Scientific Journals
of the Maritime University of Szczecin

Zeszyty Naukowe
Akademii Morskiej w Szczecinie

2017, 49 (121), 28–33
ISSN 1733-8670 (Printed)
ISSN 2392-0378 (Online)
DOI: 10.17402/197

Received: 29.04.2016
Accepted: 03.03.2017
Published: 17.03.2017

The dual-fuel engine as an alternative marine propulsion system

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Key words: European Parliament and Council Directive 2012/33/EU, Emission Control Areas, LNG fuel, dual-fuel technology

Abstract

This article presents an alternative solution for marine units operating both inside and outside areas covered by strict controls on sulphur emissions. Emission Control Areas include the waters of the Baltic Sea, the North Sea, the English Channel, and the coasts of North America. Shipping in these areas is obliged to use fuel with a sulphur content in accordance with European Parliament and Council Directive 2012/33/EU. The technology to power units with marine diesel oil and other fuels compliant with the requirements of the Sulphur Directive is described. Low-sulphur fuel is efficient and environmentally friendly, and liquefied natural gas (LNG fuel) is an example of the technology described.

Introduction

The Sulphur Directive (European Parliament and Council Directive 2012/33/EU of 21st November 2012) amending Annex IV of the International Convention for the Prevention of Pollution from Ships (the MARPOL Convention) came into force on 1st January 2015. Since that date, it has been necessary to adapt to new fuel standards. The directive concerns the maximum authorised sulphur content of marine fuels used by ships and requires a significant reduction of these, from 1.0% to trace amounts of 0.1%. It applies to units in areas under strict sulphur-emission control, or Emission Control Areas (ECAs): the Baltic Sea, the North Sea, the English Channel and the coastal waters of North America (The European Parliament and Council Directive 2012/33/EU).

The use of clean fuel requires shipowners to adapt their units to the new rules. An alternative solution is to use liquefied natural gas (LNG) as a vessel's propulsion fuel.

Vessels with LNG fuel propulsion

To date, the most common LNG-powered vessels have been short-sea shipping vessels such as car-ferries, tugs, patrol units or other offshore-type Platform Supply Vessels (PSVs) supplying drilling rigs. These require frequent bunkering because they do not belong to very large-capacity ships; therefore, so as not to waste space on the ship, the volume of the tanks must be limited.

It should be noted that the major limitation for vessels with LNG fuel is the lack of stations serving bunkering operations along the entire coastline. There are five regasification stations in the area of the southern and central Baltic Sea, located as shown in Figure 1 and Table 1:

1. Poland, Świnoujście.
2. Lithuania, Klaipeda.
3. Estonia, Tallinn.
4. Sweden, Malmö.
5. Denmark, Copenhagen.

Figure 1. Location of regasification stations in the area of the southern and central Baltic Sea (author's own study based on available data (The Map, 2016))

The LNG terminal is adapted to receive and regasify LNG fuel. The process of regasification (conversion of state from liquefied to gas form) is also used to facilitate the storage and transportation of fuel to places outside the reach of gas networks. Regasification stations allow a larger gas audience to be reached, including areas where there is no possibility of import. Regasification stations will further redistribute gas to smaller terminals and allow the reloading of gas to smaller ships and road transport. The Sulphur Directive is one of the main factors contributing to the significant development of LNG fuel.

World LNG fuel distributors with regasification stations

The following table (Table 2) presents global LNG fuel distributors with regasification stations. Eleven of the world's largest distributors of natural gas in the world supply the whole world with LNG fuel (Dutta, 2015). Regasification stations are able to redistribute gas to smaller terminals which handle smaller vessels or on-the-road needs. Gas is also sent to direct recipients who are interested in using LNG fuel to reap energy or drive road vehicles or for other purposes (e.g., cooling or heating).

Relative to previous years, 2016 was characterised by a conspicuous lack of correlation between crude oil and gas prices. This phenomenon is closely associated with the definition of price formulae arising from contracts concluded between the parties concerned. The construction of these contract formulae (e.g., import contracts, energy exchange, long-term contracts and short-term contracts) predetermines the delayed effect of gear oil prices on the price of gas. It should also be noted that this causes the price of natural gas to change much faster, as stated on spot markets. The following table (Table 3) shows the changes in oil and gas prices.

It is worth noticing that in European countries, natural gas prices are set on the basis of the rates for natural gas from Russia at the border with Germany. In March 2016, the cost of gas decreased by 56% in comparison to the previous year. However, it must be taken into consideration that the continuation of the upward trend in oil prices may stop, decline or lead to increases in the following months (Figure 2) (LNG Snapshot, 2016b).

Table 1. Location of regasification stations in the area of the southern and central Baltic Sea (author's own study based on available data (Roupe, 2015; Jegelevicius, 2016))

No. on map	Terminal	Type	Tank capacity [m³]	Characteristics
1	Poland, Świnoujście	Intended for use	320 000	The Baltic LNG terminal in Świnoujście is one of the largest Polish energy investments. The terminal can be used by land and sea transport.
2	Lithuania, Klaipeda	Intended for use	170 000	Terminal started operations on 3rd December 2014.
3	Estonia, Tallinn	In construction/ Partly intended for use	90 000	When construction is complete, it will satisfy the LNG needs of the Baltic States and Finland. The first step of local construction has been completed and the regional station is operational.
4	Sweden, Malmö	Partly intended for use	10 000	Redistribution of LNG between Malmö and Copenhagen is carried out by road and rail gas transport.
5	Denmark, Copenhagen	Partly intended for use	10 000	Storage of LNG between Sweden and Denmark has to be set in advance.

Table 2. World LNG fuel distributors (author's own study based on available data (Dutta, 2015))

Name	Location	Characteristics
Eni	Italy, Rome	Branches in 70 countries around the world.
Gazprom	Russia, Moscow	The world's largest extractor of natural gas, it controls 17% of the world's gas reserves.
Total SA	France, Paris	Takes care of the transport, processing and distribution of natural gas and crude oil.
ConocoPhilips	United States, Texas, Houston	A major distributor in the LNG industry.
Chevron Corporation	United States, California, San Ramon	Has offices in 180 countries in the world. Part of the 6th largest fuel corporation in the world.
Saudi Aramco	Saudi Arabia, Dhahran	The most valuable company worldwide, meeting 10% of global demand for the raw material.
China National Petroleum	Republic of China, Beijing	Business leads in 27 countries of the world.
Sinopec	Republic of China, Beijing	4th place on the list of the largest companies in the world in terms of sales volume.
BP	United Kingdom, London	Third place on the list of the world's largest oil companies (after Royal Dutch Shell and ExxonMobil).
Royal Dutch Shell	Netherlands, The Hague	Deals with the extraction of natural gas and crude oil, and their transmission, processing, distribution and sales.
ExxonMobil	United States, Irving, Texas	The largest group in the world market for fuels and lubricants.

Table 3. Changes of the price of oil and gas (author's own study based on available data (Kowalik & Herczakowska, 2010; LNG Snapshot, 2016a; 2016b))

	CRUDE OIL	LNG
TREND	In January 2016 in relation to January: • Year 2015 – prices drop by 37%. • Year 2014 – prices drop by 71%. In the first quarter of 2016, the price of crude oil reached its lowest value in 13 years (end of 2003): • in March, 2016, the price increased by 20.3% in comparison with the previous month. • in March, it was 24.8% higher than in January 2016.	• Gas prices at the beginning of 2016 were unchanged from the third and fourth quarter of 2015. • The price of gas in January 2016 reached a value of approx. 45% less than in January 2015. • The cost of LNG fuel in March 2016 was less than 10.5% of that in the previous year, and about 1.5% cheaper than that in February 2016. • The volume of imported LNG fuel (Japan) in long-term contracts in March 2016 created a LNG fuel price level 35.2% smaller than in March 2015.

PRICE	Average costs of crude oil in 2016 were:
	• In January \$29.9 per barrel,
	• In March \$37.3 per barrel:
	  • Decrease in price by 29% compared to March 2015.
	  • Decrease by 64% compared to price in March 2014.
		At the beginning of 2016, the price of gas had declined significantly – from \$430 per 1000 m^3 to \$215–250 per 1000 m^3.
		
		In 2015, the average price of LNG fuel remained level at \$350 per 1000 m^3.

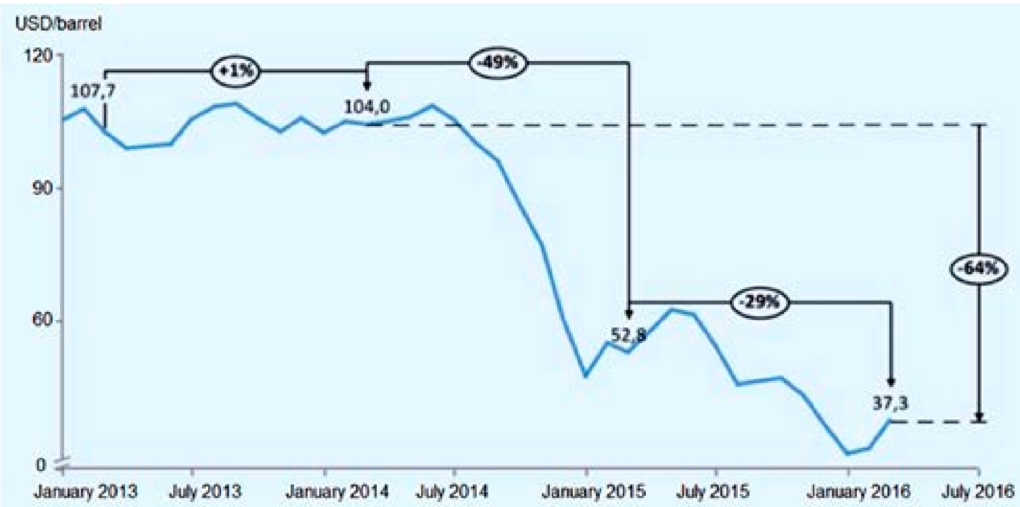

Figure 2. Average prices of crude oil (LNG Snapshot, 2016b)

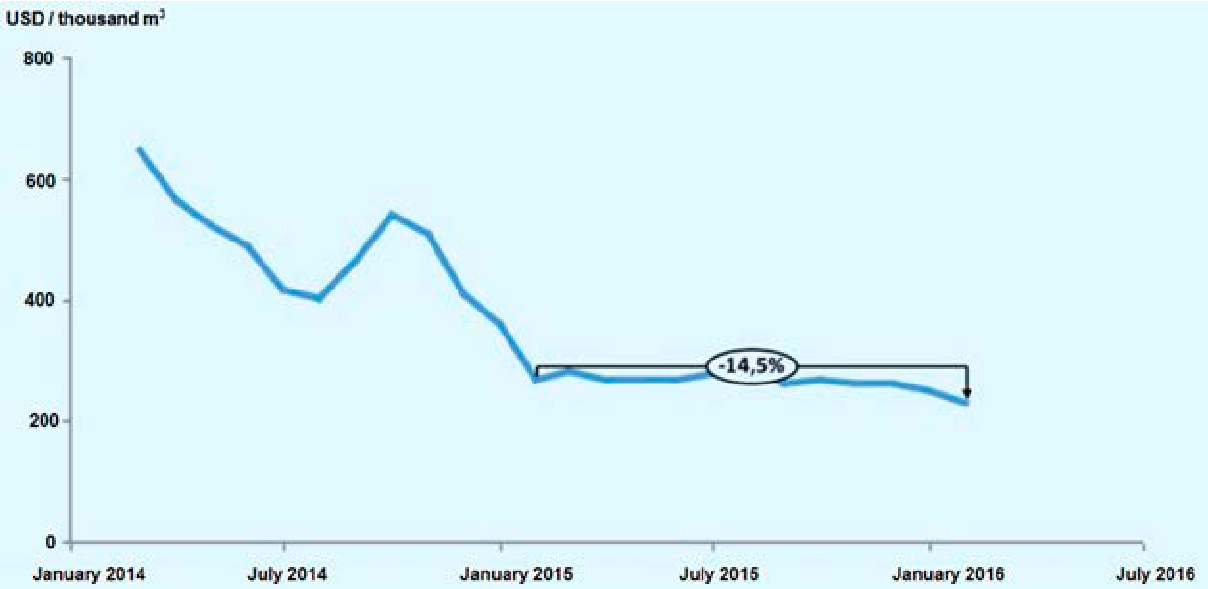

Figure 3. Average price of LNG on the spot market with delivery to Japan (LNG Snapshot, 2016b)

As previously mentioned, the fall in oil prices has a direct effect on the contract price. The high price difference (2014–2015, a decrease of 13%; 2015–2016, a decrease of 46%) was due to the delay in translating oil prices in the first quarter of 2016 (in particular in the months of March and April). Analysing the average LNG fuel price in the spot market, an increase is noted in the second quarter of 2016, which might indicate a downtrend reversal (Figure 3) (LNG Snapshot, 2016b).

Global warming, which was observed in winter 2015 (the so-called "warm winter") and in the first quarter of 2016 (the warmest quarter in the history of quotations) continuously decreases the demand for natural gas. High temperatures are characterised by a demand for low-energy fuels.

Dual-fuel technology

Units operating in ECAs should use fuel with a sulphur content in accordance with the standards contained in the Sulphur Directive. An analysis of shipping routes around the world reveals that some entities move only a small part of their total sea journeys within ECAs. The following figure (Figure 4)

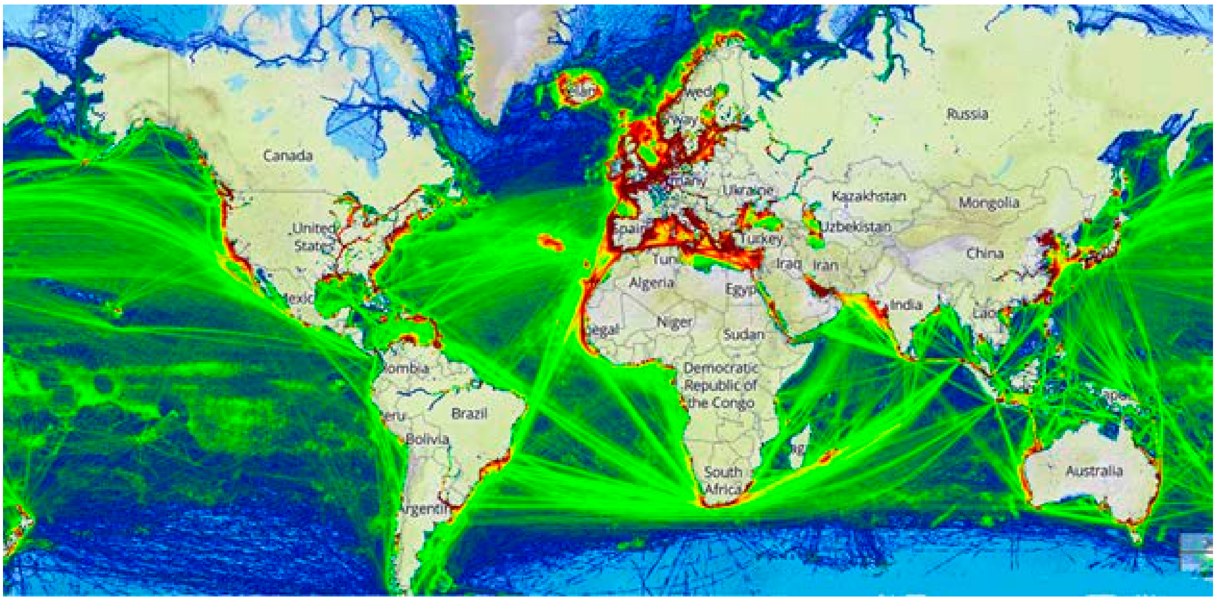

Figure 4. Worldwide vessel traffic (Marine traffic – AIS, 2016)

shows that the main shipping routes include, for example:

- coasts of North and South America;
- routes from European ports to the ports of North America;
- European ports, through La Manche Canal to African ports;
- etc.

In this case, vessels can use two types of fuel:

- outside the ECAs – non-low-sulphur types, in accordance with the Sulphur Directive;
- in ECAs – low-sulphur fuels, for example LNG.

From an economic point of view, the most attractive option for these units is the use of dual-fuel engines that are capable of burning two fuel types. At the same time, they process conventional fuel and gas LNG (low-sulphur fuel).

The design is intended to create a unique and non-invasive system that allows for the conversion of existing diesel drives to more efficient, environmentally-friendly and flexible engines that can be supplied with, for example, diesel and LNG, or diesel and biomethane. It allows for the possibility of a return to conventional diesel-only power at any time. Fuel represents a significant share of the operating costs, particularly in the so-called giant container ships. Dual-fuel diesel allows for the replacement of expensive diesel fuel (diesel) by a cheaper fuel, e.g., LNG (Kowalewicz, 2008; Luft & Skrzek, 2012; Olczyk et al., 2015). With the use of this system, there are fewer toxic emissions and soot from diesel engines than when only diesel fuel is burnt. The world's largest multinationals, such as the Finnish Wartsila and the German Man Diesel SE, have led the design of these systems. The most common engine used on a bulk carrier is the duel-fuel (gazo-diesel) powered engine 8L5160DF (Figure 5).

Figure 5. Dual-fuel engine 8L5160DF (MAN Diesel & Turbo, 2013)

In addition to dual-fuel engines, internal combustion engines powered by LNG can be distinguished by single-fuel engines with spark ignition, using only gas. This type of engine was first developed in the early 1990s. Vessels using LNG as their only drive fuel require the installation of suitably sized tanks. For this reason, singe-fuel motors are used on marine units which provide their services in areas with a well-developed network of bunker stations for frequent refuelling. Dual-fuel type engines (characterised by a complex structure) are more often suitable for units with larger capacities (in relation to units fuelled), which allows for a smaller bunker-station availability.

The company MAN Diesel & Turbo received orders to build thirty dual-fuel working engines to supply six Chinese LNG carriers. According to data from the DNVGL organisation, forty-five ships are deployed around the world using dual-fuel engines (Table 4). In 2018 the next forty-seven dual-fuel units (ordered by Norwegian ship owners) will become operational. They are of the following types:

- offshore (especially PSV type – Platform Supply Vessels);
- ro-pax;
- containers.

Table 4. Examples of vessels using dual-fuel engines (author's own study based on available data (Data provided by DNVGL))

Flag	Name of the vessel	Type
Norway	Matson	container
Norway	Stril Pioner	multipurpose / offshore
Norway	Viking Energy	multipurpose /offshore
Sweden	Stena Germanica	ferry
Canada	Salish Orca	ferry
Bahama	Greenland	bulk carrier

The containers have a totally different look. These are vessels of increasingly large capacity (currently, flying units can be traced of up to 19 thousand TEU). These big container vessels carrying all sorts of goods all over the world are supplied with expensive diesel fuel whereas smaller units are starting to be supplied with drives using LNG.

Conclusions

The global market for LNG fuel offers a wide range of innovation and challenges for many branches and economic sectors. One of these is the area of maritime transport, in which development allows for the use of new technologies to meet the requirements of the Sulphur Directive. From an economic point

of view, the use of dual-engines fuel decreases operating costs due to:
- low price of fuel;
- efficiency;
- efficient use of received cold;
- efficient use of heat.

In addition, the use of multi-tasking engines allows for the use of a unique system that is more efficient in terms of cost and, most importantly, is friendlier to the environment than previously used fuels. This allows units using dual-fuel to be used and converted back at any time to allow the use of a conventional power supply.

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