Service Contract for a Cost Benefit Analysis to Support the Impact Assessment accompanying the revision of Directive 1999/32/EC on the Sulphur Content of certain Liquid Fuels

Report on Task B2: Use of distillate fuels by ships at berth

Association ASPEN

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1 Introduction

From 1 January 2010 ships using ports within the EU will be required to use low-sulphur fuel, maximum 0.1 wt% sulphur, while at berth, with an exception for those making only short stops (Directive 2005/33/EC). The regulations apply also to ships that are anchored. The fuel switch should be done as soon as possible after arrival and as late as possible before departure. This regulation applies to all engines and to all boilers, including auxiliary boilers.

These regulations will most likely make it necessary to use distillate fuel while at berth. There are concerns that there are risks associated with switching from residual oil to distillate fuel in boilers.

This report has been drafted under the project “Service contract for a Cost Benefit Analysis to support the Impact Assessment accompanying the revision of Directive 1999/32/EC on the sulphur content of certain liquid fuels”, which was undertaken for the Commission by a team including TNO, IVL and AEA under an AEA-led framework contract. It tries to clarify these risks associated with the problem outlined above and aims to address the following questions:

- Identify the type of ships where these risks may be relevant.
- Estimate the number of such ships in 2010 and 2020.
- Describe the nature of these risks.
- Indicate technical solutions and assess the costs of these.

The study has been undertaken through literature searches and searches on the internet as well as through interviewing representatives of industry and relevant authorities. We have had contact with manufacturers of boilers and accessories, representatives of ship-owners, port authorities, and maritime administrations. There are only a few reports that address the problem.

2 Outline of the problem

Boilers that are constructed for the use of Heavy Fuel Oil (HFO) can in general not be used with Marine Gas Oil (MGO) without modifications. A switch from HFO to MGO in a boiler that is designed for HFO use could lead to operational problems with potential flame failure and an increased risk of a boiler explosion. To avoid these problems, boilers may have to be modified before a switch from HFO to MGO can take place in a safe way. The modifications needed must be assessed for each boiler individually. The exact number of boilers that will need modification, as well as the costs and time needed for these modifications, are difficult to assess because the figures are not well known by the ship-owners.

Boilers are typically used at berth and tankers, in particular, use large boilers for heating the cargo and for steam-driven cargo pumps.

A number of LNG-carriers use boilers for propulsion where boil-off cargo is used as fuel in combination with HFO. These boilers, which are also used at berth for cargo transfer, need to be modified before they can be used with MGO.

In order to comply with Directive 2005/33/EC, ship-owners thus must assess what boilers need to be modified, and to what extent, and have these modifications done before the end of 2009. Some ship-owners have made the assessments and taken steps to do the necessary modifications, while many ships still need to be investigated. The process seems to have been started during 2008 in most cases and is more intense in 2009. The reason that the industry has not acted earlier seems to be multifold. Some ship-owners anticipated that the EU directive would be brought in line with the IMO directives of Marpol Annex 6 and thus that the 0.1 sulphur-limit would be implemented in 2015 as it will be for SECA areas. It was also expected that the sulphur directive would be reviewed before 2010. Further, some ship-owners seem to have anticipated, until relatively recently, that HFO with 0.1% sulphur would be made available.

3 Types of ships where the risks may be relevant

Boilers are used on ships either for propulsion or as auxiliary boilers. Boilers for propulsion are used in combination with steam turbines and, although once abundant, they are today relatively uncommon. The reason is that diesel engines show a higher thermal efficiency and are thus more fuel efficient.

One application where **boilers are used for propulsion is for ships that transport LNG**. The reason is that some of the cargo will boil off during transport and with boiler propulsion this gas can be used as fuel for the ship. This is thus a means to utilize the part of the cargo that otherwise would be lost. For reasons of thermal efficiency, these boilers operate at high pressure of about 60 bar. Some newer ships instead use reliquefaction plants to collect the boil-off gas. Boil-off gas (BOG) is used for propulsion in combination with a liquid fuel. Depending on power demand and operational mode, the fuel can be either 100% BOG or a combination of oil and BOG. The reasons for the dual fuel arrangements lie in safety and reliability for propulsion. In the case of manoeuvring or other changes in boiler power, the gas fuel may not respond fast enough and the changes will be taken up by a change in the oil supply to the boilers. In such situations, dual fuel mode is used where oil and BOG is burnt simultaneously. A change in power can then be taken up more slowly by using gas. Further, in case the gas supply to the boilers is unintentionally reduced or interrupted, the system uses a so called fuel-oil boost up to ensure continuity in power. There is also a limited turn down ratio of the gas burner and therefore oil is used at low loads. The boiler powered LNG ships used today are designed for a combination of BOG and HFO. Typically, a ship that would use 150 tonnes HFO per day if operated on HFO alone uses around 10 tonnes of HFO in dual fuel mode. The boilers use small amounts of MGO during flashing from cold when furnace temperatures are low (normally after refit) but cannot use MGO during normal operation without modifications (see below).

Auxiliary boilers may be divided into:

1) **small boilers** used on ships to produce steam that can be used to heat residual oil, to produce hot water and for the purpose of heating; and
2) **larger boilers used on tankers** for heating cargo and to drive steam turbine pumps.

Auxiliary boilers are used on practically all ocean-going ships. These boilers can be designed to be used with either HFO or distillate fuel. Some boilers can use both HFO and MGO. Typically, boilers are used with HFO on ships that use this fuel for propulsion. The type of fuel used in auxiliary boilers has not been investigated in detail since the fuel consumption is normally assumed to be a minor part compared to main and auxiliary engines. Therefore, it is difficult to establish the exact distribution of boilers that use only MGO, only HFO or a combination. However, the vast majority of boilers use HFO and this is certainly true for the larger auxiliary boilers on tankers.

4 Relevant number of ships

The need for an assessment of the potential modifications on existing boilers to manage the switch from HFO to MGO applies in principle to all ships by 2010. It is today not clear how many of these will need modifications. Both the leading manufacturer of boilers, Aalborg industries (Aalborg 2009) and a study by the California Air Resource board (CARB 2008) conclude that most boilers can at least temporarily use MGO without problems. However, both studies, as well as a report by DNV (DNV 2005) states that MGO should not be used in a boiler designed for HFO before it has been inspected. Further, a large number of boilers will need modifications before they can be used safely with MGO. Although a number of ship-owners have assessed and— when necessary—modified their boilers, it seems unlikely that all boilers will be able to run on MGO by the 1st of January 2010.

The number of **chemical and oil tankers** which use steam for cargo pumps or cargo heating that enter EU ports is at least 2 368 out of 3 476 according to OCIMF. Other ships may use diesel engines or electrical motors to drive the pumps, and some use electrical heating. These boilers are more likely to need modifications since they use relatively large amounts of fuel which affects valves and fuel pumps. A number of tank owners will have difficulty making these modifications before the end of the year, although the exact number is difficult to say. Modifications on all ships will, in all likelihood, not be complete until late 2010.

The boilers on tankers are often used during the discharge of the cargo. Intertanko estimated that in 2006 there were 8 000 - 10 000 port calls of tankers in the EU. With a fuel use per discharge of 50 - 90 tonnes, this amounts to a total fuel use of around 400 - 500 ktonnes per year in the EU in the boilers for the purpose of discharge.

There are 262 **LNG ships with steam turbine propulsion** of which most service EU ports. 32 ships use diesel propulsion while 19 are dual fuel diesel electric. A number of LNG ships are several decades old but the production of LNG tankers has increased a lot recently. About 43% of the LNG ships are delivered between 2005 and 2008. The trend for new ships seems to be that diesel engines in combination with reliquefaction plants are preferred to steam propulsion. There is also a development towards dual fuel diesel engines that can burn fuel oil (distillate or HFO) and gas. LNG tankers are in for refit about every 2.5 years up to 5 years for newer ships. If modifications needed to comply with the sulphur directive are done during refit it will be approximately 2014 before all ships are modified. The ships could also be taken out of service for the modifications, which could be complete within approximately one - two years. The latter alternative then implies extra costs when the ships are out of service for modifications.

There are approximately 690 deliveries by LNG tankers per year to the EU. At each port visit, around 50 tonnes of HFO is used adding up to about 35 ktonnes per year.

By 2020 all ships will have had enough time to make the necessary adjustments on their boilers.

5 The nature of the risks

There are reports of boiler explosions due to defects or improper operations. This can occur if the flame is out for some reason and a high pressure of fuel gas is built up in the burner and the control system is malfunctioning or disconnected. In such a case, the furnace must be purged before ignition. Failure to do this may cause an explosion, as for example reported by the British Department of Transport (1983). There are flame supervision and control systems that will automatically purge the furnace so that during normal operation the risks for explosions are small.

There are concerns that these risks may be elevated when switching over from residual oil to distillate fuel. This is noted by the IMO subcommittee on bulk liquids (2007), which states: "The routine switching between marine distillate and Heavy Fuel Oil (HFO) has safety implications for existing boilers. The boiler combustion systems may require to be modified to prevent the risk of boiler furnace explosions in distillate operation". The risks are also noted in a recent US Coast Guard maritime safety alert (2009) in relation to regulations for California which apply from 1 July 2009. These regulations stipulate that Marine Gas Oil (MGO) or Marine Distillate Oil (MDO) must be used in all engines including boilers (with the exception of boilers for propulsion). The notice points out that "proper procedures, training, and maintenance are essential for vessels to safely switch between heavy/intermediate fuel oils and marine distillates". The notice is about all engines and auxiliary boilers and suggests that each system should be assessed for modifications and that training and routines should be established.

The reason for the special concerns regarding a fuel switch from HFO to distillates is that the pipes and other parts are heated when using residual oil. When the distillate enters the furnace there are concerns that it will fail to ignite, causing a build-up of gases that in turn is an explosion risk. When introducing distillate fuel in hot piping, vapour locks in pipes may cause irregular fuel flows towards the burners (this may also be an issue for diesel engines). This irregular fuel and vapour flows/bursts towards burners can cause flame extinction. The lighter the fuel, the easier the evaporation and the larger the risk for an air/fuel mix which is potentially unsafe. There are concerns that the crew on many ships may not be familiar with how to handle safely these situations.

The boilers do normally run on MGO during start up; however, at this point the system has not yet been heated. After the boiler pressure is up, the pipes can be emptied of MGO and then heated and used for HFO. MGO is thus not introduced to the boiler through heated pipes at this stage.

In normal ship installations, "heat tracing" of pipes (by steam or electric heating) can be turned on or off. In this kind of installation, proper operation may be sufficient to avoid the risk of an explosion. In many cases, the operation of fuel switching is automatically handled by the ships' hardware and software (and there is no difference between fuel flows towards engines and boilers in this respect). This may be the situation in many ships that have been delivered during the last years. However when fuel switching cannot be done automatically, ship officers must obey very precise operational instructions.

Besides the mentioned concern about explosions inside the boilers, there are some other issues that need to be addressed before a boiler designed for HFO can be used with MGO. These issues are reported by DNV (DNV 2005) and Aalborg industries (Aalborg 2009):

- Fuel pumps and valves may need to be replaced due to the different viscosity of the fuels. There is an increased risk of wear and pump breakdown if the oil has a higher viscosity and lower lubricity than what the pump is designed for.
- There may be increased smoke emissions since the amount of fuel injected in the burner is set for HFO with a higher density and lower calorific value than MGO.
- On certain types of burners (rotary cup) coke deposits may be built up when using distillate fuel. In steam atomising burners the MGO may be heated causing vaporisation.

There are other concerns raised by the shipping industry about the regulations from 1 January 2010. These are related to:

1) problems with the supply of fuel with 0.1% sulphur for ships at berth;
2) issues with ships not having enough fuel tanks to store the different kinds of fuels that they will need; and
3) concern that there is not enough time to modify existing boilers and train crews.

The objective of the present study is not to investigate possible problems with the supply of MGO. However, according to a study by Entec (2002) c. 3 000 ktonnes of fuel was used for manoeuvring and in port in the EU in the year 2000. The main portion of this fuel will likely have to be MGO from 2010 and, considering the increase in shipping, a rough estimate is that around 4 000 ktonnes of MGO is needed.

For the LNG ships with steam propulsion, the issues are essentially similar to those described above with some additional concerns. Since the boilers are used for propulsion, it is essential that the fuel supply is not interrupted. As described above, there must be a reliable supply of fuel oil in addition to the BOG. The fuel oil systems in these ships are designed for HFO. They should not be used with distillate fuel for a number of reasons:

1) There would be an increased risk of failure in fuel pumps and valves.
2) The distillate fuel could be unintentionally heated in pumps or in the burner leading to the mentioned problems with evaporation.
3) Most of the burners used have fuel injectors of the concentric type where the atomising steam is in between the tubes for fuel oil where distillate fuel may be heated. Other burners have parallel tubes for steam and fuel oil. Here the heating of the distillate fuel is less of a concern but temperature gradients when cold fuel oil is used could cause distortion of the tubings for oil supply.
4) The burner management system and flame supervision is designed for HFO.

6 Technical solutions and costs

For the safety and operational reasons discussed above, all boilers designed for the use of HFO should be inspected before they are used with distillate fuel. Many boilers may be used temporarily with gas oil without modifications, but for others modifications may be needed on fuel pumps, burners or pipes, as well as flame supervision and adjustments in air/fuel ratio, fuel flow and post-purging sequence. These modifications are further described in Aalborg (2009) and DNV (2005). Modifications will have to be approved by a Classification Society. The solutions for LNG tankers with boiler propulsion are discussed separately at the end of this section.

The **risk of a boiler explosion** discussed above is thus associated with the vaporisation of distillate fuel in combination with flame failure and improper purging. To avoid the heating of MGO in the piping system, heaters should be by-passed or the tracing of fuel pipes turned off. The fuel system should have time to cool to around 60°C before MGO is introduced. The pipe system may have to be converted to contain two parallel feeds to the burners. The fuel may also be unintentionally heated in fuel pumps which then have to be adjusted or replaced. There are potential problems with gassing in steam atomising burners, which may have to be modified. Protective heat shields should be present on rotary cup burners to avoid deposit build-up and unintended ignition after flame failure. The flame supervision may have to be complemented with another flame scanner due to the different properties of HFO and MGO flames. The control system may have to be modified to implement automatic post-purching sequence. This will ascertain whether a potentially explosive gas mixture in the furnace has been purged in a safe way.

Fuel pumps may have to be modified or replaced to be able to tolerate MGO, with lower viscosity and lubricating properties than HFO, for a longer period. In some cases, it may be sufficient to modify the control system.

To avoid smoking, fuel pressure may have to be adjusted and/or burner nozzles replaced. The air/fuel ratio may have to be adjusted.

The costs associated with these measures will vary depending on the modifications needed. The exact distribution of costs for the existing boilers is not known. Boiler suppliers estimate costs in the range of 5 000 to 25 000 € per boiler when modifications are needed. For tankers with large boilers, costs around 150 000 € per ship have been quoted. There will also be costs for approval and certification.

For LNG ships with steam turbine propulsion, the boil-off from the cargo is used in combination with HFO. For the reasons described above, these ships should be modified before they are used with MGO.

The boiler management system (BMS) settings will have to be adjusted. New flame scanners may have to be installed. A separate fuel supply system for MGO will be needed. The majority of burners will have to be modified to avoid vaporisation. Further, fuel changeover procedures have to be investigated. Some ships may also need larger tanks for MGO in order to accommodate enough fuel for one port stay.

These modifications and actions would make it possible to use MGO rather than HFO at berth and thus comply with the directive. There are still some concerns that there may be an increased number of flame failures and that the main boiler manufacturers lack experience in burning MGO during normal operation. However, after the modifications, these incidents would be handled in a safe way by the BMS, although there may be interruptions and operational problems. The costs for these measures have been estimated by SIGTTO. The costs are difficult to estimate and figures ranging from 70 000 to 1 400 000 € per ship have been cited with a median of around 600 000 €. To this should be added costs for taking the ships out of service if the modifications are done outside a regular refit.

An alternative solution would be to use 100% BOG while at berth. There are, however, concerns about the stability of the boiler power at low loads. It is unclear if this can be implemented on all ships and modifications to the control system and BMS will be needed. Further, there are situations where 100% BOG cannot be used. This applies for relighting after a flame failure and in cases where there is no LNG cargo, as when ships enter/leave refit/dry dock. Therefore, this alternative does not comply in full with the EU directive. No cost estimates are available for this alternative. This is because the extent of modifications needed has not been investigated. This alternative may require substantial modifications and may be more expensive than the previous alternative. The problems with stability and non-compliance make this alternative less attractive for the industry. Further, some ship-owners do not see this as a solution to comply with the SECA rules coming in 2015, since 100% BOG will be unsuitable during some operational modes.

A third possibility which seems more attractive to ship-owners is to minimise the use of HFO and use as much BOG as possible. The dual fuel combination of low sulphur HFO and BOG would then be used in such a way that the emissions of SO_2 are lower than what they would have been if 0.1% fuel oil were used at berth. If the scheme is set up in such a way that BOG together with minimum amounts of low sulphur HFO is used for the complete port stay (including manoeuvring) the resulting SO_2 emissions could be lowered further. This option would allow for fuel boost with HFO in the case of flame failure. This option requires fewer modifications on most ships and thus lower modification costs. It may not be suitable for older ships. Whether or not this solution is in compliance with the EU regulations depends on whether the equivalence principle outlined is regarded to be in line with paragraph 4c. Further, the ships would still need to use HFO after refit. This option would be likely to require a monitoring system with either control of fuel use and sulphur levels in the fuel or the installation of flue gas monitoring systems to monitor the SO_2 emissions. The latter costs in the order of 70 000 € per ship.

The option of using exhaust gas scrubbing is not considered possible by the end of the year since the technology has not yet been tested for this application.

7 Conclusions

One can state that there are real safety concerns with switching from HFO to MGO in existing boilers. This is supported through knowledge gained through contacts with the industry and authorities. Secondly, there are technical and operational ways to circumvent these risks.

Although many boilers can be used with MGO, all boilers should be inspected. The exact number of boilers that need to be modified is uncertain at this point. There are 262 LNG ships with steam propulsion that need to be modified. There are around 2500 tankers that use boilers for steam driven pumps and/or cargo heating, and most will likely need to be modified.

The main safety concern is that a distillate fuel may vaporise in hot boilers with heated pipes. If the boiler system has not been modified, there is—in the case of flame failure and improper handling—a risk of an explosion.

There are technical solutions to solve these issues where fuel piping systems, burners, and flame inspection systems are modified. The control system may have to be modified and new handling routines established. For LNG ships, modifications are required. The costs range from 5 000 € to 25 000 € for small auxiliary boilers, around 150 000 € per ship for tankers and 70 000 € to 1 400 000 € for LNG tankers.

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