1. Introduction

Shipping is the most efficient mode of transport for cargoes, with the highest economies of scale per tonne mile compared to other forms of mass transportation. However, as shipping activities grow, the industry has been criticized for not doing enough to protect the environment.

According to a study submitted by Corbett and Winebrake to the International Maritime Organization, pollution from shipping causes approximately 60,000 premature deaths around the world each year, and the death toll is expected to grow 40% by 2012, with the continued increase in global trade and shipping traffic.

In the 1940s, a series of innovations made the use of residual oil in diesel engines possible. High alkalinity cylinder lubricants then became available to neutralize the acids generated by the combustion of high sulfur residual fuels, and wear rates became comparable to those found when using distillate diesel fuel. From that point on, low-cost and readily available high-sulfur residual oil became the fuel of choice for marine diesel propulsion.

The widespread use of high sulfur residual fuels has benefited refiners looking for ways to dispose of crude residues, as well as consumers seeking low-cost transportation. Motor ships using high sulfur residual fuel oil gained in popularity and in the second half of the 1960s, motor ships overtook steamships, both in terms of numbers and in gross tonnage. By the start of the 21st century, motor ships accounted for almost 98 percent of the world fleet.

Some of these fuels contain sulfur as high as 45000 ppm, contributing almost 10% of the total SOx emissions. On shore, a vehicle in Europe burns fuel containing no more than 15 ppm Sulfur. Such a contrast explains to some extent why the half-century-plus history of engine development and fuel use in the maritime industry is now being reshaped by various sulfur regulations.

This paper briefly reviews the development of sulfur regulations in shipping and some operational issues in this area.

2. Sulfur regulations

Reduction of global sulfur to $\leq 3.5\%$ will have little impact on the industry for another decade since the majority of the fuels around the world are much below that level.
A study on worldwide bunker data in the past year by DNV Petroleum Services (DNVPS) showed that only about 11% of fuels sampled in the major ports had a sulfur level greater than 3.5%. Furthermore, the study indicated that the average fuel sulfur level was ≤2.4% worldwide during the same period.

The new IMO regulations aim to eliminate most of the high sulfur fuels from the marine bunker market by 2020. However, we believe that this timing may have to be extended following the IMO scheduled review of the situation in 2018 because refiners have claimed that they may not be able to supply sufficient quantities of low sulfur fuel oil (LSFO) or gas oil to replace high sulfur fuel oil (HSFO) by 2020.

In an Emission Control Area (ECA), the further reduction of sulfur to ≤1.0% may contribute to poor stability and other fuel quality problems. Purchasers will need to pay particular attention when stemming low sulfur products.

It is unlikely the demand for ≤0.1% or perhaps ≤0.5% sulfur fuel can be met by selective blending. While DNVPS cannot speak for the refining industry, it appears to us that the only way the ≤0.1% or ≤0.5% sulfur requirement can be met is with low sulfur distillates.

3. Other options

Fears are growing among owners that the 0.10% sulfur limit in the ECAs from 2015 might lead to a shortage of suitable bunker fuels, and the low-sulfur fuel would come at a high price. The cost of running on 0.10% sulfur fuels could be so high that sea transport could become uncompetitive and lose its appeal over other mode of transportations.

Some owners are participating in the development of ‘green’ technologies as they believe scrubbers offer a “better competitive advantage” by substantially cutting fuel costs and allowing the continued purchase and consumption of HSFO, which would be much cheaper than distillates.

However the new systems are still in the development stage with much to be learned regarding the relevant parameters. Scrubber manufacturers must demonstrate that their equipment is easy to fit, economical and not a diversion of emission from funnel stack to sea.

The prospect of either a bunker fuel levy or an emissions trading scheme may also become a reality in near future.

Emissions trading in principle means that the possibility of polluting more than the specified limits can be bought from...
ships that are polluting less than they are allowed to. Whether emissions trading can be applied in the marine sector in the way practiced between power stations is still rather unclear, as the administrative load would be extensive and the possibility of checking for compliance with the trading rules would be limited.

Whichever scheme gets the final approval, it will likely require a new international convention, along with a secretariat to administer the multi-billion dollar revenues created by the instrument.

4. Some operational issues

Quality of LSFO

DNVPS fuel analysis findings add to the observation that LSFO products have often been prepared by blending high or normal sulfur fuels with a low sulfur cutter stock to achieve the required sulfur level. This method compromises quality as the cutter stocks used as blend components are not always closely regulated and can directly impact the quality of the final product.

The most common deficiencies found in blended LSFO products are elevated quantities of catalyst fines, poor ignition and combustion quality, instability of the blended products and even chemical waste contamination.

The DNVPS chemical screening program has detected an increasing tendency for bunker fuels to contain potentially harmful chemicals. Such chemicals do not naturally occur in crude oil, nor are they generated or employed as part of the normal refining process. Yet, their presence can potentially cause operational, health & safety and environmental problems relating to clause 5.1 of ISO 8217: 2005.

DNVPS analysis data also show the average catalyst fines in low sulfur fuels are noticeably higher compared to high sulfur fuels. Accelerated wear in the cylinder gears and injection equipment can be expected if catalyst fines at engine inlet are more than 15 mg/kg.

The ignition and combustion quality of heavy fuel oils in general is believed to deteriorate as result of refineries increasing conversion of residual streams thereby optimizing yield of the more valuable distillate products. The quality is further tampered by the source and composition of the blend components.

5. Cylinder lubrication

Use of high TBN (Total Base Number) cylinder oil in low sulfur environment can produce hard deposits. These deposits form primarily on the crown land and disturb the oil film, leading to scuffing, and ultimately deposit behind the piston ring and grooves.

Some degree of ‘controlled corrosion’ is needed to retain the oil film. Use of high TBN cylinder oil in a low sulfur environment leads to lack of controlled corrosion. Liners may become too smooth to hold the oil film and when this happens, wear can take place and the liner surface roughness becomes polished. If it continues, scuffing can occur due to metal to metal contact.

The enforcement of 1.0% sulfur fuels in the Emission Control Areas from 1st July 2010 may still be within the range of 70 TBN oil use, but the feed rate has to be adjusted to ensure adequate lubrication and some degree of controlled corrosion.

With the tough sulfur rules ahead, one fuel and one grade of cylinder lubricating oil could soon be an arrangement of the past. Ship engaged in international trade may need to lift...
multiple grades of fuels and more than one grade of cylinder oil in order to comply with a series of regulations.

6. Viscosity/ Lubricity

Low sulfur distillates lack the dry lubrication properties that reduce metal-to-metal contact of fuel handling and engine components. Therefore, frequent or continuous use of low sulfur distillate fuels could result in accelerated wear to fuel pumps, injectors and other system components.

It seems that the ultra low viscosity fuels are not yet common worldwide. However, as the future holds stricter fuel sulfur requirements and as the request of low sulfur marine fuel increases, the viscosity of the offered fuels may also decrease.

DNVPS analysis data over the past one year shows that only a few deliveries had MGO viscosity less than 2 cSt but fuel users must not forget that the ISO 8217 specification allows low sulfur gas oils viscosity to be as low as 1.5 cSt.

The fuel pump design, condition and clearances are important factors deciding the minimum viscosity an engine can take safely. MAN B&W recommends a fuel oil viscosity of minimum 2 cSt at the engine inlet and suggests renewing the fuel pump if the index increases by about 10% to avoid fuel pump seizures/sticking and in particular starting problems. MAN also recommends that the lubricity is tested by an independent laboratory prior to using such low sulfur distillates.

Since 1st July 2009, two-stroke diesel engines and auxiliary boilers on ships operating within 24 nautical miles of the California coastline have been required to use low sulfur distillates due to the legislation passed by the California Air Resources Board. No one should disagree that the use of better quality distillates will harm those machineries. But will these machineries, designed for high sulfur residual fuels, be able to burn low viscosity distillates for long periods without causing damage?

There have been news about engine problems already reported in California waters while changing over from residual fuels to low sulfur distillates. There have been incidents where ships had to maintain higher RPM in order to keep the engines operating as they entered the harbor.

The exact cause is not known to us but similar problems can be expected if the engine cannot maintain a satisfactory hydrodynamic film between fuel pump plunger and barrel.

Most auxiliary boiler’s fuel injection systems have so far been designed to burn HFO as the main fuel and problems may not be expected with temporary change-over to distillate operation.

The concern is however when the boiler runs on distillates for prolonged periods. The actual operating temperature might be higher, causing the viscosity to drop further. There is a risk of increased wear and tear as well as breakdown if the fuel pumps and burners are unsuited for the viscosity. This is especially so for the steam atomizing burners which are commonly designed to burn fuel in the 15-30 cSt range.

Ship owners must check with boiler makers if any modification is needed to the fuel pumps or burners fitted to their vessels. This is not just a matter of complying with regulations but equally a serious safety matter.

7. Incompatibility at fuel change-over

When switching from HFO to a distillate fuel with a lower aromatic hydrocarbon content, there is a risk of incompatibility between the two products. The changeover procedure takes quite some time, during which there will be a mix of the two very different fuels for an extended period of time. The asphaltenes of the HFO are likely to precipitate as heavy sludge, with filter clogging as a possible result; which in turn will cause fuel starvation in the engine. Even though incompatibility seldom occurs, the most obvious way to avoid this is to check the compatibility between the fuels before mixing.

Change-over to and from distillate can be somewhat dangerous for the fuel equipment as hot heavy fuel is mixed into relatively cold gas or diesel oil. The mixture is not expected to be homogeneous immediately and some temperature and viscosity fluctuations are to be expected. The process therefore needs careful monitoring of temperature and viscosity.

During change-over, the temperature increase and decrease rate should be gradual and uniform to protect the fuel equipment from thermal shock, which can cause sticking.

A fully automatic change-over function such as Diesel
Switch invented by Man B&W could be beneficial to avoid incidents related to human mistakes but this would come at cost.

8. Conclusion

SOx reduction by lowering fuel sulfur content may seem a straightforward solution obtained from the refining process rather than the installation of exhaust gas scrubber on board each vessel, imposing bunker levy or allowing emissions trading. However, the solution still requires that it is feasible for the refineries to lower the sulfur level at a reasonable cost and effort. The question is whether there will be sufficient low-sulfur fuel oil available in the future, and whether other options will be the ultimate solutions to a wider extent.

For decades the maritime technology concentrated on inventing fuel efficient engines and burning viscous high in sulfur residual fuels into those engines is considered an achievement. Now there are calls for a U-turn and the expected operational issues arising from the switch to low sulfur distillate may not be solved by installing a cooler or chiller. If switching to distillate becomes an ultimate solution the industry must invest in designing new engines suited for permanent burning of low sulfur distillates.

Compliance with the regulations will necessitate a considerable amount of new investments and changes in operations, both on land and at sea.

The main battleground will be between the refiners and the ship owners as to which group will have to take lead and in making the required investment. Behind these two groups will be the politicians, law makers and the institutions and service providers responsible for shaping the entire industry as well as establishing the national dimensions for enforcing compliance with the regulations.