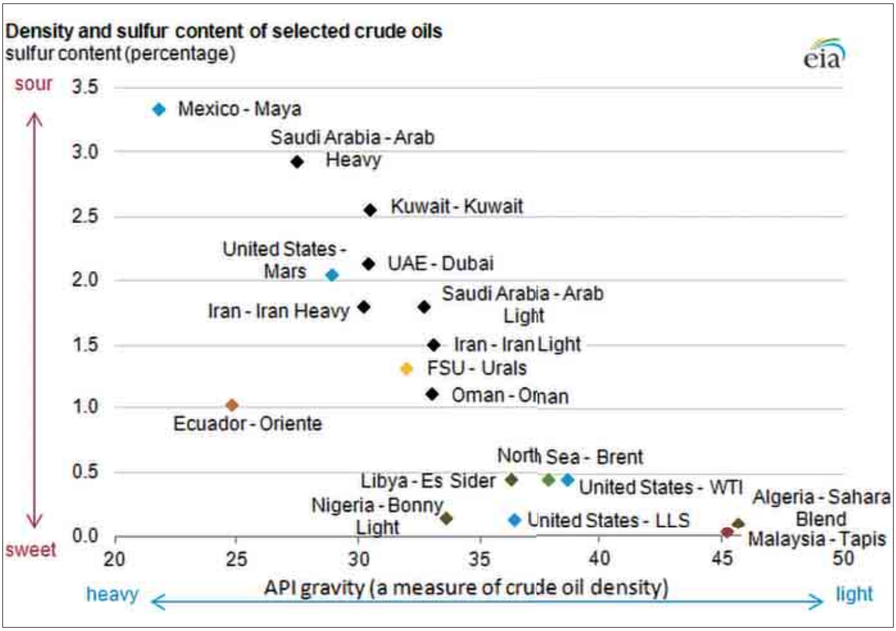


Figure 5-4 Density and sulphur contentof selected crude oils

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 IMO 2020 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.

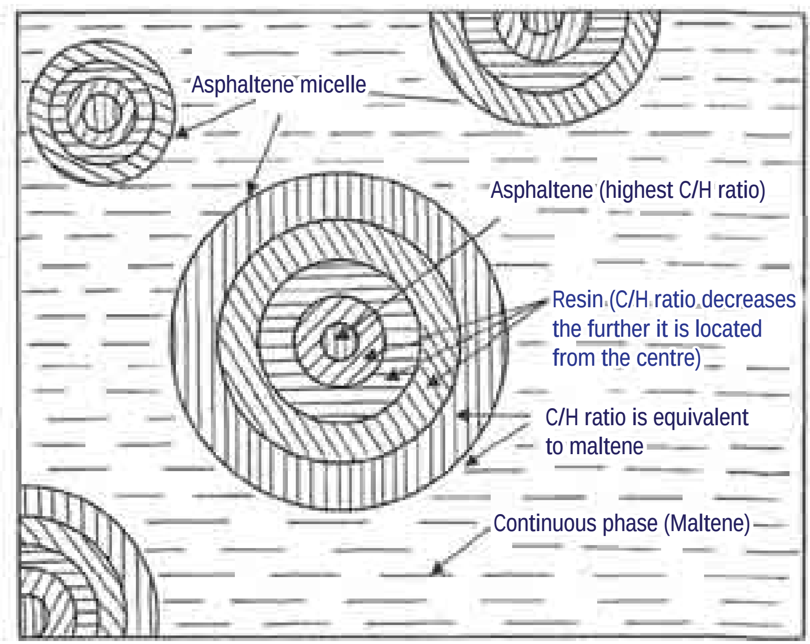
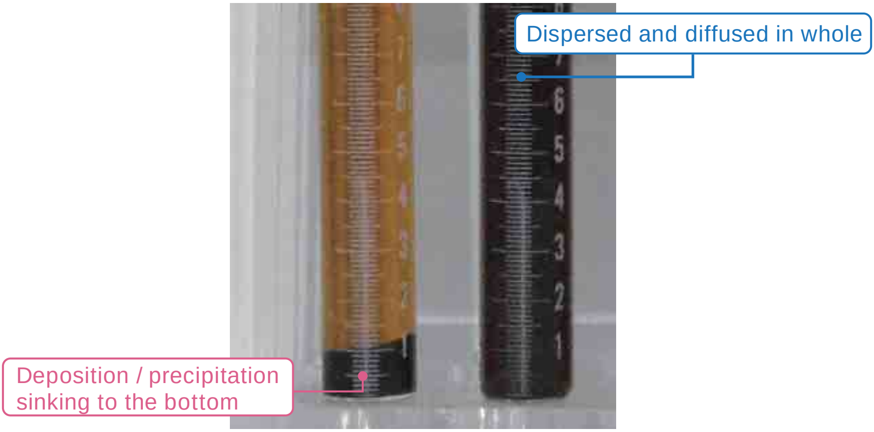


Figure 5-5 Structure of asphaltene micelle

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 5-10.

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

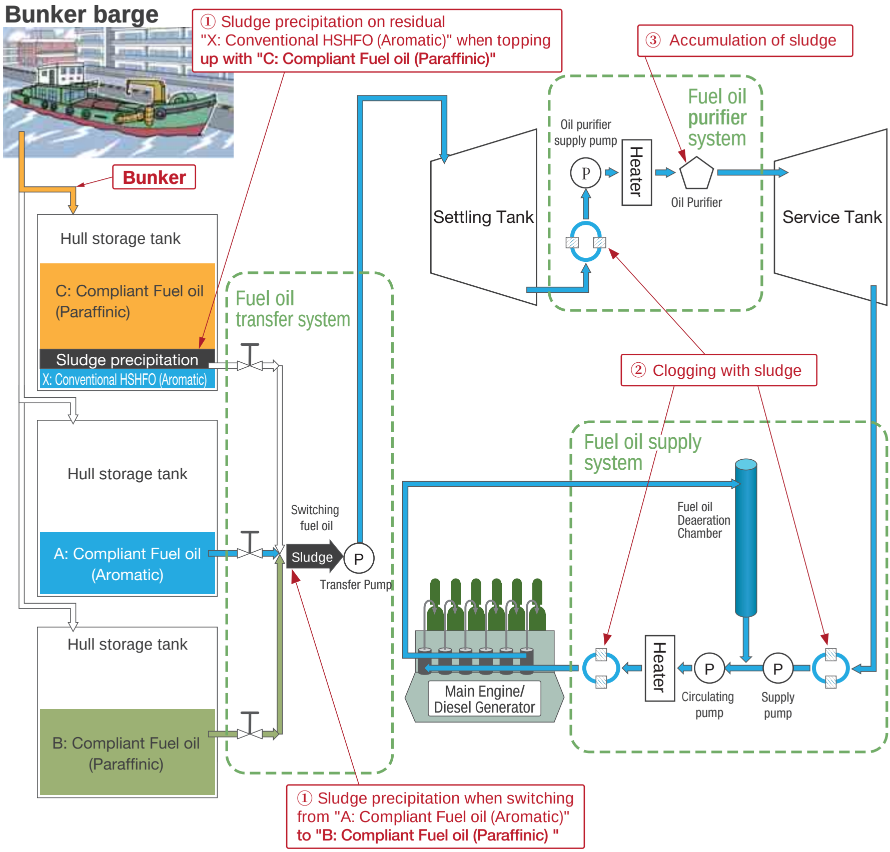


Figure 5-8 Fuel oil piping system (1)

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, 5-13 and 5-14

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).

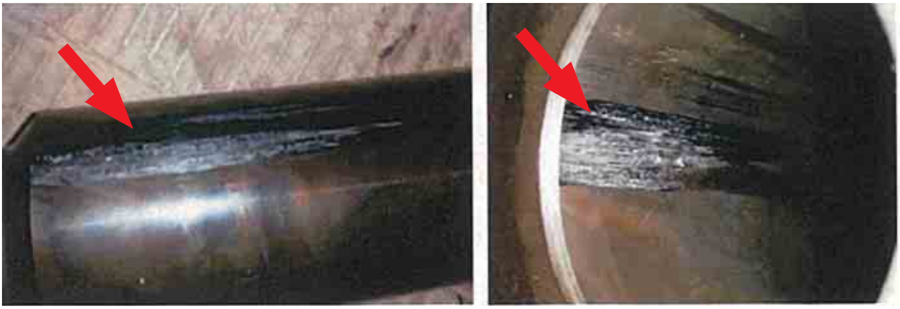
② Overhauls and maintenance
Some VLSFOs have a high kinematic viscosity and a large amount of residue. The clearance between the sliding parts of the fuel supply pump and the fuel injection system can increase due to wear.
If the kinematic viscosity of fuel oil is significantly lower than that which 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.

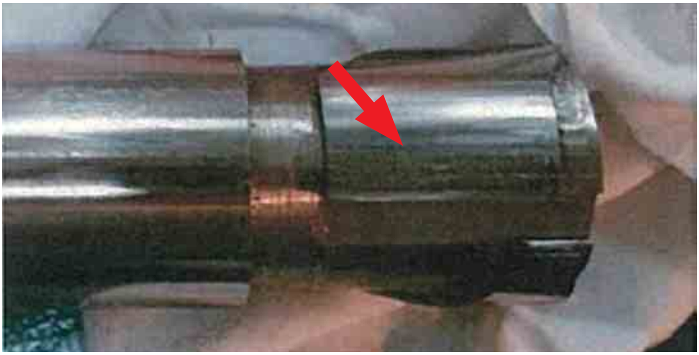
② Monitor fuel oil temperature so that viscosity remains within the recommended range of the manufacturer.
Kinematic viscosity can be controlled if the fuel oil is 100 cSt @50℃ or higher. However, if kinematic viscosity is low, crew should be aware that it may be difficult to adjust onboard by steam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

Q 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!

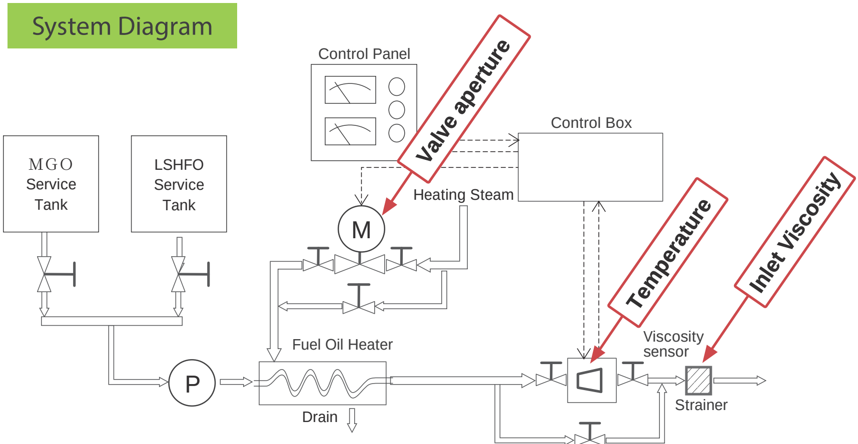
Understand the technology
Viscosity Controller

Check ⇒ System Diagram

Understand the science
Viscosity Characteristics of HFO

Check ⇒ Diagram

System Diagram



Low kinematic viscosity: Beware! It may require cooling.

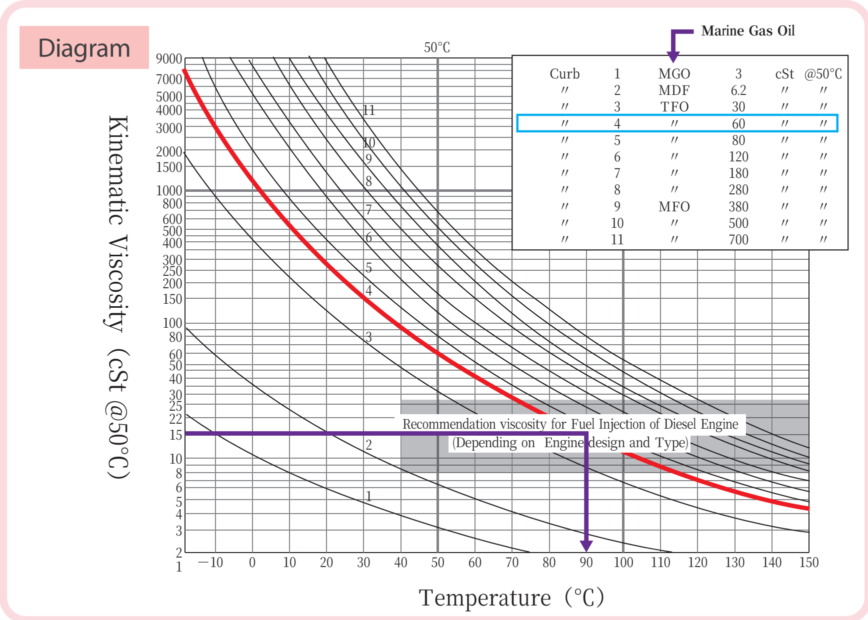


Figure 5-15 Viscosity controller

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

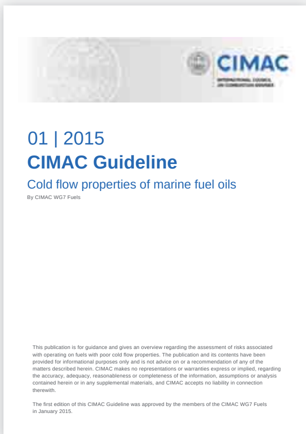


Figure 5-16
01| 2015 CIMAC Guideline Cold flow properties of marine fuel oils

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 °C 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

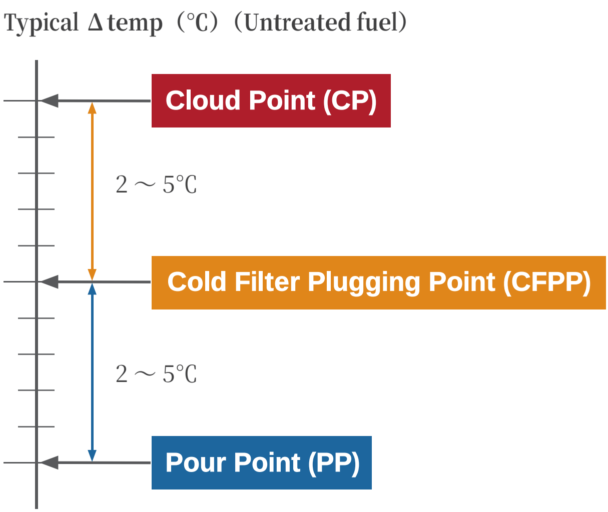


Figure 5-18 Definition of cold flow properties

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℃).

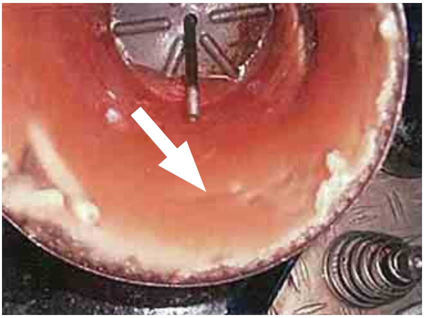
1. When using fuel oil without a heating device, ensure that the operating environment (*) is PP+10 ℃ or above, taking into consideration the navigation route and season.
   When fuel oil cannot be used, employ wax suppresants to control wax formation.
   ＊Operating environment: Conditions which affect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

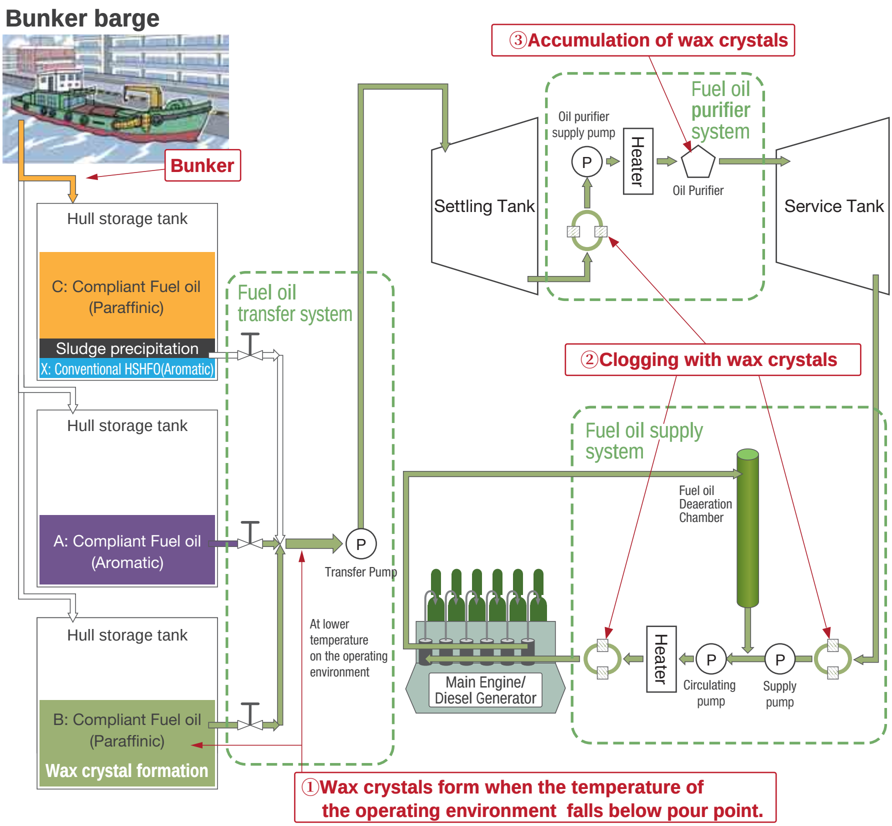
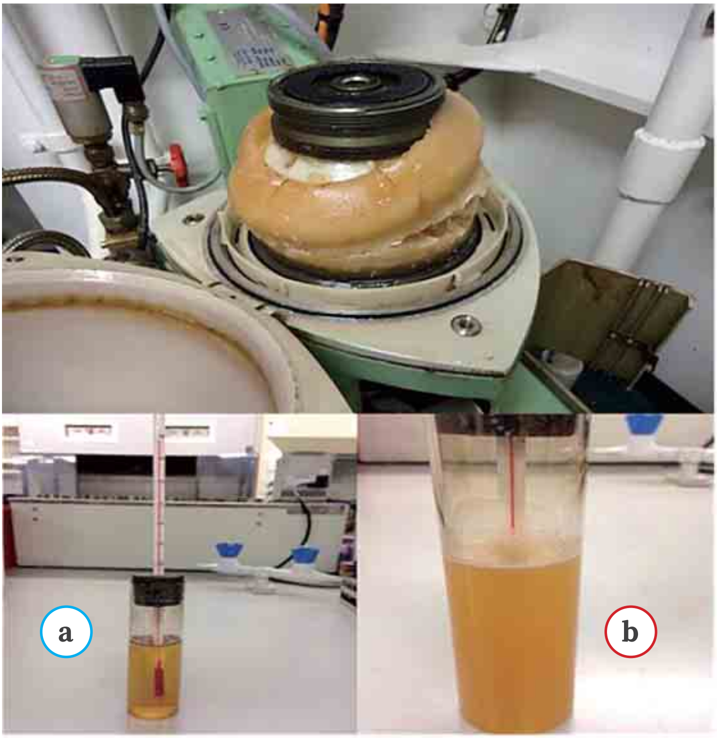


Figure 5-21 Fuel oil piping system (2)

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 ($Al2O3$) and silica ($SiO2$).

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.

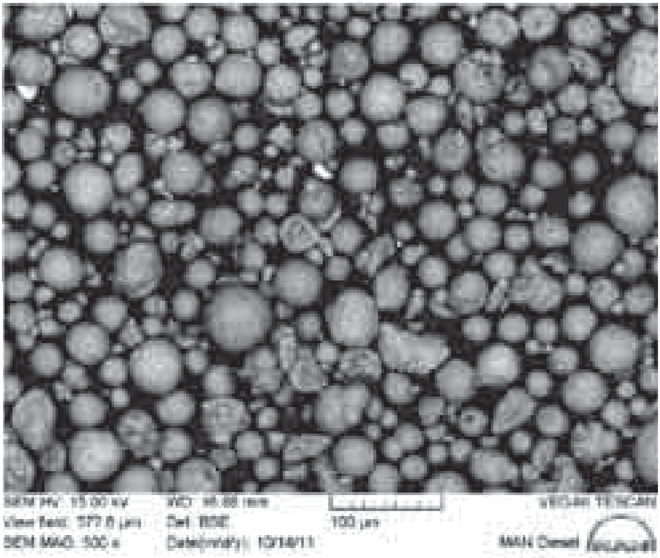
7 Operate the filter in front of the engine inlet in accordance with the engine manufacturer's operating manual. Pay particular attention to the following:

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”

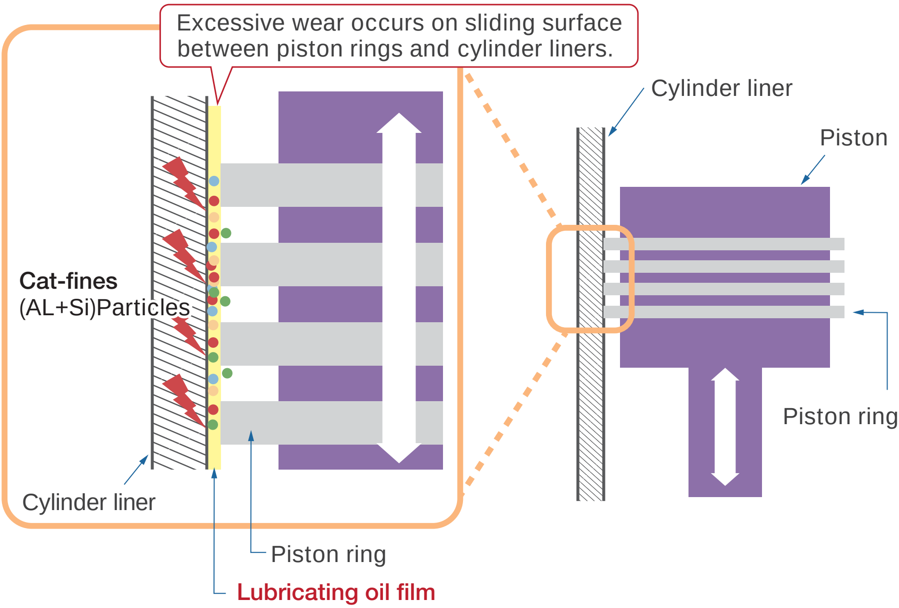


Figure 5-26 Cylinder abrasion by cat-fines

(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).

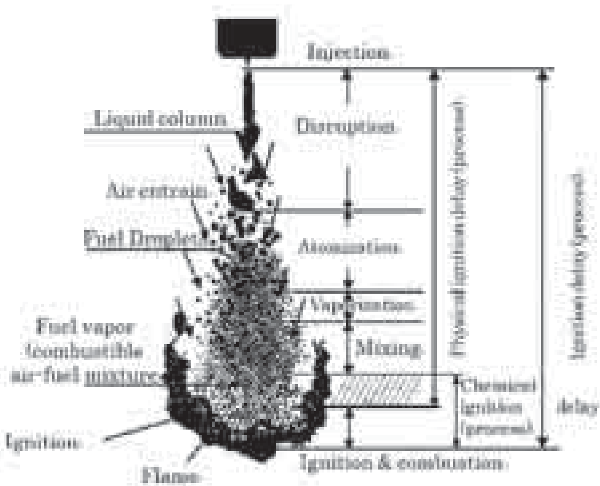


Figure: ClassNK Guidance

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:

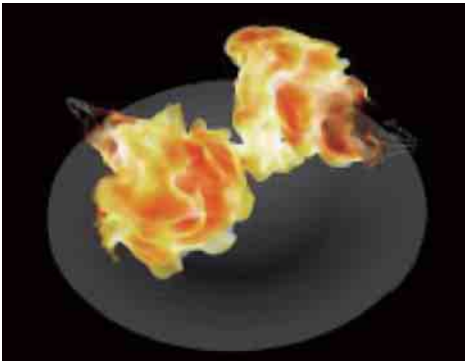
$$CCAI = \rho_{15} - 81 - 141 \cdot \log_{10}[\log_{10}(v + 0.85)] - 483 \cdot \log_{10}\frac{T + 273}{323}$$

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 oil leakage caused by abrasive powder from the abnormal wear of piston ring/cylinder liner.

④ Surface wear and burn-out of exhaust valve.

⑤ Exhaust valve sticking due to accumulation of unburnt deposits in the exhaust valve guide aperture.

⑥ Blow-by and high-temperature corrosion, due to poor sealing of exhaust valve seat.

⑦ Surface wear and burn-out of piston crown.

⑧ Turbocharger problems due to accumulated unburnt deposits (e.g., explosion overrun).

2 Medium/high speed 4-stroke diesel engine problems

The higher the engine speed, the greater are the chances of adverse ignition delay. In particular, when the temperature and pressure inside the cylinder are low and the load is also low, diesel knocking may lead to unstable combustion. This will also increase PM and black smoke emissions. Such situations can be alleviated by increasing the load to improve ignition condition. Bear in mind that the same problems related to the low speed 2-stroke engine mentioned above, can also occur in the medium/high speed 4-stroke engine.

Table 5-30 Ignition and combustibility issues

Detection of and countermeasures for issues arising from oil with poor ignition and combustibility

Table 5-31 shows a summary of diagnostic issues regarding the detection of ignition and combustion problems.

Diagnosis of potential issues	Countermeasures
It is essential that crew members carefully monitor the following engine conditions and make a correct diagnosis:	In the event of any abnormal combustion, crew members must take immediate onboard action and follow the appropriate measures outlined below:

Diagnosis of potential issues	Countermeasures
1 2-stroke engine ① Ensure proper maintenance of the fuel injection valve and secure the valve opening pressure in order to atomize fuel oil properly and produce a good spray. ② Enhance engine monitoring (e.g. monitoring of exhaust gas temperature, rpm of the turbocharger 〈surging〉, specific fuel consumption, concentration of iron in drain oil sampled from the bottom of the cylinder liner). ③ For engines equipped with temperature sensors, continuously monitor the cylinder liner temperature. ④ For engines equipped with cylinder pressure sensors, crewmembers must evaluate the state of combustion by reading the cylinder pressure. Where sensors are not equipped, measure and evaluate in-cylinder pressure with a mechanical indicator.	**1 2-stroke engine** ① **Reduce engine load.** Reducing engine load will help to reduce thermal and mechanical loads at relevant locations. This is effective in preventing any further deterioration. ② **If mechanically possible, crewmembers should adjust and advance fuel injection timing.** Be aware though that by advancing fuel injection timing, Pmax (maximum in-cylinder pressure) and Nox (nitrogen oxide) values will also rise. Crewmembers must ensure that Pmax limits are within a range which does not exceed the upper limit outlined in the Nox technical file.
2 4-stroke engine ① Ensure proper maintenance of the fuel injection valve and secure the valve opening pressure in order to atomize fuel oil properly and produce a good spray. ② Enhance engine monitoring (e.g. monitoring of exhaust gas temperature, rpm of the turbocharger 〈surging〉, specific fuel consumption). ③ In order to improve startability, cylinder cooling water in the engines should be preheated, if possible.	**2 4-stroke engine** ① If possible, adjust and increase the engine output to a medium load. However, for the generators, consideration must be given to the balance between onboard power demand and the number of operating engines. ② Crewmembers should add a combustion improver to the fuel (in case of emergency, it is advisable to keep a reserve stock of combustion improver onboard).

Table 5-31 Detection of and countermeasures for ignition and combustibility issues

5-3 Countermeasures for the safe use of cylinder oil

The following is a summary of recommended precautions for the selection of cylinder oil when using low-sulphur compliant fuel oil.
In a two-stroke engine, cylinder oil, which has a close relationship with combustion, serves the following functions:

① **Prevention of corrosion of the cylinder liner and other combustion chamber components by neutralizing acids formed from the by-products of the fuel oil combustion process.**

② **During Hydrodynamic Lubrication, it spreads uniformly over the cylinder liner surface forming a stable oil film between the piston rings and the cylinder liner to ensure smooth lubrication.**

③ **Provision of a gas seal between the piston rings and the cylinder liner to prevent blowing out of combustion gas and compressed air.**

④ **Prevention of build-up of deposits in the piston rings, piston ring grooves and cylinder liner which could otherwise lead to ring sticking or breakage.**

Engine crew members should therefore ensure proper management and control of the cylinder oil which is designed to suppress deterioration of the fuel oil. Care must be taken to maintain both oil viscosity and the proper functioning of any additives to the cylinder oil. These additives help to disperse any sludge generated by the products of combustion and prevent agglomeration and adhesion to machine parts, whilst also reducing the formation of deposits. Compliant fuel oil (VLSFO sulphur content 0.50% or less) has a lower sulphur content than conventional fuel oil (HSHFO sulphur content 3.50% or less). When selecting a lubricating oil, careful consideration must be given to the ability of that oil's alkalinity to neutralize acid (refer to the above mentioned point ①).
The main component of additives is an alkaline earth metal (mainly Ca). The alkaline ability to neutralize is expressed as the base number (BN).

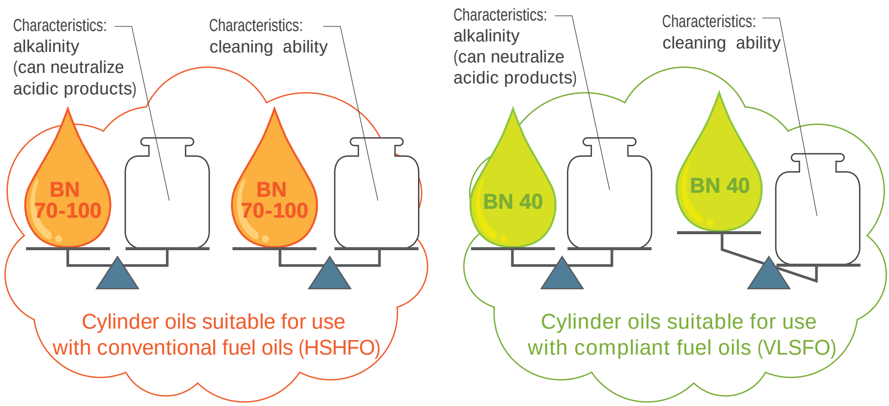


Figure 5-32 BN selection considerations based on degree of pollution by sludge, deposits etc.

If cylinder oil previously used in the conventional fuel oil HSHFO is used in the compliance fuel oil VLSFO, the alkalinity will be excessive, and carbonate deposits will form around the piston and on the piston crown.

In two-stroke engines prior to 2020, ships used a cylinder oil of about 70 to 100 BN for the high sulphur content of the conventional fuel oil HSHFO in open sea areas outside of ECAs.

However, from 2020, ships need to use a cylinder oil of 40 BN which corresponds to fuel oil with a sulphur content of 0.50% or less.

As shown in Figure 5-32, cylinder oil with a high BN has a high ability to disperse incomplete combustion products, such as soot and other substances inside the cylinder oil film. Careful consideration should be given to this dispersing ability when the piston ring/cylinder liner are in poor condition, and when using fuel oil with poor combustion quality. It is therefore recommended that the company consult with the engine manufacturer before selecting and using cylinder oil for a two-stroke engine. Pay careful attention to the matching of compatible fuel oil VLSFO and cylinder oil.

Similarly, consultation is also recommended when selecting lubricating oil for a four-stroke trunk piston type engine.

5-4 Onboard check

Regarding the five properties of compliant fuel oil as previously described, there is a short and simple method to diagnose the compatibility, cold flow properties, and ignition and combustion quality, which can be done in about 30 minutes whilst bunkering.

Photograph 5-33(a) Ship bunker manifold

Photograph 5-33(b) Sampling of fuel oil

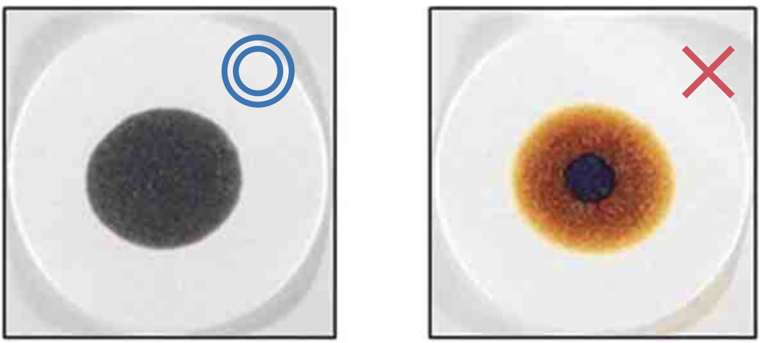
=Simple diagnostic test=

5-4-1 Diagnosis of Compatibility

As described in "5-2-1 ① Compatibility", asphaltene can begin to aggregate when different fuels are mixed, and/or when undergoing thermal shock or when the fuel is oxidized. These particles will grow from fine to coarse, and will finally deposit as asphaltene sludge.

Photograph 5-34 Spot test kit for FO compatibility and stability

Compatibility can be checked by a fuel oil spot test (ASTM D4740) using a portable test kit as shown in Photograph 5-34. Assessment is made by the circular patterns that appear after the heated sample oil is dropped onto the test paper and dried. Particles that cannot smoothly pass through the test paper are deposited in a circular shape (inner ring), making it easy to judge by their appearance. As shown in Photograph 5-35, when a more distinctive spot can be seen in the center of the filter paper, this implies that the fuel is unstable. If we think of the filter paper as a strainer, it can be seen that the strainer would immediately become clogged if the oil did not spread evenly and appears thick around the center.



Left ：Evaluation 1 Good compatibility　　Right：Evaluation 5 Very Poor compatibility

Photograph 5-35　Example of test result (compatibility of FO)

5-4-2 Diagnosis of cold flow properties

As described in “5-2-3 ③ Cold flow properties”, these properties indicate the ability of a fluid to flow at low temperatures. Since the average temperature of most domestic refrigerators is around 5°C, crew members can simply evaluate the cold flow properties of fuel oil by leaving a cup of bunker sample oil in a refrigerator for about 30 minutes with a thermometer.

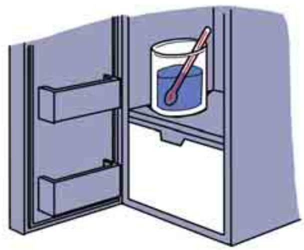


Figure 5-36
Simplified test methods
for Pour point in refrigerator

Any low viscosity or loss of cold flow properties should be reported to the charterer and the ship operator and a request made to implement the countermeasures shown in 5-2-3 above.

For issues regarding “Cold flow properties” and “Compatibility”, please refer to Japan P&I News No. 1044 “THE 2020 GLOBAL SULPHUR CAP — Precaution of “Compatibility” and “Cold flow properties” for compliant fuel oils” published by this club on 11 November 2019. Please also refer to the TEC-1190 “Booklet for ship crew members Precautions concerning change-over to 0.50% sulphur compliant fuel oils [First Edition]” published by ClassNK on 30 September of the same year. This is a particularly practical booklet containing details about additive manufacturers.

5-4-3 Assessment of ignition quality

As described in “5-2-5 ⑤ Ignition and combustion quality”, CCAI has until now been the main indicator of ignitability. CCAI can be calculated by referring to the density and kinematic viscosity described in the Bunker Delivery Note (BDN). Depending on the oil quality grade, the international standard “ISO 8217:2017 Petroleum products — Fuels (class F) — Specifications of marine fuels” states that a CCAI value of 860 or 870 or less is required for the operation of marine engines. This should be compared to the estimated value calculated by the crew and used as a guide to the ignitability index. If CCAI exceeds the upper value limits, the ship should report this to the charterer and the ship operator, and make a request to implement the countermeasures shown in Table 5-31 above.

5－5 Summary

For safe usage of compliant fuel oil, it is recommended that the shipowner, ship management company, and crew members adopt the following onboard measures:

1 **With the manufacturer's cooperation, review the operation manual for proper fuel oil management (engine, purifier, fuel oil, lubricating oil, additives, etc.) and draw up a revised set of operation procedures.**

2 **Verify previous cases of fuel oil problems.**

3 **Establish a system for the monitoring of the operational status of machinery, and countermeasures to deal with any abnormalities.**

4 **Organize regular inspections to ensure the proper working of machinery in accordance with the manufacturer's instruction manual.**

5 **Ensure a sufficient store of spare parts and fuel oil additives onboard.**

6 **Make sure that crew members are fully versant with various work procedures, previous cases of trouble, and appropriate emergency responses, and provide emergency onboard training drills based on set contingency plans.**

Chapter 6 Conclusion

In the current climate, in Japan’s domestic shipping industry, the securing of younger crewmembers is becoming a challenge, and the current personnel is aging, thus the shortage of human resources is becoming more serious. On the other hand, in Japan, the international shipping industry tends to rely heavily on foreign crew because of intense international competition, meaning that more Japanese crewmembers are engaged in land-based activity. As a result, there is a growing emphasis on theoretical knowledge over practical experience.

In the past, when ocean-going vessels were crewed entirely by Japanese personnel or when coastal vessels had a more balaced age distribution, maritime skills were passed down more naturally. However, such skill transfer become increasingly difficult due to these changing conditions. The STCW Convention and the Mariners Act in Japan require that crewmembers of the engine department acquire ERM ability to function more organically with resources such as information, human resources, and equipment.

As mentioned in the conclusion of Chapter 2, how to create a sustainable workplace is key. Experienced crewmembers are required to redefine their own sense of comfort, supporting the growth of the next generation of younger crewmebers, and foster a safe environment where those younger members feel seen and supported. By developing such non-technical skills, experienced crewmembers can lead the team toward greater mutual understanding, nuture cooperation and empathy, and ultimately build the strongest possible teamwork.

On the other hand, it is impossible to prevent human error that may cause a marine accident. And, in order to break the chain of human errors, it is also necessary to foster harmony amongst people, systems, and the environment. Shipowners, ship management companies, and even the ship may realize a reduction in engine accidents by including awareness, that harmonizes and aligns the gap between technical safety and human weak points, to form a firm understanding of (must-do) maintenance.

For "effective engine management and maintenance", the engine department's crew members should build the strongest "One Team" relationship through mutual understanding. They must then continually be aware that human beings are to be at the center daily jobs being performed, such as lubricating oil management, fuel oil management, and inspection/repair/maintenance of the engine. Furthermore, through regular drills/training, shipowners, ship management companies, and even the ship need to prepare measures that incorporate both soft aspects and hard aspects, so that human beings do not panic in an emergency and can respond calmly without making errors.

Reference Materials

Reference Material 01:
Ability diagnosis of onboard work performance: Main Text P. 7

To achieve the purpose and mission on board, the Chief Engineer conducts the engine department's ability diagnosis within one week after boarding.

- **There are 3 scores (A: Merit, B: Pass, C: Needs to improve) allocated for all aspects of the engine department that make up a comprehensive evaluation. If ability or knowledge is not satisfactory (less than 60%), an "F" will be given.**

- **Chief Engineers and First Engineers will work together with experienced crewmembers in order to further strengthen management of the engine department.
They are to support younger crewmembers and develop countermeasures that will work on improving their weak points.**

- **If anyone remains below average for 3 months, it is considered dangerous, so it will be necessary to consult with the captain and discuss the reassignment of crew with the Human Resources Department.**

Rank	Behavioural characteristics	Each person's fundamental capability	Total Score	Average score	Emergency response	Blackout recovery	Alarm Response	SMS	Communication	Routine Work	Engine & Equipment operation	Periodical maintenance	No. of ships experienced
C/E	Hurries (impatient)	75	A	80.9	81	81	78	86	76	86	76	83	15
1/E	Lazy	80	A	84.9	85	85	82	90	80	90	80	87	13
2/E	Emotional	65	B	74.9	75	75	72	80	70	80	70	77	9
3/E	Assumptions (preconceptions)	55	C	69.9	70	70	67	75	65	75	65	72	4
G/E	Does not notice	75	B	79.9	80	80	77	85	75	85	75	82	13
Engineer /Other	Transgression (violation)	30	F	59.9	60	60	57	65	55	65	55	62	2
Fitter	Hurries (impatient)	50	B	74.9	75	75	72	80	70	80	70	77	20
Oiler/A	Only able to see one thing	45	C	64.9	65	65	62	70	60	70	60	67	15
Oiler/B	Transgression (violation)	55	C	69.9	70	70	67	75	65	75	65	72	10
Oiler/C	Moments of inattention	60	C	64.9	65	65	62	70	60	70	60	67	10
Oiler/D	Careless	45	F	54.9	55	55	52	60	50	60	50	57	5
Wiper	Forgets	35	F	39.9	40	40	37	45	35	45	35	42	4
Oiler/Other	Panics	30	F	34.9	35	35	32	40	30	40	30	37	2
Total evaluation score of Engine Dept.	—	54	F	65.7	65.8	65.8	62.8	70.8	60.8	70.8	60.8	67.8	—

Table: Reference 1 Example of ability diagnosis

Reference Material 02:
Under what circumstances does an error occur?: Main Text P. 16

The following tables are from a seminar on human factors of the Japan Aeronautical Engineers' Association, and is used by the shipowner/ship management company or the ship to analyze fault weaknesses. If it is known how such errors occur, it will help develop efficient responses to human factors that may have caused the fault.

(1) Error when registering information

Information is not registered.	・Vision/hearing is limited. ・Field of view is limited. ・Visible range is limited.
Information is registered, but not processed.	・A lack of interest.
Information registered, but was illuded.	・The information is of interest but misinterpreted. (Hasty judgments, misunderstanding, assumptions)

Table: Reference 2 Error when registering information

(2) Error in the memory process (lapse)

To prevent errors in the memory process (Lapse), there must be opportunity for crew members review everything repeatedly. For example, in the engine department, "In the meeting before work starts, the person in charge explains the specific notes of important work from the viewpoints of 4 M." Moreover, "Engine crewmembers check the emergency response procedures, including the low probability of accidents, one theme each day."

Limitation of Short-term memory	・Memory is limitated. Most of the information kept in short-term memory will be stored for approximately 20 seconds. The memory can be improved using visuals and rehearsal. ・Normal person, 7 items (5-9) Example: Colours of the rainbow, musical scales (c d e f g a b), main characters of a drama (The Magnificent Seven) ・It is easy to remember telephone numbers, because they are grouped.

Limitation of Long-term memory	Please imagine the folowing situations. ・When you know something, but cannot recollect it when you need to. ・When you lose your memory. ・When your memory gets distorted. ・Semantic memory: letters, symbols, numbers, etc. ・Episodic memory: personal memories such as joining a company or wedding. ・Procedural memory: procedural (how to ride a bicycle, how to use chopsticks, etc.)

Table: Reference 3 Error in the memory process (Lapse)

(3) Error in the judgment process (mistake)

Making misjudgements such as:		
・Insufficient consideration	・Prospect	・Short cut reaction
・Mechanical reaction	・Hopeful observation	・Speculation
・Reckless/indiscreet		

Table: Reference 4 Error in the judgment process (mistake)

(4) Temptation to deviate (violation)

May deviate from the rules because of: ・Time pressure ・Too much work ・Respect for speed (even if the outcome of work is not perfect, it is fast anyway) ・Rules that are unclear or unfit for the situation. ・Situations where it is permissible not to follow the rules ・Inappropriate deployment of appropriate facilities and materials (resources) ・Supervisor is too tolerant or lacks ability to manage ・A climate that overvalues boldness ・A climate that places less emphasis on safety (aloft work/high places of work 〈2m or more〉 but no safety belt is worn)
Countermeasure: We must not make excuses.

Table: Reference 5 Temptation to deviate (Violation)

(5) Error in the output process (slip)

Errors in output (behaviour) ⇒ Subconsciously unwillingly.

In spite of the correct judgment result, if the action (output) is different from the decision result at the action stage, an error may be caused by any of the following.

- Limitation of movement capability (force, dimensions).
- Limitation of operating time.
- Confused by surrounding events.
- Subconsciousness.

Example: He meant to address the audience with "an opening address" but instead used "a closing address".

Table: Reference 6 Error in the output process (Slip)

Reference Material 03
Problem Solving Method: Main text P. 21, P. 41

Even if younger crewmembers have little experience, they can analyze accidents in a logical way, and can plan countermeasures by utilizing solution methodology.

MUST POINT

- Build up a stock of solutions.
- Finally, establish a successful formula.

We have provided the following with reference to "Jyohowo shunjini seirishi Aidhiawo Umidasu! Noto・Memo Furukatsuyo Jyutsu." (provisional translation) by Nagaoka Shoten.

1. Logic tree: We would like to analyze problems and plan solutions!

1. Introduction
"How to analyze problems & come up with a solution!" (Provisional translation.)

A logic tree is a useful thinking tool for logically analyzing work problems and formulating solutions.

First, break down a problem or solution into elements to be considered and then analyze them **further into a lower hierarchy**.

As a result, the logical reason is shown in the form of a tree diagram (tree)

2. Advantage
① It is possible to grasp the whole picture of the task.

② It is possible to avoid oversight/omission of problems, and it is possible to find solutions easily.

③ It is possible to correct gaps in the discussion easily, because it is clear which hierarchy the discussion belongs to.

3. How to draw a logic tree (Refer to Figure Reference 7)

① At the starting point, write down the problem you want to solve and start thinking about how you may solve it, e.g. reducing work stress.

② Break down the starting point task into 2 to 4 components (up to 5). (The first layer in Figure: Reference 7)
At this time, it is important to be aware that there should be "no overlap, mutually exclusive and collectively exhaustive" information (called "MECE"). Also, depending on the task, the method of disassembling will be "Result⇒Cause" (Why), "Purpose-Means" (How), "Whole-Part" (What), etc.

③ Disassemble the disassembled components into 2 to 4 elements.We will extend it to lower layers to make it more specific. (The second layer in Figure: Reference 7)

④ Similarly, disassemble the components disassembled in the first layer to appear in the second layer. Do this until you reach the fifth layer.

⑤ Objectively compare and examine ways to solve problems by referring to the completed logic tree.

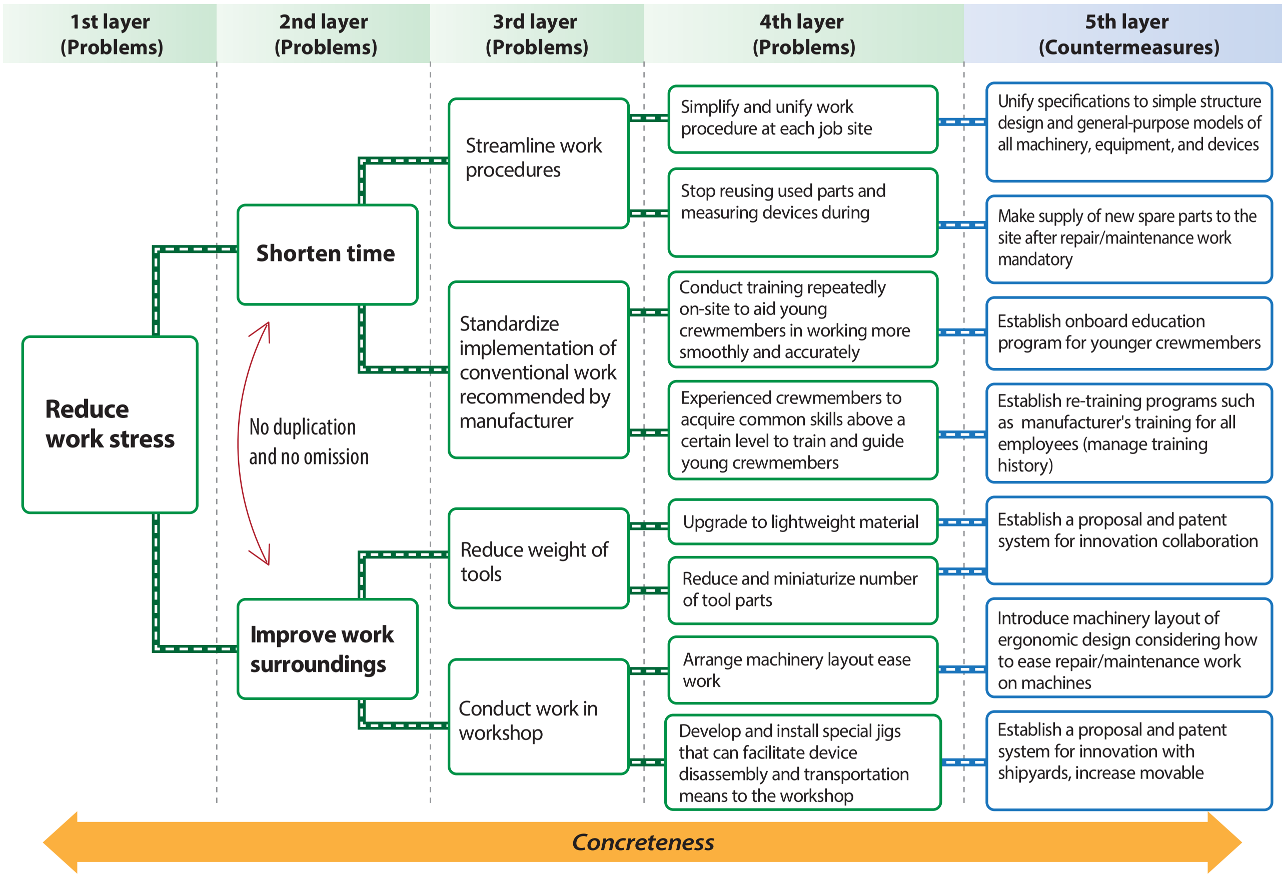


Figure: Reference 7 How to consider reducing work stress

2. Fishbone: Illustrate issues and their causes in the form of a fish skeleton!

1. Overview

・Fishbone is an idea generation method that looks at "Cause and effect".

・Originally it was a classic tool for analyzing factors that affect quality characteristics in the quality control of products.

・Business analysis often uses this method. This is similar to a logic tree.

・It is not exhaustive. This method's characteristics are such that we can understand the causal relationship between issues and factors **more intuitively**.

2. Advantages

① It is easy to visualize causal relationships and find solutions.

② It is possible to grasp issues and factors intuitively.

③ It is easy to summarize important points and organize discussions. We can also apply ideas to develop a special tool for maintenance.

3. How to draw a Fishbone diagram (Refer to Figure Reference 8)

① We draw an arrow shape with a triangle and a horizontal bar and write our theme (issue or situation) in the triangle. This corresponds to the fish head and bones.

② We focus on 3 to 8 important factors when thinking about the theme. We draw large bones coming out of both sides of the spine in a well-balanced manner and write each factor at the end of each large bone.

③ We further break down the factors written at the end of the large bones and consider 3 to 6 elements. We draw medium-sized bones on either side of the large bones and write down considered elements.

④ We then break down these elements further and consider causes and solutions. Similarly, stretch small bones from the medium-sized bones and write down considered elements.

⑤ After you have completed your Fishbone diagram, you can develop ideas and further ideas based on this. It is similar to a logic tree, but it is not a bird's-eye view, yet it allows you to intuitively understand causal relationships.

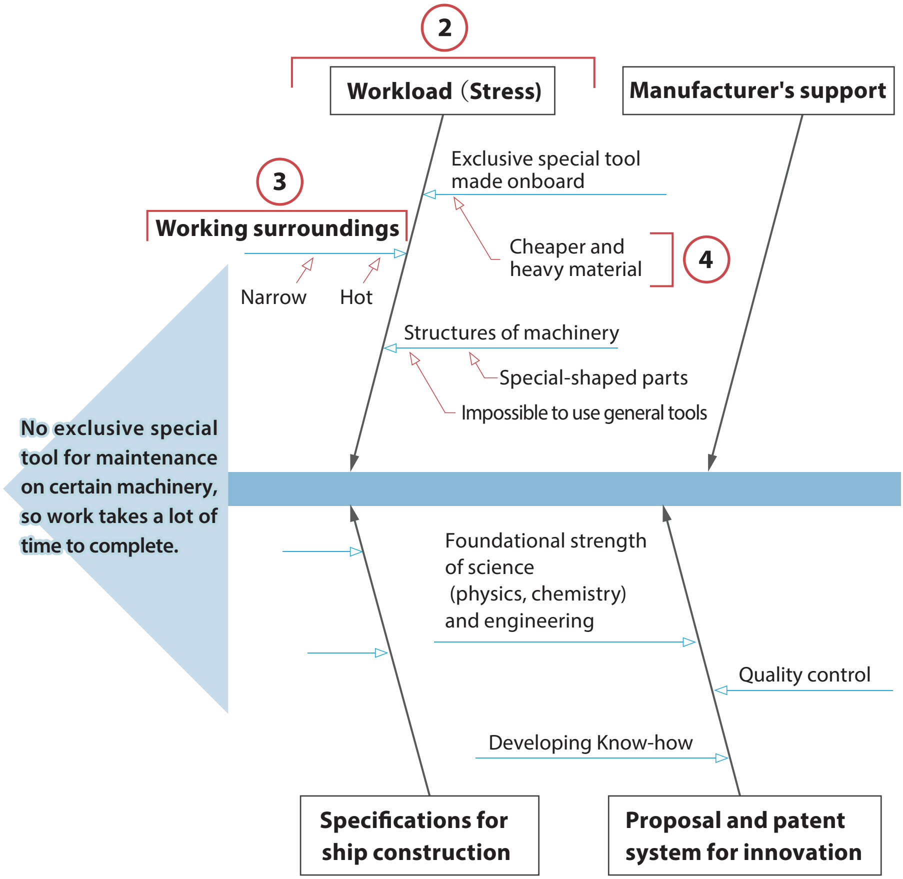


Figure: Reference 8 How to develop a special tool for maintenance

Reference Material 04:
Details of Power Loss Accident in Norway: Main Text P. 35

Chapter 3 introduces an accident in which an electric propulsion ship lost its power completely while cruising in stormy weather and where it was forced to urgently drop anchor.

The details of the accident are as shown in Table: Reference 9 below.

Accident details	
(1)	At 13:50 on March 23, 2019, an electric propulsion passenger vessel was sailing southwest from Tromsø in Norway to Stavanger with three generators operating.
(2)	The weather at that time is as follows. Strong gale to storm winds: from the southwest (Beaufort 9-10 or 22-25 m/s). Very high waves: Total Significant Wave Height from the west over deep water of 9-10 meters (with a mean wave period of 12-13 seconds).
(3)	The total number of people was 1,373 people. (915 passengers on board and 458 crew members.)
(4)	The following abnormalities in the generator had occurred by the time the accident occurred on the afternoon of March 23. (a) On March 16, the turbocharger on No. 3 generator (hereinafter referred to as DG3. In the same manner No. 1, No. 2, and No. 4 generator are referred to as DG1, DG2, and DG4 respectively) failed rendering the turbocharger inoperable. On the day of the blackout, a maker's technician was on board to dismantle the damaged turbocharger to prepare for a replacement to be fitted at the next port. (b) The ship was equipped with 4 generators, but since DG3 was inoperable, generators DG1, DG2, and DG4 continued to operate. 3 generator engines could manage to supply electric power for the propulsion machinery and ship services without the use of a standby generator engine. (c) Between 05:00 and 09:04, on March 23, before the accident occurred, the operational DGs registered alarms of "Lubricating oil low level and low volume" 18 times. The Engineers on watch accepted them, but each alarm was cleared within a few seconds. After that, the alarms did not occur until 13:37.

Accident details	
	(d) 13:37 When DG4 registered an alarm indicating that the DG was shedding load due to low lubricating oil pressure. A few seconds later, it registered a low lubricating oil pressure alarm. (e) 13:39 DG1 registered a low lubricating oil sump level alarm. (f) 13:45 DG4 shut down, and then eight seconds later, DG2 shut down. (g) 13:56 DG2 was restarted. 13:58 DG1 and DG2 shut down. It caused a complete blackout and loss of propulsion, and then the ship began drifting toward the bank (shoal). (h) Within 30 seconds of the blackout: The emergency diesel generator started and powered the emergency switchboard.
(5)	14:00 Master broadcasted a "mayday".
(6)	14:06 ～ 14:20 Master instructed the crew to drop both anchors. However, the anchors did not hold, and the ship continued to drift astern towards the shore at a speed of 6–7 knots.
(7)	14:22 The engineers transferred a total of 10.8 m^3 of lubricating oil to the lubricating oil sump tanks of DG1, DG2, and DG4. DG2 started. DG2 restored power to the main switchboard, in manual load-sharing mode.
(8)	14:29 ～ 14:34 hours: Both propulsion motors started, providing sufficient propulsive power to maintain slow speed ahead.
(9)	15:05 The first helicopter hoisting operation took place. The evacuation of passengers continued until the next morning.
(10)	15:24 ～ 15:46 DG1 and DG4 were restarted in automatic load-sharing mode, and the starboard propulsion motor was restarted to enable the propulsion motors' output to maintain a speed between slow ahead and half ahead. Although DG1, DG2, and DG4 had been restarted, the engineers had to continuously balance the electrical load manually. The Navigation Officers manoeuvred towards open waters, still with both anchors lowered.
(11)	16:40 The first tugboat arrived. However, the weather conditions were too severe to secure a towline.

Accident details	
(12)	Until the morning of March 24, the helicopter rescue of passengers continued.
(13)	06:30 On 24 March: Weather conditions had improved sufficiently to enable tugs to be made fast, and towlines were secured fore and aft, although the vessel maintained its propulsion.
(14)	09:15 The master decided that the vessel was out of danger and that it was safe to stop the passengers' evacuation. The local Police reported that 479 passengers had been evacuated safely and received at the emergency centre ashore.
(15)	Around 16:25 The ship was moored alongside in Molde.

Table: Reference 9 Details of power loss accidents on electric propulsion ships

Reference Material 05:
The investigation reports of the Japan Transport Safety Board: cases of loss of power: Main Text P. 39

Probable causes and countermeasures for the eight accidents in “3-2-3 Transport Safety Board investigation reports for Japan: Cases of loss of power” are summarized in Table: Reference 10 and Table: Reference 11.

List of probable causes of loss of power in Japan

Accident No.	Location	Vessel type, Accident type	Probable causes	If emergency anchored
1	Coastal Northern Japan	Cargo ship (Blackout)	In stormy weather following a wind, snow and wave warning, during coastal navigation, the ship became unable to run the main engine due to loss of power (blackout). The coast guard patrol boat tried in vain to tow the ship but was forced to give up due to the stormy weather. After anchoring and repairing by the crew, the ship restored power, and she resumed sailing after anchoring. There was no announcement as to the cause.	Dropped emergency anchoring
2	Inside harbour Central Japan	Car carrier (Blackout)	While departing port, the "crimp type terminal connecting the electric wires of electric motor for the stern thruster " broke due to hull vibration, resulting in a single-phase operation. An overcurrent flowed, the overload protection device of the stern thruster was activated, and the generator was unable to accept the load fluctuation which resulted in over-speed. Since the over-speed protection device activated, the ship lost electric power and could not run the main engine.	—
3	Coastal Central Japan	Cargo ship (Loss of control power)	While the ship supplied power onboard using a shaft generator during coastal navigation, the fuse holder of the DC24V power on charge and discharge board caused contact failure, and the ship lost control power. Finally, the ship could not run the main engine.	—

Accident No.	Location	Vessel type, Accident type	Probable causes	If emergency anchored
4	Coastal Central Japan	Cargo ship (Loss of control power)	During coastal navigation, the cooling fan of the "converter that converts AC current to DC current" broke down, which caused the converter to overheat, and the ship became unable to supply DC 24V as control power. Finally, the ship could not control both the main engine and the changeable pitch propeller. After emergency towing, the ship dropped emergency anchoring.	After emergency towing, dropped emergency anchoring.
5	In the bay Central Japan	Cargo ship (Blackout)	The ship operated two generators in parallel while manoeuvring for entering port operation. However, emergency stop was activated due to a lubricating oil leakage of the governor. The ship equipped with four generators driven by a diesel engine, two of which were operated in parallel normally while passing the narrow channel, and the ship used the other two as standby generators. However, when the accident occurred, the crew cleaned the engine's lubricating oil strainers, and set the automatic start switch to manual so as not to start the standby generator. Therefore, the backup standby generator could not automatically backup.	—
6	Inside harbour Western Japan	Passenger ferry (Blackout)	While departing port, a phase-to-phase short circuit occurred in the wiring of A and B circuits in the junction box, resulting in a short-circuit current flow between circuits A and B. Then, the safety protection device of the main switchboard A-MCCB (Moulded Case Circuit Breaker) was activated. The function worked and turned off (disconnected). At that time, the two branch lines connected to the A-MCCB were damaged and bounced off, resulting in an interphase short circuit caused by contact with the C-MCCB branch line. The ground fault generated by contact with the wall surface of the main switchboard caused an excessive current to flow to the main switchboard's busbar. As a result, the ACB (Air Circuit Breaker) safety protection function was activated and opened. The ship stopped the main engine due to loss of power, and the generator was still running, and crewmembers tried to reconnect the ACB, but it was impossible.	Dropped emergency anchoring

Accident No.	Location	Vessel type, Accident type	Probable causes	If emergency anchored
7	Inside harbour Central Japan	Cargo ship (Blackout)	While entering the port at the harbour, the safety protection device functioned incorrectly due to a defective sensor board of the boiler. This resulted in the main boiler misfiring. Therefore, in order to reduce steam consumption, crewmembers transferred electric load from one of the two turbine generators (2,500 kW) to the diesel generator. However, after crewmembers opened the ACB of one turbine generator, the operation condition of the manually started diesel generator (1,500kW) became unstable. As a result, the ACBs of both generators tripped, and the ship lost power.	After the emergency towing, dropped emergency anchoring.
8	In the bay Southern Japan	Cargo ship	The Chief Engineer stopped using the heavy fuel oil shortly after leaving the port in the bay. In order to improve the combustion condition of the main engine, the switching valve was opened halfway in an attempt to mix marine gas oil with heavy fuel oil. He had "confirmation bias" regarding the check valve, and he assumed that heavy fuel oil would never flow to the marine gas oil side. Since the heavy fuel oil service tank's oil level was higher than that of the marine gas oil service tank, the switching valve opened at the same time, so the heavy fuel oil flowed back into the marine gas oil service tank. In the generator engine, heavy fuel oil flowed to the marine gas oil service tank. As a result, the running generator received Fuel oil with increased viscosity, and the atomization of the fuel injection valve became defective and the generator engines stopped, resulting in the ship losing power. As a result, the main engine also stopped suddenly (emergency procedure). After the accident, crewmembers discovered that the valve was not a switching valve.	Dropped emergency anchoring

Table: Reference 10 List of probable causes of loss of power in Japan

List of countermeasures of loss of power in Japan

Accident No.	Countermeasures: Safety Action:
1	The ship must review measures for stormy weather. The ship is to implement additional remedial measures if necessary.
2	The ship must make an inspection plan for the crimp type terminals that connect the electric wires of the thruster motor. This is to be carried out regularly.
3	(1) The ship is to establish an inspection plan for the fuse holder of the DC 24V power supply charge/discharge board. To be carried out regularly. (2) Since the managers/supervisors of the ship management companies had discovered that the fuse holders had deteriorated after the accident, fuse holders on all ships have been replaced.
4	(1) The ship must develop an inspection plan for the cooling fan and regularly carry it out. This is to be replaced if necessary. (2) The ship must install a failure alarm device for the cooling fan.
5	When carrying out maintenance and inspection work on generators, and so on, the ship must consider the navigation area. When passing a narrow channel traffic route such as the Uraga Channel and Kanmon Straits, the ship must maintain an engine plant system so that it can automatically start the standby generator in case of an emergency. The crewmembers must refrain from cleaning the strainer.

Accident No.	Countermeasures: Safety Action:
6	As a safety measure for the entire company, the management company held a Masters/Chief Engineers meeting to disseminate information among the ship and other managed ships within the company. The ship must do the following: (1) Secure the wiring to the junction box. (2) Replace any damaged MCCB (Moulded Case Circuit Breaker). (3) Correct final drawings and important documents for newly installed electric equipment for appropriate inspection/repair/maintenance. Carry out an occasional survey by a Recognized Organization after the repair. (4) Measure and record insulation resistance of electric equipment and devices for refrigerated vehicles with an insulation resistance tester, every month: ① insulation resistance between the electric circuit and the hull and ② interphase insulation resistance. (5) Regularly vacuum-clean the interior of electrical equipment and devices and remove soot and dust. (6) ① Inform and remind crewmembers of the danger of short circuits related to electrical equipment and devices, and ② conduct re-training regarding safety such as inspection, cleaning, and electric shock. (7) Crewmembers must use and operate the public address system onboard effectively based on the procedure "Information for passengers in an emergency" to provide the correct information to passengers. **Other recommended measures** (1) The ship must consult with manufacturing companies, and so on, regarding the main switchboard and MCCB, and establish regular maintenance plans for all equipment and devices, including equipment and devices that were not part of the accident. The company must continuously confirm and evaluate the record of insulation resistance measurement of electric equipment and devices for refrigeration vehicles with the managing ship and their crewmembers of their ship.

<table>
<tr><th>Accident No.</th><th>Countermeasures: Safety Action:</th></tr>
<tr><td>7</td><td>The management company must instruct on the following safety measures to both the ship and other ships.
(1) A major casualty may occur during manoeuvring standby, berthing, and passing congested or high traffic routes if the main boiler misfires.
A ship must not operate the main boiler in combustion mode if it is difficult to handle load fluctuations well.
(2) The ship must regularly hold tests to confirm the starting and running of diesel generators, with it operating in normal load. The generators are also to be regularly overhauled.
A ship must carry out the following maintenance: Renewing air cooler, and repair/inspect/maintain/overhaul the turbocharger and cooling freshwater system, and so on.
(3) A ship must hold tests to confirm the starting and running of the emergency diesel generator using a load applicable the machinery in accordance with the manual.
A ship must carry out the following maintenance: Inspect the switchboard, and replace ACB.
(4) A ship must increase the frequency of operation tests for the boiler safety protection device. A ship must carry out the following maintenance: Renew damaged sensors.</td></tr>
<tr><td>8</td><td>(1) The ship must evaluate risk and check for any adverse influences on the system using piping diagrams before opening and closing the valves.
(2) The ship must mix marine gas oil and heavy fuel oil using a dedicated device and not mix them directly by operating several switching valves simultaneously.</td></tr>
</table>

Table: Reference 11 List of countermeasures of loss of power in Japan

Please refer to the URL in a list of references at the end of this bulletin regarding details of the above tables.

Reference Material 06:
Emergency response checklist immediately after loss of propulsion and loss of power: Main Text P. 45

The following is a checklist for emergency response on board.

CHECK LIST

- ☐ Master must follow the company SMS procedures for loss of propulsion and blackout, which is described in the "Emergency Procedures Manual" as a contingency plan.

- ☐ Crewmembers must record the position of the vessel and time accurately in the deck logbook and in the engine logbook.

- ☐ Master may have to drop anchors to reduce the ship's speed. When manoeuvring in confined waters, the anchors should be 'cleared' for immediate use.

- ☐ Master and Chief Engineer must "keep good" and efficient communication between the bridge and the engine room. The bridge and engine room should exchange critical information so that key personnel can fully understand the situation and make informed decisions. Each department on board must quickly inform other departments as follows:

  - What they require,
  - what is happening at their station,
  - what problems they are facing and experiencing,
  - and what risks are present? And so on.

If bridge and engine room crewmembers do not exchange critical information during an emergency, we must know that there is a risk that key personnel will not be fully aware of the situation and may make ineffective decisions.

☑ CHECK LIST

- ☐ Master and Chief Engineer must instruct some of the crewmembers to go to the emergency generator room to try and start the generator when it does not automatically start.

- ☐ Master and Chief Engineer must instruct some of the crewmembers to go to the steering room to attempt emergency steering.
  However, the master and deck officers must predict and recognize that this becomes less effective when the engine has stopped and when the ship's speed is reduced to below steerage along with the vessel's forward movement cutting through the water.

- ☐ When engineers find that the machinery driven by steam turbine devices has stopped after a blackout or boiler emergency trip, they must carry out turning the rotor shaft by any means possible to prevent the rotor shaft from bending.

- ☐ Engineers must operate the feedback system from ESB to the main switchboard (MSB) if possible.
  Some ships are equipped with an electric feedback system. On such a ship, the electric power source from the emergency generator via the ESB can feedback to the main switchboard, so that the ship recovers power to the main switchboard (MSB) during a blackout. (Please refer to "3-3-3(2) 2) Precautions for recovery work"). Engineers must understand and be familiar with how to operate and control it practically.

- ☐ When engineers find an overload of current on the electrical devices, they must operate (push) the reset button to reset and recover the electrical breaker function after it has tripped.

- ☐ It will probably be necessary to bring the engine to a STOP to enable the restart. The engine control room should take control until power has been fully restored.

Reference Material 07:
How to prevent panic: Main text P. 55

(1) Inability to move or think

Ms. Amanda Ripley investigated and wrote about some of the most harrowing catastrophes in history in order to piece together exactly how humans react in a crisis such as survivors from the September 11 attacks and Hurricane Katrina, in her book “The Unthinkable: Who Survives When Disaster Strikes - and Why”, Random House Audio (Translated into Japanese by Machiko Oka, Kobunsha Co., Ltd.). According to the book, in moments of total disaster, the first phase of human reaction is “denial”, the next phase moves into “deliberation” that considers the actions to be taken, and as a result, humans take “action”. However, in many cases, after “awareness of the situation”, most people tend to shut down their mind entirely in the disaster and seem to lose all strategic awareness. On the other hand, those who have been selected for special missions have the common features of being able to react more effectively under stress, which is probably due to the environment and background in which they developed.

In other words, when humans are exposed to hazards, they experience what is known as normalcy bias in which they consider themselves to be indifferent or minimally affected by threat warnings, “It is okay” and “That can’t be true.” when faced with a situation. However, in the event of an emergency, ship crewmembers are required to do the following:

① to train themselves to deal with stress effectively,

② to react calmly, and

③ to respond immediately to critical situations without panic, in the same way as those who are selected for special missions.

(2) Preventive measures against panic

As mentioned above, when humans encounter an emergency, they fall into a state of "Inability to move or think". To prevent this, it is essential to plan controllable measures for emergencies and implement such manageable measures during normal conditions as well. (Please always be ready for what you have planned).

① Reduce the anxiety factor (discomfort) in an emergency

② Foster a flexible mentality that can cope with anything on site

According to the book "Behavioral Science of Natural Disasters, (preliminary translation)" in order to prevent panic, it is possible to divide panic into soft aspects and hard aspects for both during normal times and in emergencies:

Soft aspect measures

(measures that include information and social psychological elements) :

・・・Information transmission, trouble recovery procedures, training for situation judgment, and so on.

Hard aspect measures

(measures that mobilize both physical and human resources) :

・・・The reviewing and improvement of machinery, securing of personnel, emergency machinery operation, emergency repair, and so on.

The table "Panic prevention measures during disaster evacuation (preliminary translation)" from the book is divided into 2 classifications of which 4 categories can serve as countermeasures. Following the same structure, we have applied this to the case of loss of power, as can be seen in Table: Reference 12 below.

For example, regarding soft aspect measures during ordinary times, "emergency response training, including low probability accidents" should be carried out repeatedly.

Regarding hard aspect measures, "modifying wiring to important machinery such as cooling water pumps and air compressors from an emergency generator" and "changing specifications of the speed control scheme of the induction motor using the pole change method, so that these motors will be able to run using the power supply from an emergency generator" should be prepared.

It is recommended that the ship management company and the ship take account of these tips when considering a further framework for emergency response.

Preparation for panic prevention measures for loss of power

	1. Soft measures	2. Hard measures
A. Ordinary	(1) Clarify and establish information transmitting organization / role allotment. (2) Produce manuals for: ・normal recovery procedures, ・feedback method from the emergency generator via emergency the switchboard to the main switchboard, ・the switching method receiving power from the main switchboard to emergency switchboard for the Diesel generator air compressor in an emergency. ・the special recovery procedures to plant-up the engine system by the emergency generator. (3) Regularly conduct recovery training for loss of power, including low probability situations (Normal start-up, air circuit breaker failure, emergency generator start fail, regular use generator start fail, emergency anchoring, etc.) (4) Conduct simulations (to strengthen the mind) assuming that the worst-case scenario occurs based on past accident cases.	(1) Reconfirm fuel supply pipeline of the regular generator and the emergency generator. (2) Carry out regular inspections of the following batteries: ・for starting the emergency generator. ・for the control system power source. (3) Improve regular repair and maintenance methods for defective piping, structure, wiring, machinery, and equipment. (4) Re-inspect machinery/equipment that can be operated from the emergency generator and switchboard. (5) Modify the power supply wiring that can start the regular generator start air compressor from the emergency switchboard. Modify auxiliary machinery required for plant-up to low power variable specifications. (Please consult this with the classification society, manufacturer, and shipyard beforehand.) (6) Test run emergency generator and backup alternative power supply. (7) Secure and store parts for important machinery. (8) Secure space for temporary evacuation space when engine room overheats.

	1. Soft measures	2. Hard measures
B. In time of emergency	(1) Report and share accurate information related to trouble. (2) Establish a common understanding and recognition of the situation. Promptly instruct regarding recovery work procedures. (3) Status report on recovery prospects. (4) Cooperate with other departments. Propose a special system for emergency anchor and cargo management. (5) Provide any other information to reassure everyone.	(1) Mobilize personnel from other departments in time of emergency. (2) Operation of emergency generator and backup alternative power supply. (3) Prevent engine room from overheating. Repair defective machinery. Rescue and nurse injured persons. (4) Secure a means of contact with the head office.

Table: Reference 12 Preparation for panic prevention measures for loss of power

References

Chapter	Page No.	Corresponding section	References
Chapter 2	P. 5	The standards of naviga-tional watchkeeping	Web site of Ministry of Land, Infrastructure, Transport and Tourism, Japan Kokai tochoku kijyun (heisei 8 nen unyusho kokuji dai 704 go) (saishu kaisei heisei 25 nen 3 gatsu 1hi kokudo kotsu sho kokuji dai 158 go), (in Japanese), URL http://www.mlit.go.jp/notice/noticedata/pdf/201703/00006415.pdf
Chapter 2	P. 8	6 capabilities	"Boueidai ryu saikyo no rida", Yoshifuru Hamagata, Gentosha Inc., (in Japanese), 2017
Chapter 2 Reference Material	P. 11/108	A seminar on the human factors of aeronautical engineers Reference Material 02 Under what circum-stances does an error occur?	"Koku seibi niokeru hyuman fakuta semina (1nichi kosu)" Japan Aeronautial Engineers' Association, (in Japanese), URL https://www.jaea.or.jp/
Chapter 2	P. 22	Managing Maintenance Error	"Managing maintenance error : a practical guide" James Reason, Alan Hobbs, Ashgate Publishing Company (Kenichi Takano translated into Japanese, JUSE Press. Ltd.) , 2005
Chapter 3	P. 34	3-2-1 Incident case of loss of propulsion in the US: Incorrect operation of the main engine at the wheelhouse	Investigation report of U.S. National Transportation Safety Board, NTSB/MAR-11/04, PB2011-916404, "Tankship Eagle Otome" URL https://www.ntsb.gov/investigations/AccidentReports/Reports/MAR1104.pdf

Chapter	Page No.	Corresponding section	References
Chapter 3 Reference Material	P. 35/116	3-2-2 Incident case of loss of power in Norway: In-adequate replenishing of system lubricating oil to diesel generators on electric propulsion vessel Reference Material 04: Details of Power Loss Accident in Norway	Investigation report of Accident Investigation Board Norway -Interim Report 12 November 2019 On the investigation into the loss of propusion and near grounding of Viking Sky, 23 March 2019 URL https://www.atsb.gov.au/publications/investigation_reports/2019/mair/me-2019-005/ URL https://www.aibn.no/Marine/Undersokelser/19-262"
Chapter 3 Reference Material	P. 38/119	3-2-3 Transport Safety Board investigation reports for Japan; cases of loss of power Reference Material 05: Transport Safety Board investigation reports for Japan; cases of loss of power	The investigation reports of the Japan Transport Safety Board; cases of loss of power, (in Japanese), Accident1 URL http://www.mlit.go.jp/jtsb/ship/rep-inci/2019/keibi2019-6-3_2018hd0069.pdf Accident2 URL http://www.mlit.go.jp/jtsb/ship/rep-inci/2018/keibi2018-11-7_2018yh0029.pdf Accident3 URL http://www.mlit.go.jp/jtsb/ship/rep-inci/2016/keibi2016-3-9_2015yh0132.pdf Accident4 URL http://www.mlit.go.jp/jtsb/ship/rep-inci/2015/keibi2015-4-9_2014yh0152.pdf Accident5 URL http://www.mlit.go.jp/jtsb/ship/rep-inci/2015/keibi2015-9-19_2015yh0029.pdf Accident6 URL http://www.mlit.go.jp/jtsb/ship/rep-inci/2019/MI2019-3-2_2018tk0008.pdf Accident7 URL http://www.mlit.go.jp/jtsb/ship/rep-inci/2013/MI2013-11-1_2013tk0012.pdf Accident8 URL http://www.mlit.go.jp/jtsb/ship/rep-inci/2012/keibi2012-10-47_2012mj0062.pdf
Chapter3	P. 45	Photograph 3-11	DVD "Ship Handling in Restricted Waters - Anchoring -", Japan Captains' Association

Chapter	Page No.	Corresponding section	References
Chapter 4	P. 57	Photograph 4-1 (a), (b)	"07 August 2018 Contaminated Bunkers damage hundreds of ships Do authorities really care? Prelude to 1 January 2020 safety problems? ", An INTERTANKO Critical Review (INTERTANKO) , URL https://www.intertanko.com/topics-issues/issuearticle/contaminated-fuels-an-intertanko-critical-review?topicID=115
Chaper 4	P. 58	Law Offices of Toda & Co.	"Importance of Preservation of Evidence in Bad Bunker Issue", Lawyer Mr.Aoki, Marine Proctor Mr. Yamatani, Law Offices of Toda & Co. URL http://www.todalaw.co.jp/index.html
Chapter 4 Chapter 5	P. 60/61 /99	Photograph 4-2 (a), (b) Table 4-3 Photograph 5-33 (b)	Text Book "BUNKERING" published by JSU, IMMAJ, MOL Engineering. URL http://www.immaj.jp/
Chapter 5	P. 65	Figure 5-1	Web site of U.S. Energy Information Administration (EIA) "Coming changes in marine fuel sulfur limits will affect global oil markets DECEMBER 14, 2018 (based on International Marine Organization, European Union, and China's Ministry of Transport)" URL https://www.eia.gov/todayinenergy/detail.php?id=37793
Chapter 5	P. 66/67	Figure 5-2 5-1-1 Production of marine fuel oils	"2020nen no IMO kisoku tekigouyu nitsuite", Manabu watanabe, JXTG Nippon Oil & Energy Corporation, Japan Ship Machinery and Equipment Association, dai 27kai hakuyo gijyutsu foram, September 19th 2019, (in Japanese)

Chapter	Page No.	Corresponding section	References
Chapter 5	P. 66/69 /97	5-1 IMO 2020 compliant fuel oil concerns 5-2 Precautions and countermeasures for safe usage of IMO 2020 compliant fuel oil 5-3 Countermeasures for the safe use of cylinder oil	2019 ClassNK Technical Seminars, (in Japanese) (Tokyo June 6th , Kobe June 12th ,Imabari June 13th , Hiroshima June 14th), URL https://www.classnk.or.jp/classnk-rd/seminar/2019/0606.html
Chapter 5	P. 66/69 /97	5-1 IMO 2020 compliant fuel oil concerns 5-2 Precautions and countermeasures for safe usage of IMO 2020 compliant fuel oil 5-3 Countermeasures for the safe use of cylinder oil	ClassNK "Guidance for onboard use of Compliant Fuel Oil with SOx regulation from 2020" (March 2019) Guidance is available to download free of charge via ClassNK's website www.classnk.com for those who have registered for the ClassNK My Page" service. URL http://www.classnk.or.jp
Chapter 5	P. 66/69 /101	5-1 IMO 2020 compliant fuel oil concerns 5-2 Precautions and counter-measures for safe usage of IMO 2020 compliant fuel oil 5-4-2 Diagnosis of cold flow properties	ClassNK "Booklet for ship crew members: Precautions concerning change-over to 0.50% sulphur compliant fuel oils", (September 2019), URL https://www.classnk.or.jp/hp/pdf/activities/statutory/soxpm/soxbooklet201909en.pdf

Chapter	Page No.	Corresponding section	References
Chapter 5	P. 66/67	5-1-1 Production of marine fuel oils Figure 5-3	"Sekiyu seihin no dekirumade", Petroleum Association of Japan, June 2010, (in Japanese), URL https://www.paj.gr.jp/about/publications/
Chapter 5	P. 66/67	5-1-1 Production of marine fuel oils Figure 5-3	"Hakuyo teiiou nenryoyu no seizo houho to kyokyu taisei", Toshiaki Hayashi, Journal of the Japan Institute of Marine Engineering, Vol.43No.2 (2008), (in Japanese), URL https://www.jstage.jst.go.jp/article/jime2001/43/2/43_2_164/_pdf/-char/ja
Chapter 5	P. 66/67	5-1-1 Production of marine fuel oils Figure 5-3	"Production Method and Quality of Low Sulfur Fuels", Toshiaki Hayash, Journal of the Japan Institute of Marine Engineering, Vol.50No.3 (2015), (in Japanese), URL https://www.jstage.jst.go.jp/article/jime/50/3/50_341/_pdf
Chapter 5	P. 66/67	5-1-1 Production of marine fuel oils Figure 5-3	"Ippan kaiki 2020nen tekigoyu no seizo houho to hinshitsu nitsuite" Toshiaki Hayashi, National Institute of Maritime, Port and Aviation Technology, Japan Marine Engineers' Association, Technical lecture, November 15th 2019, (in Japanese), URL http://www.marine-engineer.or.jp/keihin/

Chapter	Page No.	Corresponding section	References
Chapter 5	P. 66/67	5-1-1 Production of marine fuel oils Figure 5-3	"Banker jyuyu no tyakkasei hyoka", Yuta Mitsui, JXTG central technical research laboratory. JXTGTechnical Review Vol.55No.3 (October 2013), (in Japanese), URL https://www.eneos.co.jp/company/rd/technical_review/pdf/vol55_no03_07.pdf
Chapter 5	P. 66/70 /82	5-1-1 Production of marine fuel oils Figure 5-5 Graph in Figure 5-15	"Fuel oils", Nobuyuki Awai, Osamu Hanashima, Saiji Yokosawa, Sankaido Publising Co.,Ltd., 1994, (in Japanese)
Chapter 5	P. 68	Figure 5-4	Web site of U.S. Energy Information Administration (EIA) "Crude oils have different quality characteristics JULY 16, 2012 (international crude oil handbook density and sulphur content of selected crude oil)", URL https://www.eia.gov/todayinenergy/detail.php?id=7110#
Chapter 5	P. 74/83 /87/91 /94	Photograph 5-9 Photograph 5-17 Figure 5-18 Photograph 5-22 Photograph 5-25 Photograph 5-29	"Sulphur Cap 2020 Tackling a Paradigm Shift in the Shipping Industry 6 sept 2018" Kjeld Aabo (Director New Technologies, MAN Energy Solutions), Charlotte Rojgaard (Bureau Veritas), Fuel 2020 Circle SMM in Hamburg Sep. 2018 CIMAC Circle at SMM, URL https://www.cimac.com/cms/upload/events/circles/circle_2018_SMM/CIMAC_Circle_SMM_2018.pdf

Chapter	Page No.	Corresponding section	References
Chapter 5	P. 75/86	Photograph 5-10 Photograph 5-20	Web site of Ministry of Land, Infrastructure, Transport and Tourism, Japan Guide for use of 2020 SOx regulation compliant fuel oils ver.2, (Maritime Bureau of the Ministry of Land, Infrastructure, Transport and Tourism), Oct 2019, (in Japanese), URL https://www.mlit.go.jp/common/0013074 84 .pdf
Chapter 5	P. 77	Table 5-11	"Summary of Damage" ClassNK Technical Review (Kaishi), (No312, No316)
Chapter 5	P. 86	Photograph 5-20	CIMAC Guideline "Cold flow properties of marine fuel oils" CIMAC WG7 Fuels. 2015, URL https://www.cimac.com/cms/upload/workinggroups/WG7/CIMAC_WG7_2015_01_Guideline_Cold__Flow_Properties_Marine_Fuel_Oils_final.pdf
Chapter 5	P. 87	Photograph 5-23	Guidance for shipowners and operators on MARPOL Annex VI Sulphur Regulation [Sulphur 2020: What's your plan?] Lloyd's Register URL https://info.lr.org/l/12702/2018-06-04/4yx18k/12702/188510/mo_sulphur_2020_guidance_document_201805.pdf
Chapter 5	P. 90/92 /102	Table 5-24 5-2-5 ⑤ Ignition and combustion quality 5-4-3 Assessment of ignition quality	ISO 8217:2017 Petroleum products — Fuels (class F) — Specifications of marine fuels, International Organization for Standardization URL https://www.iso.org/home.html (in English), Japanese Standards Association URL https://www.jsa.or.jp/ (In Japanese)

Chapter	Page No.	Corresponding section	References
Chapter 5	P. 97	5-3 Countermeasures for the safe use of cylinder oil	"Performance of Marine Lubricants", Shigeki Takeshima, Journal of the Japan Institute of Marine Engineering, Vol.45 No.1（2010）,(in Japanese), URL https://www.jstage.jst.go.jp/article/jime/45/1/45_44/_pdf/-char/ja
Chapter 5	P. 97	5-3 Countermeasures for the safe use of cylinder oil	"Kinnen no hakuyo enjinyu wo torimaku kankyo to taio gijyutsu" Yoko Morita, ENEOS Technical Review, Vol.54No.1(February 2012),(in Japanese), URL https://www.noe.jxtg-group.co.jp/company/rd/technical_review/pdf/vol54_no01_07.pdf
Chapter 5	P. 97	5-3 Countermeasures for the safe use of cylinder oil	CIMAC Recommendation 31 "The Lubrication of Two-Stroke Crosshead Diesel Engines" CIMAC WG8 Marine Lubricants 2017 URL https://www.cimac.com/cms/upload/Publication_Press/Recommendations/Final_Draft_Recommendation_31_2017-06-23_CIMAC_WG8-SG4_2-Stroke_Lubrication.pdf
Chapter 5	P. 100	Spot test kit Photograph 5-34 Photograph 5-35	Nippon Yuka Kogyo Co., Ltd. Onboard test kit: fuel oil spot test URL https://www.nipponyuka.jp/products08.html
Reference Material	P. 111 /114	Reference Material 03: Problem Solving Method (1) Logic tree (2) Fishbone	"Jyoho wo shunji ni seiri shite aidhia wo umidasu! Noto ・ Memo furu katsuyo jyutsu" Nagaokashoten Henshu-bu, (in Japanese) , 2011

Chapter	Page No.	Corresponding section	References
Reference Material	P. 127	Reference Material 07: (1) Inability to move or think	"The Unthinkable: Who Survives When Disaster Strikes – and Why" Amanda Ripley, Random House Audio (Machiko Oka translated in Japanese, Kobunsha Co., Ltd.)
Reference Material	P. 128	Reference Material 07: (2) Preventive measures against panic	"Anzen. kikikanri ni kansuru kosatsu (sono2) Kinkyuji no ningen kodo tokusei""Tomihiko Furuta, Kokusai chiikigaku kenkyu, No.6 March 2003 Faculty of Regional Development Studies Toyo University (in Japanese), URL https://toyo.repo.nii.ac.jp/?action=repository_uri&item_id=3884&file_id=22&file_no=1
Reference Material	P. 128	Reference Material 07: (2) Preventive measures against panic	"Natural Disaster and Panic" Shunji Mikami, Fukumura Shuppan Inc., (in Japanese) , 1998

Acknowledgment:

The author sincerely thanks everyone for their precious contributions and advice. Extended thanks also go out to colleagues and those who kindly allowed us use of their reference materials.

JAPAN P&I CLUB
日本船主責任相互保険組合

Website www.piclub.or.jp/en/

Principal Office (Tokyo)	15th Floor, ARK Hills Front Tower, 2-23-1, Akasaka, Minato-ku, Tokyo 107-0052,Japan Phone: 81-3-6687-0505 Fax: 81-3-6871-0051
Kobe Branch	6th Floor Shosen-Mitsui Bldg. 5, Kaigandori Chuo-ku, Kobe, Hyogo 650-0024, Japan Phone: 81-78-321-6886 Fax: 81-78-332-6519
Fukuoka Branch	3rd Floor Hakata-Ekimae Center Bldg., 1-14-16 Hakata Ekimae, Hakata-ku, Fukuoka, Fukuoka 812-0011, Japan Phone: 81-92-260-8945 Fax: 81-92-482-2500
Imabari Branch	5th Floor Imabari-Kitahoraicho Building, 2-2-1 Kitahoraicho, Imabari, Ehime 794-0028, Japan Phone: 81-898-33-1117 Fax: 81-898-33-1251
Singapore Branch	80 Robinson Road #14-01 Singapore 068898 Phone: 65-6224-6451 Fax: 65-6224-1476
Japan P&I Club (UK) Services Ltd	5th Floor, 38 Lombard Street, London, U.K., EC3V 9BS Phone: 44-20-7929-3633 Fax: 44-20-7929-7557

Edited by Loss Prevention and Ship Inspection Dept. Japan P&I Club