Issues and measures for use of low-sulfur fuel oil

1. Introduction

While various kinds of regulations are being enforced to inhibit the emission of atmospheric pollutants from ships, other controls are being imposed on sulfur content in fuel oils to restrict the emission of sulfur oxides (SOx) and particulate matter (PM) included in exhaust gases of diesel engines, boilers, and so on. Because of these controls, the use of low-sulfur fuel oil, which is a distillate of gas oil, etc., is being demanded in ships that were using mainly low-grade residual oil until now.

With the use of low-sulfur fuel oil, new issues are now being pointed out in machinery in which the use of such fuel oil was not envisaged during the design stage because of the inherent properties of this oil. Thus, measures are needed to ensure safe operation.

These issues, the measures being adopted by various machinery manufacturers, and the activities of the Society are introduced in this report.

2. Overview of controls

The following are the controls related to sulfur content in fuel oil; these controls are meant to restrict the emission of sulfur oxides (SOx) from ships.

2.1 MARPOL 73/78 Annex VI (Reg. 14)

Among the SOx controls, the level of control of sulfur content in fuel oil varies for designated emission control area and areas other than designated emission control area. The existing controls are as below.

➢ Control of sulfur content in fuel oil

- Area other than designated emission control area 4.5% or less
- Designated emission control area* 1.0% or less

  * Note: Baltic Sea area and North Sea area (see Fig. 1)

During the session of MEPC 57 held from 31 March to 4 April 2008, a revised proposal reinforcing stepwise reinforcement of controls as shown in Table 1 was agreed upon. These controls can be achieved not only by using distillate oils but also by adopting alternative technologies if they are at least as effective in terms of equivalent SOx emissions reductions.

Table 1 Controls on the concentration of sulfur content in fuel oil

Effective date	Area other than designated emission control area	Designated emission control area
Before 1 July 2010	4.50 %	1.50 %
On and after 1 July 2010	↓	1.00 %
On and after 1 January 2012	3.50 %	↓
On and after 1 January 2015	↓	0.10 %
On and after 1 January 2020*	0.50 %	↓

* Note: The decision on whether to make 2020 or 2025 as the next control period will be taken in 2018.

During the session of MEPC 60 held from 22 March to 26 March 2010, a proposal was adopted to amend the MARPOL Convention by designating the areas within 200 nautical miles from the coasts of North America and Canada (excluding a part of the areas such as the West Coast of Alaska) as the North American Emission Control Area for controlling the emissions of NOx, SOx and PM from 1 August 2012. (See Fig. 1.)

Accordingly, on and after this day, ships plying in the designated areas must use fuel oil with sulfur content complying with the regulations of the designated emission control area in MARPOL Annex VI.

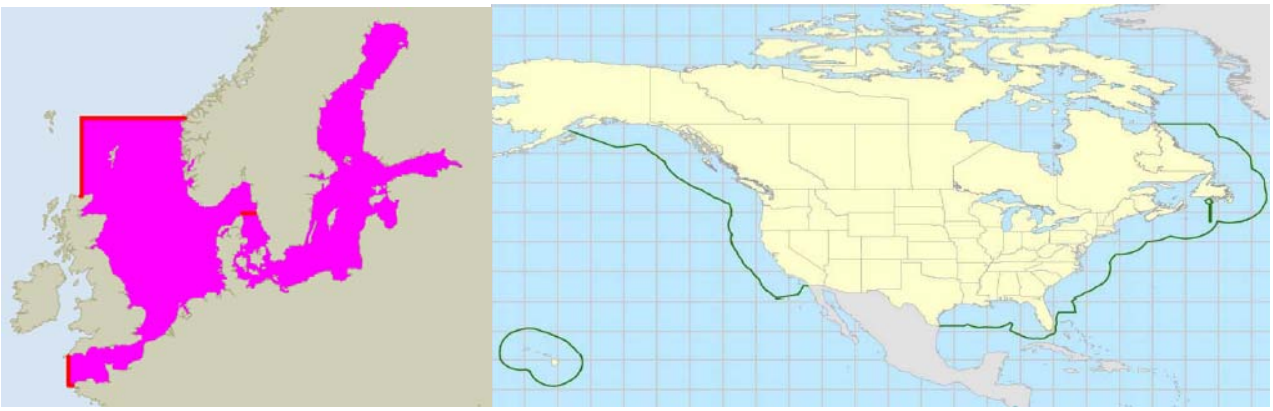

Fig. 1 SOx Emission Control Area (ECA)

2.2 California Air Resources Board (CARB)

California State specifies the use of fuel oil shown in Table 2 for diesel main engines, auxiliary engines (including diesel engines for electric propulsion) and auxiliary boilers installed in ocean-going vessels engaged in ocean navigation within Regulated California Waters (areas within 24 nautical miles from the border of California State and Oregon State to the border of California State and Mexico).

Table 2 Control of sulfur content in fuel oil according to the CARB

Effective date	Concentration of sulfur content in fuel oil
On and after 1 July 2009 (Phase I)	Marine gas oil (MGO) at or below 1.50% or marine diesel oil (MDO) at or below 0.50%
On and after 1 July 2012 (Phase II)	MGO or MDO at or below 0.10%

2.3 European Commission directive 2005/33/EC

This directive requires the use of fuel oil shown in Table 3 for ships berthed for two or more hours at any port in the European Union. Since this control applies to machinery used while the ship is at berth, it need not normally be applied to main engines.

Table 3 Concentration of sulfur content in fuel oil according to EC directive 2005/33/EC

Effective date	Concentration of sulfur content in fuel oil
On and after 1 January 2010	0.10 %

Although measures such as modification may be necessary to ensure safe operation of boilers and other machinery using low-sulfur fuel oil that was not envisaged at the time of manufacture of the same, it has been pointed out that many ships exist for which no measures can be taken before the control becomes applicable.

In view of these circumstances, the European Commission issued the Commission Recommendation on 21 December 2009, giving a grace period not exceeding eight months for ships that cannot comply with the directive before the specified date, and also notified the Member States of the European Union that if documents such as contract with a manufacturer for modification work and a retrofit plan approved by the ship's classification society are available as evidence indicating that preparations are being made to achieve compliance, then a reduction in the degree of penalty may be considered. Most of the Member States have accepted this recommendation, but some have set their own limits as shown in Table 4, and are demanding a faster response.

Table 4 EU Member States setting their own compliance limits

Compliance limit	Name of Member State
6 months	Belgium, Germany, Ireland
Before 1 July 2010	Finland
Before 1 August 2010	Norway

3. Low-sulfur fuel oil

Low-sulfur fuel oils that generally comply with the regulations mentioned above include Marine Gas Oil (MGO) defined as DMA grade, DMX grade or DMZ grade, and Marine Diesel Oil (MDO) defined as DMB grade in ISO 8217. The main properties of these fuels are given in Table 5.

Table 5 Main properties of fuel oil defined in ISO 8217 (2010)

Grade	MGO			MDO
	DMX	DMA	DMZ	DMB
Sulfur content % (m/m)	max. 1.00	max. 1.50	max. 1.50	max. 2.00
Viscosity cSt @40˚C	min. 1.40 max. 5.50	min. 1.50 max. 6.00	min. 3.00 max. 6.00	max. 11.0
Flash point ˚C	min. 43	min. 60	min. 60	min. 60

4. Characteristics of low-sulfur fuel oil

4.1 Low viscosity

The viscosity of low sulfur fuel oil is extremely low compared to the viscosity of heavy fuel oil (C) and marine diesel oil (A). (Min. 1.5 cST at 40˚C in DMA grade of ISO 8217) As a result, internal leakage in FO pump, increase in flowability of fuel from the fuel injection nozzle, and so on, are likely to occur, and the effect of these on various equipment is a cause for concern.

4.2 Low lubricity

Since the lubricity of fuel oil depends on the viscosity, the lubricity of low-sulfur fuel oil is low. Consequently, abnormal wear is likely to occur in the sliding/contact parts of pumps, etc.

4.3 Acidity

The sulfur content in fuel oil changes to acid salt because of combustion, but most of it becomes sulfur dioxide (SO_2) while a part of it gets converted to anhydrous sulfurous oxide (SO_3). Anhydrous sulfurous oxide reacts with water in scavenging air or water generated during combustion to form sulfuric acid (H_2SO_4). With the reduction in sulfur content, the amount of sulfuric acid generated also reduces. When cylinder oil with high alkali base number for heavy fuel oil (C) in diesel engines is used continuously, deposits may be formed, and abnormal wear of the cylinder liner may occur.

4.4 Flash point

Fire hazard increases because the flash point of low-sulfur fuel oil, such as gas oil, is low.

The use of fuel oil with flash point below 60˚C is prohibited according to the SOLAS Convention (Regulation 4.2.1.1 of II-1). On the other hand, the lowest flash point of gas oil of DMX grade defined in ISO 8217 is 43˚C; the introduction by mistake of gas oil with such low flash point into ships is a cause for concern.

5. Precautions when using low-sulfur fuels

5.1 Diesel engines

(1) Compatibility of cylinder oils with fuel oil

The lubrication of cylinders is an important point to be borne in mind for low speed diesel main engines. Until now, it was commonplace to use high alkali base number cylinder oil (BN 70-80) for heavy fuel oil (C) (sulfur content 1.5% or more), but engine and oil manufacturers are recommending the use of low alkali base number cylinder oil for low-sulfur fuel oil (sulfur content below 1.5%). As measures for low-sulfur fuel oil, it is important to monitor the exhaust gas temperature to check abnormalities of rings/liners, and to carefully check the condition of the rings during the maintenance and inspection work. If any sign of abnormality is detected, the most realistic response that can be taken is to adopt the necessary measures after discussion with the engine manufacturer.

(2) Ignition delay and defective combustion

The viscosity and residual carbon in low-sulfur fuel oil in recent years are generally low. There is a high probability that clarified oil (CLO) with high aromatics is used as cutter stock in the

manufacturing stages of such fuel oil. Fuel oil with high aromatics tends to become ignitable, combustible, and also defective; such fuel oil generally hinders combustion because of the abnormal wear it causes in rings/liners.

When a sign of abnormality is detected (rise in exhaust temperature, etc.), the following methods may be considered as immediate measures on board the ship:

- Reduce engine output.
- Reduce cylinder cooling water temperature.
- Tentatively increase the cylinder oil quantity.
- Raise the scavenging air temperature.
- Advance fuel injection timing.
- Enhance fuel cleaning.
- Mix with normal fuel.
- Add combustion accelerating agents.

(3) Low viscosity and low lubricity

Currently, the low lubricity of gas oil is the most focused and important issue related to properties of low-sulfur fuel oil. Problems associated with low lubricity include abnormal wear of plunger/barrel and oil leakage in fuel injection pump for generator engine. Generally, the lubricity of fuel oil is considered to be due to oil film formed because of viscosity and due to the lubricity of the sulfur content itself. Generally, such low viscosity is not considered during the design stage of fuel injection pump having sliding/contact parts. To prevent problems due to low lubricity beforehand, fuel oil cooler may be installed, or agents may be added to fuel oil for improvement of lubricity.

5.2 Boilers

(1) Turn down ratio

When low-sulfur fuel oil is used in the burner of a heavy oil burning system, the turn down ratio increases, and the minimum boiler load increases. As a result, problems may occur, including deterioration of ignitability; therefore, change over to an atomizer suitable for combustion of low-sulfur fuel oil, if necessary.

(2) Flame detection ability

Sometimes combustion of low-sulfur fuel oil cannot be detected in the cadmium sulfide cell-type flame eye for combustion of heavy oil because of the difference in flame radiation spectrum. In such cases, change over to or install additional photo IC-type flame eye to suit the flame generated.

(3) Air-fuel ratio

Sometimes abnormal smoke may be emitted due to the excess supply of air for combustion because of reduction in the supply of fuel oil from the oil fuel pump and because of the difference in calorific value of heavy oil and low-sulfur fuel oil. In this case, the fuel oil injection amount or the air-fuel ratio of the boiler combustion control system needs to be adjusted.

(4) Low flash point and volatility

The risk of flashback increases when low-sulfur fuel oil leaks within the boiler furnace because

the flash point of this fuel oil is low and it has high volatile content. To prevent fuel leaks within the furnace, duplication of fuel oil shut-off valve or duplication of flame eye so as to increase the chances of detecting flame failure is recommended.

Especially, when unburnt oil enters the furnace, appropriate measures must be taken, such as cooling the boiler, adequately purging the furnace, and so on.

5.3 Fuel pump

The flow rate and pressure reduce due to low viscosity that causes an increase in leakage in the contact parts within the pump, and sometimes the quantity of fuel supplied becomes deficient. Similarly, leakage from the pump seal may occur, so the seal needs to be replaced. Also, self-lubricating ability deteriorates, leading to concern about reduction in life of the bearing.

As a measure, pump suitable for the viscosity of the fuel oil used may be additionally installed, or a spare pump may be installed.

5.4 Change-over of fuel oil

If heavy fuel oil (C) is used to operate an engine, the fuel oil is to be heated to above 100˚C and used so as to lower the viscosity. However, in this condition, if the fuel oil is changed over to low-sulfur fuel oil (particularly gas oil), the low-sulfur fuel oil with high volatility flows into the high temperature oil supply pipes and vaporizes. This may lead to abnormality in the fuel pump or cause a vapor lock. Unstable combustion and moreover, flame failure may occur in the boiler leading to a risk of explosion in the furnace.

Measures include changing over the fuel oil after the temperature of the fuel supply piping has adequately reduced, installing fuel oil cooler, and separating the supply pipes for low-sulfur fuel oil and heavy fuel oil (C); however, from the aspect of safety, it is important firstly to establish the change-over procedure of fuel oil.

The following precautions are particularly necessary during the change-over of fuel oil:

(1) Stop the steam supply to the steam tracer for fuel oil supply piping and fuel oil heater, and reduce the fuel temperature (generally below 60˚C). At this stage, bypass the safety device for fuel oil low temperature, etc., in the boiler.

(2) If pump for low-sulfur fuel oil has been provided, change over the pump.

(3) If necessary, especially in large boilers provided with steam atomizing burner, replace the atomizer and sprayer, and change over the combustion control mode to MGO mode.

(4) If combustion defect or emission of black smoke occurs from the boiler, adjust the air-fuel ratio by the fuel/air adjuster in the boiler control panel.

Since the procedure for changing over this fuel oil is indispensable for performing work safely, this procedure was generally required to be provided on board the ship conventionally, but with the amendment to Regulation 14, Annex VI of MARPOL, it became mandatory from 1 July 2010 to provide such a procedure on board the ship.

5.5 Compatibility of mixed fuels

When conventional fuel oil and low-sulfur fuel oil are mixed due to changeover operation, overflow, return from machinery, etc., large amount of sludge may sometimes be generated depending on the extent of matching of these fuel oils. It is preferable to take precautions to avoid clogging of strainers and unwanted mixing of fuels, as far as possible.

5.6 Low flash point

As mentioned in Sec.4.4 above, fuel oils with flash points below 60˚C are prohibited according to SOLAS Convention. In case of bunkering, the Bunker Delivery Note must be properly checked to ensure that the flash point is 60˚C or more.

6. Recommendations by manufacturer

For use of low-sulfur fuel oil in machinery and equipment designed for marine diesel oil (A) and heavy fuel oil (C), measures are being studied by different machinery manufacturers for the various problems raised in Sec. 4 above. However, the measures differ according to the specifications of each machinery, so it is necessary to adhere to the recommendations of manufacturers on whether low-sulfur fuel oil can be used or not, and on the modification methods.

Tables 6 and 7 show examples of major recommendations by the machinery manufacturers.

Table 6 Examples of major recommendations by diesel engine manufacturers

	Manufacturer	Lower viscosity limit (machinery intake)	Major recommendations	Others
Two-stroke	MAN	2.0 cSt	If lower viscosity limit cannot be ensured: ・Install FO cooler ・Install pipe temperature control system during change-over of fuel oil	Use appropriate alkali base number cylinder oil.
	WARTSILA	1.5 cSt	For fuel oil with 2.0% sulfur content, reduce the cooling fresh water temperature by about 10˚C.	
	Mitsubishi	2.0 cSt		
Four-stroke	Yanmar	1.8 cSt	Install FO cooler if the lower viscosity limit cannot be ensured.	Use appropriate alkali base number cylinder oil. (If the usage period is below 300 hours, continued use of high sulfur cylinder oil is permitted)
	Daihatsu	2.0 cSt		

Table 7 Examples of major recommendations by boiler burner manufacturers

Manufacturer	Fuel injection system	Major recommendations	Others
Volcano	Steam atomizing	・Replace atomizer and sprayer ・Replace flame eye (Cds type to Photo IC type) ・Add "Gas Oil Mode" (air-fuel ratio, change-over of fuel temperature alarm)	Duplication of fuel shut-off valve and flame eye (Reinforce flashback measures for fuel leaks into the furnace)
	Pressure atomizing	・Replace atomizer if quantity injected is inadequate ・Reduce discharge pressure to suit the oil fuel pump ・If the discharge pressure of the oil fuel pump is inadequate, replace the pump	
Sunflame	Pressure atomizing	・If there are two nozzles in the ON-OFF control burner, change over to one. ・Additionally install MGO pressure switch in fuel oil piping system ・Install spare oil fuel pump	
	Rotary cup	・If black smoke is emitted, reduce oil pressure, adjust the injected quantity ・If the discharge pressure of the oil fuel pump is below 0.2 MPa, replace the impeller	
Miura	Pressure atomizing	・Additionally install oil fuel pump for MGO	

7. Activity of ClassNK

7.1 Approval and survey

If low-sulfur fuel oil is to be used in ships in service that were not envisaged to use such oil at the design stage, a study is necessary to assess whether measures and modifications are necessary for safe operation of various machinery. Implementing risk assessment based on recommendations of manufacturers of various machinery is effective in this study. INTERTANKO and OCIMF have recommended implementing risk assessment in their guidance related to use of low sulfur fuels in response to the directives of the EU Commission.

(See http://www.intertanko.com)

If modifications are carried out, the drawing approval and inspections listed below based on the relevant requirements of the Rules for the Survey and Construction of Steel Ships are necessary.

(1) Drawing approval

(i) When fuel tank, piping, pump is modified or additionally installed
"Fuel oil piping diagram" (including particulars of equipment to be changed such as pumps)

(ii) When boiler combustion control system is modified or additionally installed
"Boiler combustion control system"

(iii) Drawings according to other modifications

(2) Surveys

Based on the modification, the following inspections may be required:

(i) Check the modified part
(ii) Hydrostatic tests and leak tests of fuel oil piping system
(iii) Hydrostatic tests of fuel tanks
(iv) Performance tests
(v) Check the certificates of machinery and equipment newly installed, such as pumps

(vi) Other surveys according to the modifications carried out.

7.2 Response to EU Commission directives

As mentioned in Sec. 2.3 above, measures including modifications may be necessary to comply with the regulations of the EC directive for ships that cannot comply with the directive before the date of application of the directive. If documents such as contract with a manufacturer of modification work and retrofit plan approved by the ship's classification society are available on board the ship as evidence that preparations for compliance are being made, then such documents may help to reduce the degree of penalty for non-compliance.

ClassNK has been adopting a swift response to approve modified drawings, and moreover, has been speedily implementing surveys that accompany modification. When no problems are found, ClassNK records the modification and the inspection carried out for the use of low-sulfur fuel oil in the Survey Record as required by the EC directive 2005/33/EC to establish that modifications have been carried out to comply with the regulations, and even issues the Statement of Fact if requested by the ship owner.

For ships not requiring modifications, no special measures are specified but if there is a request from the ship owner, ClassNK studies the opinions of the machinery manufacturer indicating that modifications are not necessary and other documents such as results of risk assessment, and then issues the Statement of Fact containing notes to that effect.

7.3 Proposal to IACS

If one fuel pump for heavy fuel oil on the ship is used for supply of fuel to the main engine using low-sulfur fuel oil, problems may arise, such as the load on the main engine may reduce because of the reduced fuel oil supply, or the fuel intake efficiency may drop in the fuel injection pump and response to load fluctuation may reduce. Ships navigating in areas where CARB regulations apply and in the designated areas of Annex VI of MARPOL are to be provided with two pumps operating simultaneously, including the spare pump. The concept of redundancy and arrangement of pumps in this case, have been proposed as general requirements for the use of low-sulfur fuel oil by ClassNK in the preparation of IACS Unified Requirements and its unified interpretation.

8. Conclusion

Various troubles are anticipated to occur because of the problems mentioned above when low-sulfur fuel oil is used; fortunately, however, no instances of major accident or damage have been reported until now. This is attributed to the appropriate response and measures adopted by shipbuilders and machinery manufacturers possessing the latest technologies and also by the crew members, ship management companies and ship owners engaged in the operation of ships.

ClassNK will strive to assiduously collect the latest information, offer this information to the concerned personnel and contribute to the safe operation of ships and to the conservation of the marine environment.