OPERATIONAL CONCERNS FROM COMPLIANCE OF IMO2020 SULPHUR LIMIT THROUGH VLSFO

Abhay Singh, Sanjeevi Shanthakumar,

Gujarat National Law University, India, email: advabhaysnghthakur@gmail.com

From Jan 01, 2020, International Maritime Organisation (IMO) reduced the permissible sulphur content from bunker fuel used on ships from 3.5 % m/m in 2012 to 0.50 % m/m. The maritime industry is consequently abandoning High Sulphur Fuel Oil (HSFO) and employing Very Low Sulphur Fuel Oil (VLSFO) blends or using the Exhaust Gas Cleaning System (EGCS) that allows the combustion of HSFO by removing access sulphur from the exhaust gas of a ship. However, these compliance mechanisms present their own Technical and operational challenges. The concern that the specifications of VLSFO are hidden is groundless, as they must comply with ISO 8217. Thus, the problems with VLSFO blends are not their specs but the difficulty attached to their handling and use. Major problems with VLSFO blends are the breakdown of the main engine, poor liner conditions, collapsed piston rings, and consequential scuffing caused by mismanagement of cylinder oil and feed rate, improper maintenance of Piston Rings and Cylinder liner. Some other concerns with VLSFO blends are low shelf life, high sensitivity, admissibility of onboard testing, the readiness of seafarers, and other compliance difficulties. Training seafarers, technological awareness, and constant care can only achieve adequate compliance.

Keywords: Sulphur, VLSFO, Piston, Cylinder liner, lubricating oil, engine, BN

Received 29. 08. 2022, Accepted 05. 12. 2022

1. Introduction

Historically, the maritime industry paid little concern to the importance of the marine environment and the impact caused by decades of commercial shipping [1]. With the growth in international carriage, the fleet and size of commercial ships have drastically increased [2]. In 1954, the first treaty, “the International Convention for the Prevention of Pollution of the Sea by Oil (OILPOL)”, was formulated to protect the marine environment from vessels. For the next 20 years, the protection was limited to oil pollution from ships. In 1973 with the enactment of the International Convention for the Prevention of Pollution from Ships (MARPOL) and its implementation in 1978, the other aspects of marine pollution were also regulated. Initially, the MARPOL 73/78 had V annexes, each concentrating on a different part of marine pollution; nevertheless, the threat of air pollution was still not covered at the time. In 1997, the IMO added Annex VI to the MARPOL, providing regulations for protecting the marine environment from air pollution entered into force in 2005 [3]. Annex VI aims to reduce the emission of sulphur oxides (SO_x) and nitrous oxides (NO_x) and prevent emissions of Carbon monoxide, carbon dioxide, and other gases causing ozone depletion [4].

The decarbonization and reduction of Green House Gases (GHG) have been a long-term goal since the formulation of Annex VI of MARPOL. Nonetheless, the non-GHG has also been acknowledged as capable of causing significant harm. The NO_x but the SO_x emission has been viewed as a substantial threat as its emission can cause considerable damage such as ocean acidification, heightening mortality rate in marine life, and also in humans consuming marine-based resources. The shipping industry causes high Sulphur Oxide (SO_x) emissions compared to road, rail, and air transportation [5]. Out of the total anthropogenic SO_2 emissions, approximately 5 to 10 % of the global emission, i.e., 7-15 million tonnes annually, is caused by Shipping [6]. The SO_x emission causes health-damaging repercussions. The Sulphur causes the formulation of various particulate matters, which are associated with pulmonary diseases and premature death. The Organisation for Economic Co-operation and Development (OECD) Corporate Partnership Board Report of 2016 has highlighted that sulphur emission from ships causes 20,000-104,000 premature deaths annually and severe damage to the marine environment [7]. Further, ocean acidification results from SO_x emission when it reacts with the water particles in the atmosphere and creates sulphuric acid, consequently causing acid rain [8].

The IMO restricted the permissible sulphur content in fuel from ships to 4.5 % m/m in 2005. In 2012 the permissible limit was brought down to 3.5 % m/m [9]. The IMO has reduced the permissible sulphur limit to 0.50 % m/m effective from 1st Jan 2020 by Regulation 14 and 18 to Annex VI MARPOL. The IMO has kept an even lower sulphur limit of 0.1 % m/m for sensitive areas, categorized as Emission Control Areas (ECAs) [10]. The purpose of the sulphur limit was to ensure environmental protection from the negative impact of SO_x emissions [11]. Although reducing the permissible sulphur limit in 2020 is drastic, it was not unexpected. In 2008, the MEPC (Marine Environment Protection Committee) indicated that the maritime industry would be required to reduce the sulphur content to 0.50 % m/m from 2020 [12]. Subsequently, in the evaluation conducted by the MEPC under IMO in 2016 to oversee the availability of fuel enabling low sulphur content and the readiness of the maritime industry, the MEPC confirmed the readiness of the maritime industry to abide by the prescribed limit by 2020. Consequently, the 0.50 m/m limit was implemented on 1st Jan 2020 [13].

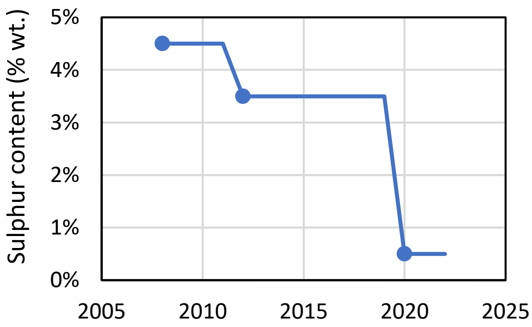

Figure 1: Changes made by MEPC in the Permissible Sulphur Content in Fuel Oil

Regulation 14 has suggested the use of alternate fuels such as Very Low Sulphur Fuel Oil (VLSFO) [14], Marine Gas Oil (MGO), or Liquefied Natural Gas (LNG) for compliance [15]. The regulation has also banned the use and carriage as a bunker of Heavy Grade Oil (HGO), High Sulphur Fuel Oil (HSFO), or Intermediate Fuel Oil (IFO 180) as bunker fuel. Nevertheless, a vessel operating with Exhaust Gas Cleaning Systems (EGCS) capable of ensuring the compliant sulphur limit is permitted to use or carry as a bunker the HGO/HSFO/IFO 180 fuel [16].

The operational, economic, legal, and environmental concerns regarding implementing the sulphur limit prevailed even before the regulation was enforced [17]. Nevertheless, post enforcement, implementing the new sulphur limit has been smooth, with very few violations and economic burdens [18]. However, the concerns have remained [19].

2. Experimental Part

Before the implementation of the IMO sulphur limit in 2020, significant concerns prevailed regarding using VLSFO as the blends, as specifications of such blends were not made public by the bunker providers. This led to the VLSFO being addressed as the "Frankenstein fuel" [20]. However, after the implementation, many concerns have been categorized as unjustified [21], as the bunker fuel can only be used on a vessel if the blend is as per the specifications mentioned in ISO 8217. The blends used for VLSFO can be residual [22] or distillate [23,24]. ISO 8217:2017 specifies different requirements for seven categories of distillate fuels and six types of residual fuel that can be used to comply with IMO 2020. Table 1 of the ISO 8217:2017 showcases Distillate and provides the required specifications, i.e., the viscosity, density, sulphur content, Flash Point, sediments, Fatty acid methyl ester (FAME), carbon residue, cloud point, pour point, water, Lubricity, and others necessary to be maintained in the fuel [25].

Table 1 VLSFO Off-Spec cases in 2020 and 2022

Parameter	cases
Viscosity	24 %
Density	4 %
Sodium content	7 %
Aluminum and Silicone content	3 %
Calculated carbon aromaticity index	9 %
Total sediment potential	9 %
Water	7 %
Acid number	1 %
Sulphur	40 %

The most commonly used distillate is DMA, followed by DMB [25]. Table 2 of the ISO 8217:2017 showcases six categories of Residual fuels providing a range of required specifications, i.e., the viscosity, density, sulphur content, flash point, sediments, carbon residue, pour point, water, lubricity, and others that need to be maintained in the fuel [26].

Table 2 VLSFO Off-Spec cases in 2022

Parameter	cases
Viscosity	7.1 %
Sodium content	6.8 %
Aluminum and Silicone content	5.3 %
Total sediment potential	13.6 %
Water	20.7 %
Sulphur	30.1 %
Others	16.3 %

The most commonly used residuals are RMG 380 and RMK 500 [27]. The (International Organization for Standardization) ISO-approved VLSFO blends formulated to ensure compliance with the 0.50 % m/m sulphur limit comprise aromatic compounds in high magnitudes, ranging between 70 % to 95 %. When these VLSFO are burned, they can increase Black Carbon emissions from 10 % to 85 % compared to Heavy Fuel Oil, and up to 67 % to 145 % compared with DMA and DMZ, which are the best quality Distillate Fuels. Although the specification regarding the VLSFO fuel is given as mentioned in the initial statement of the Experimental part, the issue of restriction on Black Carbon emission has not been prescribed. The review to analyse the readiness for implementing the IMO sulphur regulation, which took place in 2016, also did not focus on the impact of IMO 2020 specification on Black Carbon emissions. Several governmental and non-governmental Organisations (International), including the ISO, all stress that the VLSFO blends must comply with the ISO 8217 specification. Nevertheless, ISO 8217 itself is silent on the permitted black carbon emission. In consideration of the same, the MEPC called on shipowners, charterers, and member states to voluntarily prohibit the use of marine fuel, which can lead to high Black Carbon emissions [28]. Thus, it is evident that the ISO 8217 specifications are not exhaustive in tackling the environmental challenges.

2.1. Off-Specification cases in VLSFO

The anticipation regarding the use of VLSFO at the place of HSFO prevailed that the change would result in an increase in Off specification cases as the VLSFO blends may not be able to meet the required density, viscosity, water, cat-fines, TSP, carbon residue, and sulphur content [29] and comply with the ISO 8217. In 2018, the off-spec cases of VLSFO were identified as 6 %. In 2019, it showed a slight improvement to 5.8 % [30], which reached 6.3 % in 2020. However, as the maritime industry became more familiar with the use of VLSFO, the off-spec cases declined to 5.2 % in 2021 [31]. Compared to HSFO, in 2018, even though the HSFO was majorly used, the off-spec cases were only 5.2 % which in 2020 declined to 4.1 % [32]. Thus, the VLSFO off-spec has been comparatively more than the HSFO. There is no single reason behind VLSFO causing the breakdown of the main engine. The engine manufacturers and P & I Clubs have identified three primary causes for such trouble, i.e., the cylinder oil [33]. along with its feed rate [34,35], the condition of the Piston rings, and the care of the cylinder liner [36]. The result and discussion part have showcased the impact of the same.

Table 3 HSFO Off-Spec cases in 2022

Parameter	cases
Viscosity	29.1 %
Sodium content	3.9 %
Aluminum and Silicone content	4.8 %
Total sediment potential	9.1 %
Water	20.6 %
Sulphur	6.0 %
Others	26.4 %

2.2. The engine’s cylinder oil and feed rate

The cylinder lubrication is vital for the functioning of the engine. However, too much or too little lubrication can also cause damage to the engine and can even lead to the breakdown of the engine. Consequently, compatible cylinder oils must be used with the fuel being used for the combustion process. The feed rate of such cylinder oil must also be monitored carefully, as excess or little lubrication can cause severe engine damage. The IMO 2020 regulations or MEPC guidances do not provide a specific feed rate of cylinder oil to be maintained, which is compatible with VLSFO [37].

The HSFO is more acidic than VLSFO. Therefore, cylinder lubrication oil with high BN is required to control cold corrosion. The 100 BN is majorly the requirement which using the HSFO. However, an additive solution for 200BN marine cylinder lubricant has also been used, which provides adequate results. Thus, it can be seen that a compatible cylinder lubrication oil with HSFO is available. The same is not the case with VLSFO [38]. The bunker oil, including the VLSFO used in ship engines, contains acidic contents, which can cause engine corrosion. Thus, the manufacturers require vessels to use cylinder oil with grades from (Total Base Number [39]) TBN 40 to TBN 70. With the TBN 40 oil having the lowest detergency, i.e., less capability to reduce acidic formation, [40] and the TBN 70 having the highest detergency, i.e., highest ability to reduce acidic formation. To ensure the smooth functioning of the engine and the prevention of deposits, it may be viable to use the TBN 40 for four to five days and then switch over to TBN 70 for one day to flush the system. The continuous usage of lubrication Oil with high TBN along with the VLSFO in the engine can lead to excessive deposits of additives like calcium, barium, and magnesium. And the continued use of low TBN oil with VLSFO can lead to dirty piston rings and can also cause wear down of the cylinder liner and piston rings. Hence, it is vital to regularly inspect the liner's physical condition to optimize the cylinder oil's feed rate and TBN. It is impossible to stop the vessel every time in order to conduct the physical inspection at regular intervals during the voyages. Thus, the inspection is required to be conducted onboard by the Scavenge Drain Analysis (SDA) [41].

The estimate of iron content and the base number in the cylinder drain can be analysed through the SDA. The SDA can be done by analyzing the scavenging drain and system oil using the testing kits. This analysis can provide helpful information about engine performance [42]. The engine manufacturers have provided recommendations and guidance for maximum iron content in the scavenge drain. The suggestion is that for 26 to 50 cm bore engines, the maximum iron content should be 100, for 60 to 70 cm bore engines, the maximum iron content should be 150, and for 80 to 98 cm bore engines, the maximum iron content should be 200 ppm.

Table 4 Guiding drain oil levels [43]

Engine Bore	Max Fe content
26 to 50 cm bore engines	100 ppm
60 to 70 cm bore engines	150 ppm
80 to 98 cm bore engines	200 ppm

The base number of the cylinder oil while leveling the drain oil samples may vary depending on the engine and the oil type. The residual base number in the drain oil should be kept above 25 % of the original base number value [44]. This implies that for 40 BN oil, the residue BN should be above 10, which means it should be between 20 to 30 BN. If the unit shows high iron content in the SDA, the feed rate should only be increased after checking the residual BN. Increasing the feed rate when the BN is already high (i.e., close to 30 BN) can cause excessive calcium deposits on the piston head and surrounding areas (as shown in Figure 2), which may consequently cause excessive wear scuffing on the liner and sharp piston rings. In addition, regular maintenance of the lubricating system is also important as there exists a risk of loss of efficiency in old and worn lubricators, as these may not generate the expected feed rate from the hardware [45].

Figure 2 Hard Calcium deposit on piston [46]

3. Results and discussion

Para 2.1, Table 1, 2, and 3 have highlighted the fuel off-specification cases. The mentioned off-spec cases have resulted due to problems with Viscosity, Density, Sodium (Na), sulphur content, sediments, water, Aluminium, and silicate (Al & Si, also known as Cat fines), Pour Point, Calculated Carbon Aromaticity Index (CCAI), Flash Point, and Acid Number [47]. In 2020, out of the overall off-spec cases, 3 % had resulted due to cat-fine, 40 % due to Sulphur content, 24 % due to viscosity, 9 % due to CCAI, 9 % due to Total Sediment Potential (TSP), 7 % due to water, 7 % due to sodium, 4 % due to density, 1 % due to acid number.

In 2022, out of the overall off-spec cases, 5.3 % resulted from cat fine, 30.1 % due to sulphur content, 7.1 % due to viscosity, 13.6 % due to TSP, 20.7 % due to water, and 16.3 % due to other reasons.

Most off-spec is related to TSP, viscosity, and high sulphur, [48] which is in line with the already prevalent anticipation that the fuel may become more paraffinic and comparatively unstable [49]. There has been a sharp increase in off-spec due to the TSP and viscosity of the new fuels, as opposed to the conventional HSFO [50], where approximately 9.1 % off-spec in HSFO has been due to TSP or stability-related issues 13.6 % off-spec cases are due to such issued in VLSFO. The maritime industry has started to look into the mechanism of TSPs concerning the paraffinicity of these fuels. The ISO working group has also initiated to look into the same. However, there is a clear shift in the fuel industry, turning from aromatic fuels used before the year 2020 to a more paraffinic native fuel after the year 2020. Nevertheless, the increase in the off-spec cases related to viscosity and cat fines in VLSFO is not very high. Thus, the maritime industry is successfully using good quality VLSFO capable of providing stability and safety. Consequently, it can be said that the maritime industry has tackled the technical challenges to a certain extent.

The parameter limits deviating from the ISO 8217 standard are TSP (Total Sediments Potential), Aluminum and Silicon, Sulphur, Pour Point, Flash Point, and Viscosity. In several cases, increased sludge deposits in the fuel system have resulted in increased sludge accumulation in the purifiers and clogging of fuel oil filters. (It is recommended that the ISO 8217:2017 standard rather than the more commonly used ISO 8217:2010) [51].

Despite all the success, certain challenges still prevail. Since implementing the sulphur limit, the maritime industry has experienced many cases of breakdown of the main engine, poor liner conditions, collapsed piston rings, extreme air raids, and consequential scuffing. It has been seen that the scuffing of liner and wear down of piston rings can be because of single or multiple reasons such as fuel quality, handling of fuel, and treatment, or wrong selection of cylinder oil unwielded.

As mentioned in para 2.1. and 2.2 highlight that the VLSFO results in damage due to its specification and treatment. It shows that the cylinder oil and feed rate must be maintained. If the same is not maintained, damage to piston rings and Cylinder liner can be caused.

3.1. Piston Rings

The Cermet - Coated Piston Rings [52] should be used to prevent damaged damage [53]. When the Cermet Hard coating is applied to the running side of the piston ring, it results in friction caused due to the physical contact between the piston rings and the liner surface, preventing irrecoverable seizures. Nevertheless, if still any minor seizures are caused, the cermet can endure the same, provided there is an increase in the cylinder lubrication and a prompt reduction of the load on the engine [54]. The required thickness of the Cermet coating depends upon the engine's type and make. If the engine's cermet coating is above 100 microns during the inspection, this symbolises smooth functioning. However, if the cermet is 100 and 50, this indicates that the piston overhaul is needed. However, if the cermet is between 50 and 20 microns, then the piston overhaul is necessary at the first opportunity [55]. The good condition cermet-coated piston ring can be seen in figure 3, the cermet-coated piston ring with hard contact can be seen in figure 4, the cermet-coated piston ring with hard contact marks after the aluminum coating has worn off can be seen in figure 5, Partly damaged piston ring after hard contact can be seen in figure 6 [56].

Figure 3 Good condition cermet-coated piston ring

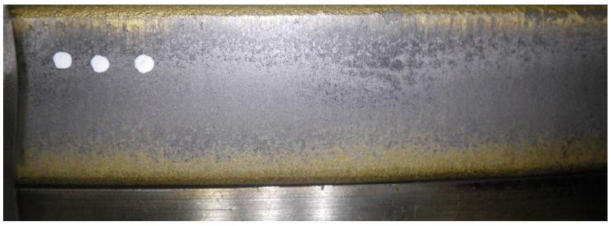

Figure 4 cermet-coated piston ring with hard contact

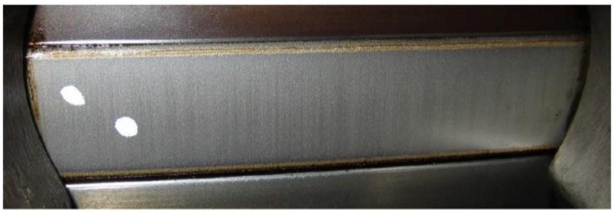

Figure 5 Hard contact marks after the Al coating has worn off

Figure 6 Partly damaged piston ring after hard contact

3.2. Cylinder liner

In the new liners, wave-cut grinding is provided, which improves cylinder oil retention and contributes to the prevention of liner polishing [57]. Using the VLSFO can lead to excessive liner wear rate and early disappearance of the wave-cut marks. If the wave-cut marks disappear, in such cases, it becomes necessary to refresh the liner running surface to ensure proper running of the piston rings [58]. The refreshing of liner can be done in two ways. Firstly, by wave cutting which provides the same pattern of the wave-cut as the new liner has by using the wave-cutting machine, and secondly, by honing process, which acts as an alternative to wave cutting [59]. The engine manufacturers recommend that at least 0.1 to 0.2 mm of the diameter be removed to ensure that the damaged surfaces are thoroughly removed. In liner scuffing, at least 0.5 to 01 mm of the diameter must be removed. It must be assured that the final roughness of the honing is at most 1.6 RA [60]. However, suppose the liner diameter is close to the maximum limit. In that case, it is better to renew the liner rather than employ the honing process [61] (the surface of a used cylinder liner with honing can be seen in Figure 7). Thus, the ship operator must identify the probable damage they can face from using VLSFO so that preventive actions can be taken. The crew must conduct frequent inspections of the main engine, liner, and piston rings during the voyage and at the port. Testing can be done by using onboard analysis equipment, which measures the iron content. It is necessary to analyse the condition of piston rings and liners and share information with the onshore office [62]. It is also vital to test the purifier efficiency at the earlier opportunity and conduct retesting every six months. The Superintendent Chief Engineer should analyze each parameter of the fuel lab report. The maritime industry has experienced a few cases of a main engine breakdown, and the mentioned measures can assist in preventing such cases from happening. The maritime industry is well aware that the crew shall take the necessary steps to ensure smooth implementation to avoid harm engine [63].

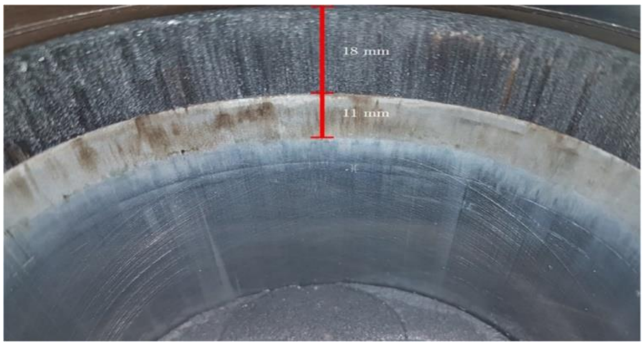

Figure 7 Photograph of the surface of a used cylinder liner. The upper 18 mm is covered by a protective "coked" lube oil layer. Wear can be seen in the swept liner surface 11 mm below the top. Post that surface where honing is done can be seen [64]

3.3. Other issues

The VLSFO is highly sensitivity. The cases of the incompatibility of HSFO are rare; however, due to the hypersensitive nature of VLSFO, the danger of becoming unstable and consequently causing severe operational problems, including clogged filters, separators, pipes, and overloading of fuel pumps resulting in issues with ignition and combustion, and a risk of permanent damage to pistons, piston rings, and cylinder liners [65]. Mixing VLSFO with HSFO or even with ULSFO can lead to the incompatibility of the fuel. Even different blends of VLSFOs must be avoided, as different bunker providers supply different specifications of VLSFOs, which can lead to instability. Even the same blend of VLSFO located at different places should not be mixed as the same can cause problems and non-compatibility. The commingling can result in incompatible bunkers onboard vessels. Shipowners must prepare for planned bunker segregation, along with the standard procedures to mitigate risks and remain vigilant while acquiring compatible fuels [66]. The shipowners, while bunkering must ensure that the new fuel is bunkered in a clean tank, as commingling can also occur if the sludge and unpumpable volumes of old fuel are prevalent in the tank [67].

Another major problem with the VLSFO blends is that they do not have long-term storage life. When the VLSFO was introduced, storage was not the primary concern. Instead, the concentration was on ensuring the fuel was stable and could be used safely. It is observed that when the VLSFO blends are stored for a long time, especially at elevated temperatures, the fuel tends to move into a more unstable structure. Due to the paraffinic nature of the fuels (which means that they are prone to adverse cold flow properties as well as stability concerns), it is considered that the longer fuel is stored, the more unstable it might become. Due to insufficient data, an exact time may not be confirmed [68]. Nevertheless, it can be claimed that the shelf life of the VLSFO may not be more than three months [69]. Furthermore, it must be ensured that the VLSFO is stored at a higher temperature to prevent it from becoming waxy (as shown in Figure 8). Nevertheless, it should not be stored at an unreasonably high temperature as that could cause potential thermal stress to the fuel [70]. For instance, if the Pour Point is +27, the fuel can be stored at 30-40 degrees C in the storage tank [71]. However, in some blends, the wax may still appear at a much higher temperature, i.e., 50- or 55-degrees C. Some operators use 50- or 55-degree C as the storage temperature or point in the bunker tank [72]. This might not be adequate as this can put thermal stress on the fuel in the bunker tank. The appearance of wax necessarily does not indicate that the fuel is going bad [73].

Figure 8 Wax on Low sulphur fuel [74]

The problem for ship operators occurs when the bunkered fuel is tested at the port state. The bunker might show a slightly higher sulphur content than what is permissible; in such cases, the utilization of such fuel will result in a breach of regulations (e.g., it has been calculated to 0.55 % m/m at the place of permissible 0.5 % m/m). It is advisable that while bunkering, the shipowner must obtain a Bunker Delivery Note (BDN), and ensure that the bunker supplier has made representation on the note regarding such specification of the bunker supplied. The shipowner must apply due diligence while procuring the compliant fuel. Nevertheless, if, even after implementing due care, the non-compliant fuel has been detected, the ship must immediately stop using such a bunker and bring the facts to the notice of the bunker supplier and the insurer. Even small off-spec can turn into quite a major issue in terms of operation [75]. However, if the sulphur content is insignificantly higher and is under the 95 % confidence level provided by ISO 8217 (i.e., is not about 0.53 m/m). This minor inconsistency may be excused. Nevertheless, the matter may be subject to the discretion of the executing authority [76].

Admissibility of onboard testing for sulphur content as evidence of compliance or non-compliance. The admissibility of onboard testing records depends on their utilization. For analysis of the stability, compatibility, and sulphur content of the VLSFO, onboard testing can be helpful [77]. However, the IMO guidelines require that the testing of VLSFO fuel for sulphur content should be done as per ISO 4259 standards in the ISO 17025 Laboratory, which is a technical accreditation that accredits the test which is done under several specified conditions, with several specified expertise [78]. Therefore, if the testing is done by the crew onboard, it may not be able to compete with the ISO 17025 accredited laboratory testing. Thus, in a situation where the onboard test has shown fuel to be compliant, but the laboratory testing shows 0.6 % m/m sulphur content, the fuel will be considered non-compliant.

Training Seafarers is another challenge, as cases of detention of the ships have been reported due to failure of proper reporting and bypassing of the required compliance system. Consequently, the crew must be adequately trained. The crew must be well-trained to find and rectify the fault [79]. If the crew cannot fix the existing fault, proper reporting of the same must be communicated to the onshore office to provide guidance to the onboard master and chief engineer. The crew must conduct testing off alarms and all the safety aspects. Simultaneously, they should be aware of the contingency plan if any problem arises. If the ship cannot comply with international rules, it might have to suspend operations [80].

4. Conclusions

The implementation of the IMO Sulphur regulation is successful to some extent as the VLSFO Blends supplied by the bunker providers are as per the ISO 8217 specification, due to which the off-spec cases of bunker supplied are very few. Nevertheless, a few concerns regarding operational troubles, specifically concerning the main engine’s breakdown, poor liner conditions, collapsed piston rings, extreme air raids, and consequential scuffing still prevail. The management in using proper lubrication has not been addressed, and its mismanagement can lead to deposits of additives and dirty piston rings, leading to seizures. Proper lubrication and Cermet-Coated on the Piston Rings can prevent irrecoverable seizures and reduce engine load. Proper running of the engine can also be ensured by ensuring that when the surface of the Cylinder liner becomes plane, the wave-cut grinding or honing should be used to refresh the liner. The crew shall perform onboard testing of fuel to ensure compliance with the permissible Sulphur emission and must conduct repairs whenever needed. To do so, the crew onboard must be properly trained and equipped. VLSFO is highly sensitive, and even a slight mixing, even with the same specification VLSFO blend, can make the fuel non-usable. Thus, the bunker tank needs to be emptied before refueling. Bunker fuel shall be managed properly as it has Low shelf life, and longer storage can cause waxing.

Proper functioning of EGCS must also be ensured, as any non-compliance with Sulphur limit due to fault in design, installation, and failure in the sea trial of the EGCS will lead to a violation of Sulphur regulation and attract consequential sanctions. Timely and proper examination of EGCS must be ensured.

References

1. Adebambo, O., Del Aguila Feijoo, M. C., Elhaimer, E., Hossain, T., Edwards, S. J., Morrison, C. E., Romo, J., Sharma, N., Taylor, S., & Zomorodi, S. (2019). Environmental effects of marine transportation. World Seas: an Environmental Evaluation, 505-530. DOI: 10.1016/b978-0-12-805052-1.00030-9
2. United Nations Conference on Trade and Development. (2020). The Review of Maritime Transport 2020 (UNCTAD/RMT/2020). United Nations. https://unctad.org/system/files/official-document/rmt2020_en.pdf. DOI: 10.18356/9789210052719c006
3. Attard, D., Fitzmaurice, M., Martinez, N., & Hamza, R. (2016). The IMLI manual on international maritime law: Volume III: Marine environmental law and maritime security law. Oxford University Press. DOI: 10.1093/law/9780199683949.001.0001
4. International Maritime Organization. (n.d.). Prevention of air pollution from ships. https://www.imo.org/en/OurWork/Environment/Pages/Air-Pollution.aspx.
5. International Transport Forum's Corporate Partnership Board (CPB). (2016). Reducing Sulphur Emissions from Ships – The Impact of International Regulation (OECD/ITF 2016). OECD. https://www.itf-oecd.org/sites/default/files/docs/sulphur-emissions-shipping.pdf. DOI: 10.1787/5jlwvz8mqq9s-en
6. International Transport Forum's Corporate Partnership Board (CPB). (2016). Reducing Sulphur Emissions from Ships – The Impact of International Regulation (OECD/ITF 2016). OECD. https://www.itf-oecd.org/sites/default/files/docs/sulphur-emissions-shipping.pdf. DOI: 10.1787/5jlwvz8mqq9s-en
7. International Transport Forum's Corporate Partnership Board (CPB). (2016). Reducing Sulphur Emissions from Ships – The Impact of International Regulation (OECD/ITF 2016). OECD. https://www.itf-oecd.org/sites/default/files/docs/sulphur-emissions-shipping.pdf. DOI: 10.1787/5jlwvz8mqq9s-en
8. Mohajan, Haradhan, 2018. "Acid Rain is a Local Environment Pollution but Global Concern," MPRA Paper 91622, University Library of Munich, Germany, revised 10 Nov 2018.
9. Clark, R. (2018, November). The 2020 Global Sulphur Cap: An Overview. https://www.reedsmith.com/-/media/files/perspectives/2018/shipping--2020-global-sulphur-cap--november-2018--white-paper.pdf
10. International Transport Forum's Corporate Partnership Board (CPB) (2016). Reducing Sulphur Emissions from Ships – The Impact of International Regulation (OECD/ITF 2016). OECD. https://www.itf-oecd.org/sites/default/files/docs/sulphur-emissions-shipping.pdf. DOI: 10.1787/5jlwvz8mqq9s-en
11. International Maritime Orgnization. (2019, December 20). IMO 2020 - cleaner shipping for cleaner air. https://www.imo.org/en/MediaCentre/PressBriefings/Pages/34-IMO-2020-sulphur-limit-.aspx
12. International Transport Forum's Corporate Partnership Board (CPB). (2016). Reducing Sulphur Emissions from Ships – The Impact of International Regulation (OECD/ITF 2016). OECD. https://www.itf-oecd.org/sites/default/files/docs/sulphur-emissions-shipping.pdf. DOI: 10.1787/5jlwvz8mqq9s-en
13. Brown, S. E. (2019). IMO 2020: industry conditions and readiness. Tulane Maritime Law Journal, 44(1), 145-164.
14. Pskowski, R. (2019). Bad bunker: fuel contamination claims, IMO 2020, and the houston problem. Tulane Maritime Law Journal, 44(1), 217-250.
15. Columbia Global Energy Dialogues. (n.d.). IMO Roundtable: The Future of Marine Transportation. Columbia | SIPA Center on Global Energy Policy, https://energypolicy.columbia.edu/sites/default/files/GlobalEnergyDialogueIMORoundtableTheFutureofMarineTransportation817.pdf
16. Norton Rose Fulbright | Global law firm. (2019, October). IMO 2020: Are we ready? https://www.nortonrosefulbright.com/en/knowledge/publications/5c72cf58/enforcing-imo-2020-are-we-ready
17. Liang, L. H. (2020, September 6). Shipping 'extremely ill-prepared' for IMO 2020. Seatrade Maritime. https://www.seatrade-maritime.com/asia/shipping-extremely-ill-prepared-imo-2020
18. International Maritime Organization. (n.d.). IMO2020 fuel oil sulphur limit - cleaner air, healthier planet.

https://www.imo.org/en/MediaCentre/PressBriefings/pages/02-IMO-2020.aspx
19. Osipova, L., Gorgeff, E., & Comer, B. (2021). Global scrubber washwater discharges under IMO's 2020 fuel sulfur limit, International Council on Clean Transportation. International Council on Clean Transportation. https://theicct.org/sites/default/files/publications/scrubber-discharges-Apr2021.pdf and American Bureau of Shipping. (2021, August). Marine Fuel Oil Advisory. https://ww2.eagle.org/content/dam/eagle/advisories-and-debriefs/marine-fuel-oil-advisory-21141.pdf
20. 'Frankenstein fuels': The bunker industry's intensifying war of words over emissions. (2020, January 28). Ship & Bunker. https://shipandbunker.com/news/world/679399-frankenstein-fuels-the-bunker-industrys-intensifying-war-of-words-over-emissions
21. International Bunker Industry Association (IBIA). (2021, March 18). VLSFO – fact vs fiction. https://ibia.net/2021/03/18/vlsfo-fact-vs-fiction
22. Residual Fuel: "Residual fuel means a petroleum fuel with a T90 temperature at or above 700 F. For example, No. 5 fuels and No. 6 fuels are residual fuels. Residual fuel grades are specified in ASTM D396 and ISO 8217. T90 temperature is based on the distillation test method specified in 1090.1350.": source: 40 CFR § 1090.80 - Definitions. (n.d.). LII / Legal Information Institute. https://www.law.cornell.edu/cfr/text/40/1090.80
23. Distillate Fuel: "Distillate fuel means diesel fuel and other petroleum fuels with a T90 temperature below 700 F that can be used in vehicles or engines that are designed to operate using diesel fuel. For example, diesel fuel, jet fuel, heating oil, No. 1 fuel , No. 4 fuel, DMX, DMA, DMB, and DMC are distillate fuels. These specific fuel grades are identified in ASTM D975 and ISO 8217. Natural gas, LPG, and gasoline are not distillate fuels. T90 temperature is based on the distillation test method specified in 1090.1350." source: 40 CFR § 1090.80 - Definitions. (n.d.). LII / Legal Information Institute. https://www.law.cornell.edu/cfr/text/40/1090.80
24. International Bunker Industry Association (IBIA). (n.d.). Frankenstein Fuel, Debunkering the Myth, VLSFO – FACT VS FICTION,. https://ibia.net/wp-content/uploads/2021/03/WB_2021_Q1_WEB-002.pdf
25. ISO - International Organization for Standardization. (n.d.). ISO 8217:2017(en) Petroleum products — Fuels (class F) — Specifications of marine fuels. https://www.iso.org/obp/ui/#iso:std:iso:8217:ed-6:v1:en
26. International Bunker Industry Association (IBIA). (n.d.). Frankenstein Fuel, Debunkering the Myth, VLSFO – FACT VS FICTION,. https://ibia.net/wp-content/uploads/2021/03/WB_2021_Q1_WEB-002.pdf
27. ISO - International Organization for Standardization. (n.d.). ISO 8217:2017(en) Petroleum products — Fuels (class F) — Specifications of marine fuels. https://www.iso.org/obp/ui/#iso:std:iso:8217:ed-6:v1:en
28. IBIA, Frankenstein Fuel, Debunkering the Myth, VLSFO – FACT VS FICTION, https://ibia.net/wp-content/uploads/2021/03/WB_2021_Q1_WEB-002.pdf
29. Bunkerspot. (2021, January). The New Order. https://www.bunkerspot.com/features-fuel-quality/item/the-new-order-4
30. Seatrade Maritime, IMO 2020: Marine fuel trends, quality, and issues, https://www.seatrade-maritime.com/bunkering/imo-2020-marine-fuel-trends-quality-and-issues
31. VPS, VLSFO INSIGHTS, EXECUTIVE SUMMARY, 30 June 2021, https://devcms.vpsveritas.com/sites/default/files/2021-07/VLSFO%20Insights%20%2319%20-%20Executive%20Summary.pdf ip & Bunker. (2021, September 2). VPS reports lower off-spec rate for VLSFO than MGO. https://shipandbunker.com/news/world/124742-vps-reports-lower-off-spec-rate-for-vlsfo-than-mgo
32. Bunkerspot, No Easy Answers, August/September 2020 https://www.bunkerspot.com/features-fuel-quality/item/no-easy-answers
33. Kuwada, K. (2020). Tips for Effective Engine Management and Maintenance P&I Loss Prevention Bulletin. JAPAN P& I CLUB, 19. https://www.piclub.or.jp/wp-content/uploads/2020/12/Loss-Prevention-Bulletin-Vol.49_Full.pdf
34. Feed rate is "the rate at which the cylinder oil is injected onto the liner": Source; Lubrizol360. (2020, January 15). The VLSFO challenge: Looking deeper for lubricant performance. https://360.lubrizol.com/2020/The-VLSFO-Challenge-Looking-Deeper-for-Lubricant-Performance-Part-1
35. Jensen, M. C., & Jakobsen, S. B. (2019, April). Service letter SL2019-671/JA, Cylinder lubrication update for 0 to 0.50% sulphur fuels. MAN Energy Solutions. https://www.man-es.com/docs/default-source/service-letters/sl2019-671.pdf
36. Tips for Effective Engine Management and Maintenance P&I Loss Prevention Bulletin (JAPAN P& I CLUB Vol.49, December 2020) https://www.piclub.or.jp/wp-content/uploads/2020/12/Loss-Prevention-Bulletin-Vol.49_Full.pdf
37. Jensen, M. C., & Jakobsen, S. B. (2019, April). Service letter SL2019-671/JA, Cylinder lubrication update for 0 to 0.50% sulphur fuels. MAN Energy Solutions. https://www.man-es.com/docs/default-source/service-letters/sl2019-671.pdf
38. Fuels & Lubrication, A New 200bn Solution For Engines Running On HSFO, February 2020

https://www.oronite.com/content/dam/oronite/products-technology/marine/Motorship_Feb_2020_PAGES_16-17.pdf
39. The base number is "the ability to neutralize the acid formation due to sulphur and fuel": Source: Innospec. (2020, April). Customer Technical Service, VLSFO REPORT - Q1 2020. https://innospec.com/wp-content/uploads/2020/10/Marine-technical-bulletin-April-issue-1.pdf
40. The detergency 'is the ability to keep the piston and rings clean': source; CIMAC Guideline On the Lubrication of Reciprocating Gas Engines, CIMAC Working Group 8 – Marine Lubricants, 03 | 2021) https://www.cimac.com/cms/upload/workinggroups/WG8/CIMAC_WG8_Guideline_Lubrication_of_Reciprocating_Gas_Engines_2021-03.pdf
41. Adamkiewicz, A., & Drzewieniecki, J. (2011). Operational problems in marine diesel engines switching on low sulfur fuels before entering emission controlled areas. Journal of Polish CIMAC. https://yadda.icm.edu.pl/yadda/element/bwmeta1.element.baztech-article-BPG8-0055-0022/c/CIMAC_2011_6_1_001.pdf
42. Chevron Marine Products LLC. (n.d.). Marine Lubricants DOT.FAST® service Instruction Manual. https://www.chevronmarineproducts.com/content/dam/chevron-marine/fast-services/dot-fast-onboard-testing/DOT.FAST%20Manual.pdf
43. Jensen, M. C., & Jakobsen, S. B. (2019, April)., Service letter SL2019-671/JA, Cylinder lubrication update for 0 to 0.50% sulphur fuels. MAN Energy Solutions. https://www.man-es.com/docs/default-source/service-letters/sl2019-671.pdf
44. Jensen, M. C., & Jakobsen, S. B. (2019, April)., Service letter SL2019-671/JA, Cylinder lubrication update for 0 to 0.50% sulphur fuels. MAN Energy Solutions. https://www.man-es.com/docs/default-source/service-letters/sl2019-671.pdf
45. Thomas, J. F., Sluder, C. S., Kass, M. D., & Thiess, T. (2019). A Guide to Fuel, Lubricant, and Engine Concerns Relative to the IMO 2020 Fuel Oil Sulfur Reduction Mandate (ORNL/SPR-2019/1406). Maritime Administration, US Department of Transportation.
46. Chevron Marine Products. (2021). Marine lubricants information bulletin 17: Scuffing & red deposits after fuel transition: causes and solutions. https://www.chevronmarineproducts.com/content/dam/chevron-marine/technical-bulletins-2020/17%20Scuffing%20And%20Red%20Deposits%20After%20Fuel%20Transition.pdf
47. FOEI, WWF, Pacific Environment and CSC. (n.d.). AIR POLLUTION PREVENTION The need for urgent action to stop the use of blended very low sulphur fuels leading to increases in ship-source Black Carbon globally (MEPC 75/5/5). International Maritime Organisation.
48. Verifuel, IMO2020 Overview Fuel Quality And Problematic Cases, Iumi, 27 Jan 2021, https://iumi.com/uploads/Webinar/BV_VeriFuel_IUMI_Jan_2021_final.pdf
49. Verifuel. (2021, January 27). IMO2020 Overview; Fuel Quality and Problematic Cases. International Union of Marine Insurance. https://iumi.com/uploads/Webinar/BV_VeriFuel_IUMI_Jan_2021_final.pdf And Marine Environment Protection Committee. (2021). Air Pollution Prevention Review of 2020 marine fuels quality Submitted by ISO (MEPC 76/5). International Maritime Organization. https://www.nepia.com/marine-environment-protection/
50. Verifuel. (2021, January 27). IMO2020 Overview; Fuel Quality and Problematic Cases. International Union of Marine Insurance. https://iumi.com/uploads/Webinar/BV_VeriFuel_IUMI_Jan_2021_final.pdf And Marine Environment Protection Committee. (2021). Air Pollution Prevention Review of 2020 marine fuels quality Submitted by ISO (MEPC 76/5). International Maritime Organization. https://www.nepia.com/marine-environment-protection/
51. Marine Environment Protection Committee. (2021). Air Pollution Prevention Review of 2020 marine fuels quality Submitted by ISO (MEPC 76/5). International Maritime Organization. https://www.nepia.com/marine-environment-protection/
52. SAFETY4SEA. (2021, May 24). VLSFO claim numbers not significantly higher compared to other fuel. https://safety4sea.com/vlsfo-claim-numbers-not-significantly-higher-compared-to-other-fuel/
53. Cermet is a composite material of high temperature resistant ceramic and metal with high hardness and resistance to plastic deformation: Source: Richerson, D. W. (2000). 6.28 - Industrial Applications of Ceramic Matrix Composites. In Comprehensive Composite Materials (6th ed., pp. 549-570). Pergamon. DOI: 10.1016/B0-08-042993-9/00133-9
54. Jensen, M. C., & Jakobsen, S. B. (2019, April). Cylinder lubrication update for 0 to 0.50% sulphur fuels. Service letter SL2019-671/JA, MAN Energy Solutions. https://www.man-es.com/docs/default-source/service-letters/sl2019-671.pdf
55. Jensen, M. C., & Jakobsen, S. B. (2016, November). Hard-Coated Piston Rings for Operation on Ultra-Low Sulphur Fuel Including gas and liquefied gas. Service letter SL2016-633/JAP, MAN Energy Solutions. https://www.man-es.com/docs/default-source/service-letters/sl2016-633.pdf?sfvrsn=bf19817_4
56. Jensen, M. C., & Jakobsen, S. B. (2019, November). Condition-based overhaul Cermet-coated piston

rings. Service letter SL2019-685/KAMO, MAN Energy Solutions. https://www.man-es.com/docs/default-source/service-letters/sl2019-685.pdf?sfvrsn=c2f2e05b_6
57. Jensen, M. C., & Jakobsen, S. B. (2019, April). Service letter SL2019-671/JA, Cylinder lubrication update for 0 to 0.50% sulphur fuels. MAN Energy Solutions. https://www.man-es.com/docs/default-source/service-letters/sl2019-671.pdf
58. Dimkovski, Z. (2006). Characterization of a Cylinder Liner Surface by Roughness Parameters Analysis (Doctoral dissertation) Department of Mechanical Engineering Blekinge Institute of Technology Karlskrona, Sweden. https://www.diva-portal.org/smash/get/diva2:833116/FULLTEXT01.pdf
59. Jensen, M. C., & Jakobsen, S. B. (2018, March). Cermet-Coated Piston Rings for Operation on Low-Sulphur Fuels (0.5% S or lower) Including LNG, LPG, methanol and ethane Replaces. Service Letter SL2018-659/JAP , Man Diesel and Turbo. https://www.man-es.com/docs/default-source/service-letters/sl2018-659.pdf
60. IOP Marine - Chris Marine. (n.d.). The Optimum Solution Honing Spares & Consumables. https://www.chris-marine.com/wp-content/uploads/2019/03/Honing-spares_H060_1605E.pdf
61. Jensen, M. C., & Jakobsen, S. B. (2016, November). Hard-Coated Piston Rings for Operation on Ultra-Low Sulphur Fuel Including gas and liquefied gas. Service letter SL2016-633/JAP , MAN Energy Solutions. https://www.man-es.com/docs/default-source/service-letters/sl2016-633.pdf?sfvrsn=bf19817_4
62. Anderberg, C., Cabanettes, F., Dimkovski, Z., Ohlsson, R., & Rosén, B. G. (2006). Papers presented at the 12th nordic symposium on tribology, NORDTRIB 2006, Helsingør, Denmark, 7 - 9 June 2006. http://www.diva-portal.org/smash/get/diva2:239106/fulltext02
63. Jensen, M. C., & Jakobsen, S. B. (2014, March). Cylinder Lubrication Update Adjusting the ACC factor in service Replaces SL2013-571. Service letter SL2014-587/JAP , MAN Energy Solutions. https://www.man-es.com/docs/default-source/service-letters/sl2014-587.pdf?sfvrsn=f566d1ed_4
64. The Standard P&I Club and ABS. (2012, February). A Master Guide to: Using Fuel Oil Onboard Ships. https://www.standard-club.com/fileadmin/uploads/standardclub/Documents/Import/publications/masters-guides/24163-AMastersGuidetoUsingFuelOilOnboardships.pdf
65. Kjemtrup, L., Cordtz, R. F., Jensen, M. V., & Schramm, J. (2020). An experimental investigation of the corrosive influence of SO of marine engine cylinder liners. Lubrication Science, 32(3), 131-144. DOI: 10.1002/ls.1492
66. Alfa Laval. (n.d.). Marine fuels in the low-sulphur era. https://www.alfalaval.com/globalassets/documents/industries/marine-and-transportation/marine/refuel/alfalaval_article_marine-fuels.pdf
67. American Bureau of Shipping. (2021, August). Marine Fuel Oil Advisory. https://ww2.eagle.org/content/dam/eagle/advisories-and-debriefs/marine-fuel-oil-advisory-21141.pdf
68. Integr8 Fuels | Research and Advisory Services Division. (2019, November). Predicting compatibility of VLSFO fuels. https://integr8fuels.com/wp-content/uploads/2019/11/Integr8-Research-2019-11-Compatibility-esting-tprogram-v2.pdf
69. Kisil, D. (2021, March 4). ISO review of 2020 marine fuels quality submitted to the IMO marine environment protection committee. Westpandi. https://www.westpandi.com/publications/news/march-2021/iso-review-of-2020-marine-fuels-quality-submitted/ and Sahu, S. (2020, October 6). Interview: VPS exec sees bunker fuel quality alerts surging in 2020 as VLSFO use gathers pace. S&P Global. https://www.spglobal.com/commodity-insights/en/market-insights/latest-news/oil/100620-interview-vps-exec-sees-bunker-fuel-quality-alerts-surging-in-2020-as-vlsfo-use-gathers-pace
70. Raitt, D. (2020, July 29). The importance of cold flow properties of VLSFOs. Lloyd's Register. https://info.lr.org/technical-matters/the-importance-of-cold-flow-properties-of-vlsfos
71. MAN Energy Solutions. (2019, August). 0.50% S fuel operation 2020. Ship & Bunker. https://shipandbunker.com/download/Paper%200.50-s-fuel-operation-2020%20MAN%20ES%202-S.pdf
72. BIMCO, The International Chamber of Shipping (ICS), INTERCARGO, & INTERTANKO. (n.d.). 2020 Fuel Oil Quality And Safety Survey. https://www.bimco.org/-/media/bimco/news-and-trends/news/priority-news/2020/2020-fuel-oil-quality-and-safety-survey---report.ashx
73. Wilhelmsen Ships Service. (n.d.). The Waxy Issues with VLSFOs. https://www.wilhelmsen.com/globalassets/imo2020/whitepaper-3_wax-formation-in-vlsfo_042021_lr.pdf
74. Wilhelmsen Ships Service. (n.d.). Sidestepping the sludge – preventing the formation of paraffin wax in low sulphur fuels, https://www.wilhelmsen.com/imo2020/sidestepping-the-sludge--preventing-the-formation-of-paraffin-wax-in-low-sulphur-fuels/
75. North P&I. (2019, July). 2020 Vision Preparing For The Big Switch Option 2: Compliant VLSFO Products. https://www.nepia.com/publications/preparing-for-the-big-switch-compliant-vlsfo-products-option-2/

76. North P&I. (2019, July). 2020 Vision Preparing For The Big Switch Option 2: Compliant VLSFO Products. https://www.nepia.com/publications/preparing-for-the-big-switch-compliant-vlsfo-products-option-2/ And Mahajan, S., & Shepherd, L. (2020, September 10). IMO 2020: A review of the transition to VLSFOs. Gard. https://www.gard.no/web/updates/content/30350874/imo-2020-a-review-of-the-transition-to-vlsfos
77. Wilhelmsen Ships Service. (n.d.). IMO 2020: Safely navigating new VLSFO challenges. https://www.wilhelmsen.com/globalassets/marine-products/oil-solutions/documents/vlsfo-whitepaper-062020.pdf
78. CIMAC WG7 Fuels. (2016, February). 02 | 2016 CIMAC Guideline The Interpretation of Marine Fuel Analysis Test Results. https://www.cimac.com/cms/upload/workinggroups/WG7/CIMAC_WG07_2016_Feb_Guideline_Interpretation__Fuel_Analysis_Test_Results_Final.pdf
79. American Bureau of Shipping. (2021, August). Marine Fuel Oil Advisory. https://ww2.eagle.org/content/dam/eagle/advisories-and-debriefs/marine-fuel-oil-advisory-21141.pdf
80. Allianz Global Corporate & Specialty. (n.d.). Safety and Shipping Review 2021; An annual review of trends and developments in shipping losses and safety. https://www.agcs.allianz.com/content/dam/onemarketing/agcs/agcs/reports/AGCS-Safety-Shipping-Review-2021.pdf