Environmental and economical benefits of changing from marine diesel oil to natural-gas fuel for short-voyage high-power passenger ships

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Abstract: Although the actual level of marine air pollution is unclear, the contribution of ships to global emissions can be roughly indicated as being in the following ranges: nitrogen oxides (NO_x), 10–20 per cent; carbon dioxide (CO_2), 2–4 per cent; sulphur oxides (SO_x), 4–8 per cent. Several studies, which aim to minimize and reduce the maritime environmental pollution by the gas emissions from ships, have shown that there are different methods by which this can be achieved. This paper shows that the use of natural gas as the main fuel on board ships is considered to be the optimum selection for this purpose as regards the environmental and economic issues. A short-voyage ship of high power rating is deemed to be suitable for natural-gas application to obtain the maximum environmental and economic benefits. As a case study, this paper discusses the environmental and the economic benefits of using natural gas as an alternative to diesel oil on board one of the high-speed passenger ships operating in the Red Sea area between Egypt and the Kingdom of Saudi Arabia. The study illustrated that NO_x, SO_x, particulate matter, and CO_2 emissions were reduced by 72 per cent, 91 per cent, 85 per cent, and 10 per cent respectively. In addition, the cost of both fuel consumption and maintenance operation demonstrated reductions by 39 per cent and 40 per cent respectively.

Keywords: air emissions reduction, natural gas, environmental and economic benefits, dual-fuel engine, high-speed ship, Red Sea area

1 INTRODUCTION

Until 1995, dealing with the marine pollution problem had focused only on water pollution. By the end of the twentieth century a new issue had surfaced: air pollution which has become about 4 per cent of the total global air pollution. For this reason the International Maritime Organization (IMO) has issued Annex VI for MARPOL, which is referred to as MARPOL 73/78/95. (MARPOL is the International Convention for the Prevention of Pollution from Ships (MARPOL being an abbreviation of marine pollution), and 73, 78, and 95 indicate the years 1973, 1978, and 1995 respectively.)

To comply with this issue, several methods have been employed to eliminate exhaust gas emissions. These methods have largely contributed to reducing air pollution. However, in order to reach the new limits set by the IMO regarding the allowable amount of gas emissions, as shown in Fig. 1 [**1**], it will be very expensive, adding new financial costs to the ships' operation, especially with the increase in high-quality fuel prices. That is why it is highly important for all who are interested in the shipping industry to search for other methods that could achieve the environmental benefits by reducing emissions while keeping the operation costs, including fuel and maintenance costs, as low as possible at the same time.

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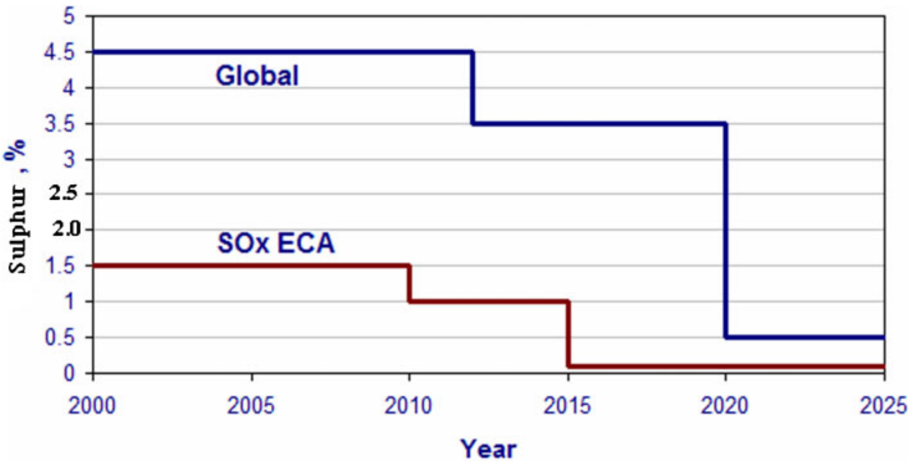

Fig. 1 Sulphur limits in marine fuels according to the latest IMO regulations [**1**] (ECA, emission control area)

2 BASIC MARINE AIR POLLUTION REDUCTION METHODS

In the last few decades, various technologies have been applied to reduce the amount of exhaust gas emissions which result from ships. Some of these are related to cleaning the exhaust gases before they are emitted to the atmosphere, such as selective catalytic reduction, exhaust gas recirculation, and catalysed particulate filters. Other technologies are concerned with improving both the combustion process and the power plant efficiency, such as combustion optimization, advanced fuel injection controls, improvement in the charge air characteristics, electronically controlled direct water injection, and waste heat recovery. In addition, using a high-quality marine diesel oil such as low-sulphur fuel has contributed to achieving this objective [**2**].

Applying these technologies on board ships revealed that there are two main problems. First, using a low-sulphur fuel will be very costly especially with the expected increase in the price of marine diesel oil in the near future, as shown in Fig. 2 [**3**]. Second, to achieve reduction in both SO_x and NO_x emissions, additional operating costs will be incurred. This makes the use of the previous emissions reduction technologies uneconomic. Research on this issue has shown a great potential for ships fuelled by alternative fuels to be environmentally friendly and economical [**4**, **5**].

3 FUTURE MARINE FUELS

The main alternative marine fuel types may be found in two forms: liquid fuels including ethanol, methanol, bioliquid fuel, and biodiesel; and gaseous fuels, including propane, hydrogen, and natural gas (NG). Despite the fact that all these fuels are more environmentally friendly than diesel oils, some are

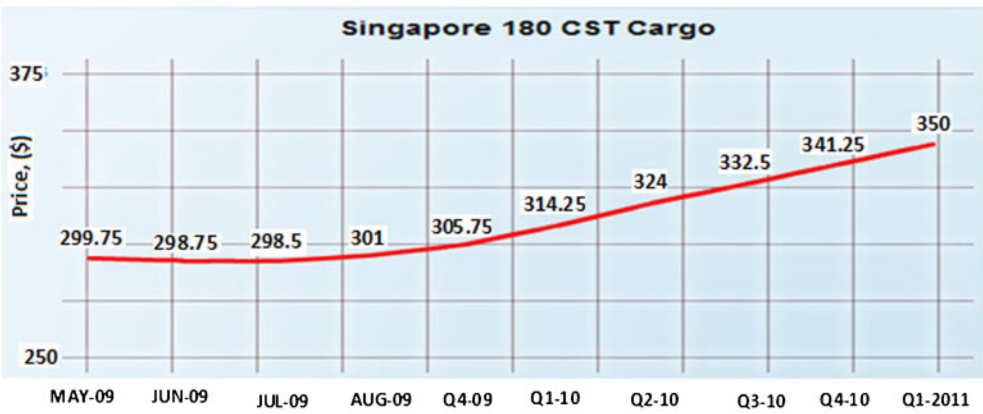

Fig. 2 Expected fuel prices through the coming months [**3**] (Q4-09, fourth quarter of 2009; Q1-10, first quarter of 2010; Q2-10, second quarter of 2010; Q3-10, third quarter of 2010; Q4-10, fourth quarter of 2010; Q1-2011, first quarter of 2011)

still difficult to apply extensively on board ships because of the problem of low energy content, e.g. methanol and ethanol [**6**, **7**]. Other possible marine fuels have limited applications owing to the problems of price and storage on board ships, e.g. hydrogen, since it has to be liquefied at −252 °C [**8**]. The weighting matrix given in Table 1 may be used to determine the optimum selection of alternative fuel. The matrix indicates that NG is the best alternative fuel for marine applications. This is due to its moderate cost, availability, and adaptability for existing engines.

4 NATURAL GAS IN MARINE USE

NG as a fuel is well established in the urban transport and power generation sectors, and this technology will be transferred to the marine industry via the availability of engines, systems, and technical assistance. Since NG is considered as a clean fuel with high energy content, this makes it suitable for all marine power plants, such as diesel engines, steam turbines, gas turbines, and new power plants such as fuel cells. This means that NG has a higher adaptability than other marine fuels [**9**], with emphasis on reciprocating engines, which have a wide application on board ship. It is obvious that changing reciprocating engines to NG-fuelled engines for both land and marine applications is more widespread now because the amount of exhaust emissions generated from the combustion of NG is lower than that produced by the combustion of diesel oil in engines [**10**].

Reciprocating gas-fuelled engines can be classified into two main types: NG spark ignition engines and NG compression ignition (CI) engines. CI engines are divided into engines fuelled by combining diesel fuel with NG in dual-fuelled (DF) operation engines and engines fuelled by NG only (gas engines (GEs)). Choosing NG CI engines is driven by several environmental and economic factors. However, the majority of NG engines operate in a DF mode where GEs have some problems related to the safety considerations.

5 NATURAL-GAS-FUELLED SHIPS

The growing consciousness of environmental issues makes NG a fuel that is of increasing interest around the world. Internationally, there were few ships that operated on compressed natural gas (CNG) before the year 2000. However, the introduction of liquefied natural gas (LNG) as a fuel instead of CNG has turned NG into a feasible fuel for many ship types and trades, where this reduces considerably the space needed for gas fuel storage. The first LNG-fuelled ferry in the world started its shuttle transport of people in Norway 8 years ago. A total of ten ships are now in operation in Norway, running on LNG, and more are being built and contracted. Now new projects with LNG or CNG as the fuel on board ships are being seriously considered in many other countries [**4**, **11**].

6 GAS-FUELLED SHIP TYPES

Experiences of NG as a fuel for ships present a true challenge for world trading requirements; initially the use of NG as a main fuel type faced many problems because of safety issues, but these have become easier to control nowadays. NG can be adapted for the following ships: LNG carriers, passenger ferries, coastguard vessels, cargo ships, small inter-city passenger vessels, tugs, and fishing vessels. In addition, research has been conducted to study the ability of using NG for special applications in inland waterway units and off-shore structures [**11**, **12**]. The selection of NG as a fuel entails the following problems: gas availability, bunkering operation in ports, storage on board, ship sailing time, and engine room design. Nevertheless, it can be said that the optimum choice for the application of NG will be for LNG carriers, where the cargo will be the main source of the fuel, and short-voyage ships such as ferry passenger ships, where the sailing time and bunkering operation will be easier.

Table 1 Weighting matrix of alternative marine fuels

	Ethanol	Methanol	Bioliquid fuel	Biodiesel	Hydrogen	Propane	NG
Availability	Very good	Very good	Excellent	Very good	Excellent	Very good	Very good
Renewability	Very good	Very good	Good	Good	Excellent	Fairly good	Fairly good
Safety	Excellent	Excellent	Excellent	Excellent	Fairly good	Very good	Excellent
Adaptability	Very good	Very good	Very good	Excellent	Good	Very good	Excellent
IMO compliance	Good	Good	Very good	Good	Excellent	Very good	Excellent
Performance	Good	Good	Very good	Very good	Good	Very good	Excellent
Cost	Good	Good	Very good	Very good	Fairly good	Excellent	Excellent

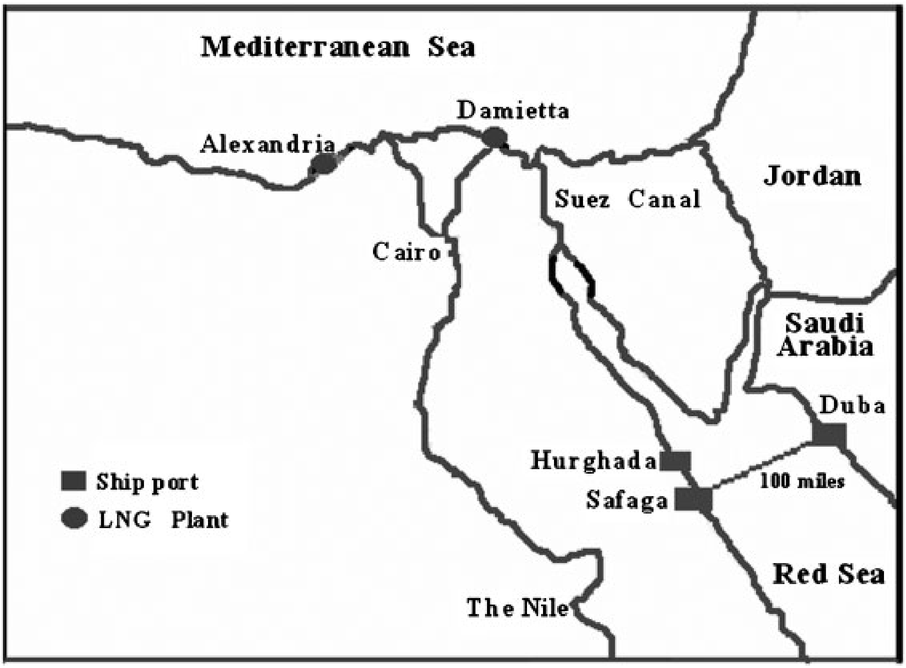

Fig. 3 Ship route and bunkering facilities

7 THE APPLICATION OF LIQUEFIED NATURAL GAS AS THE MAIN FUEL FOR A HIGH-SPEED PASSENGER SHIP (CASE STUDY)

This study discusses both the environmental and the economic benefits of the conversion of the main engines for one of the high-speed passenger ships working in the Red Sea area, called El-Mottaheda-1. The ship operates between either the port of Hurghada or the port of Safaga in Egypt and the port of Duba in the Kingdom of Saudi Arabia, as shown in Fig. 3.

7.1 The development of high-powered passenger ships in the Red Sea area

During recent years, the number of short-voyage passenger ships working in the Red Sea area has increased, as shown in Fig. 4. There is no doubt that

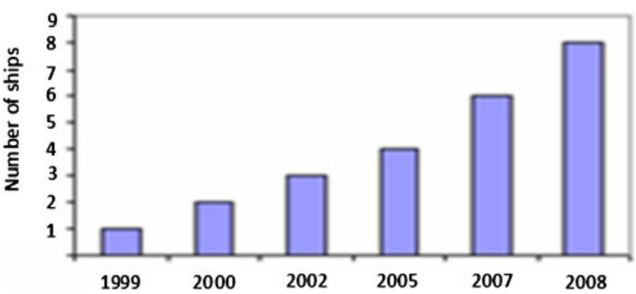

Fig. 4 Increase in the number of high-powered passenger ships

these ships have contributed to the development of maritime transport in this area. However, on the other hand, the high power of these ships has had a detrimental effect on the environment and contributed to the increasing gaseous emission rate in this area.

7.2 Environmental benefits of the conversion process

To evaluate the environmental benefits in the case of conversion of the main engines for use with NG instead of diesel fuel, the quantity of gaseous emissions from both the diesel engines and the DF engines will be calculated as follows.

7.2.1 Main diesel engine emissions calculations

Many studies have been carried out to estimate the quantity of emissions from ships. One of these was conducted by the US Environmental Protection Agency (EPA). This method follows the same general emissions estimation equation used in the Canadian inventory efforts. The equation, which is shown below, estimates ship emissions depending on the following parameters: the gross engine power, engine running hours, engine load factor, and engine emission factor. The EPA inventory method thereby encompasses defining these input parameters, which can be resolved by the type of vessel, the type of fuel consumed, and the mode of operation. Consequently, for any ship, the quantity of emissions can be calculated as

$$\Sigma E_{total} = \text{total } E_{standby} + \text{total } E_{manoeuvring} + \text{total } E_{cruise}$$

where $\Sigma\ E_{total}$ is the total emissions quantity during one trip. Also [**13**]

$$E = P\ \text{LF}\ e_{fd} T$$

where E is the emission quantity (g), P is the engine power at maximum continuous rating (kW), e_{fd} is the emission factor (g/kW h) in diesel mode, LF is the load factor (per cent), and T is the engine running time (h). The ship's power is 24 000 kW; the LFs in cruise, manoeuvring, and standby modes may be in the ranges of 80 per cent, 20 per cent, and 5 per cent respectively [**13**]. According to the data obtained from local port authorities, the average time for each trip is 8 h in total, which is divided into 40 min standby, 50 min for manoeuvring, and 6.5 h for cruise. With a main engine speed of 1250 r/min and a fuel with 1 per cent sulphur, the values of the nitrogen oxide (NO_x), sulphur oxide (SO_x), particulate matter (PM), carbon dioxide (CO_2), and hydrocarbon (HC) emissions factors are as summarized in Table 2 [**13**, **14**].

7.2.2 Calculations of dual-fuel main engine emissions

The average values of the specific emissions NO_x, SO_x, and PM in the case when NG is used as the main fuel are 2.16 g/kW h, 0 g/kW h, and 0 g/kW h respectively. With respect to the previous emissions, NG contains more hydrogen and less carbon than diesel fuels; hence the CO_2 emissions are reduced. Unfortunately, the increased emissions of methane (CH_4) reduce the net effect to an equivalent of about 15 per cent reduction in CO_2 [**4**]. It is necessary to take into consideration that the change from diesel mode to NG mode must occur at a load of more than 20 per cent to avoid any misfiring below this percentage. For a converted engine, when considering using a DF with 95 per cent NG and 5 per cent diesel fuel as the primary fuel, the equation that may be applied is

$$E = P\ \text{LF}\left(0.05e_{fd} + 0.95e_{fg}\right)T$$

where e_{fd} is the emission factor (g/kW h) in diesel mode and e_{fg} is the emission factor (g/kW h) in NG mode.

Table 3 presents the average emissions factor for NG engines under various loading conditions.

Using the emissions factors from Tables 2 and 3, the values of the emission rate (kg/min) during one trip from port to port using diesel oil and NG can be obtained and are shown in Fig. 5. The figure shows that the current diesel engine SO_x and NO_x emission values will not be compliant with the future IMO emission limits. On the other hand, the current DF engine will be within these limits. This means that changing to NG-fuelled engines will comply not only with the current IMO emission requirements but also with the future regulations.

According to the data obtained from the company that owns this ship, the number of trips carried out by the ship per year was 250; the quantity of exhaust emissions for both diesel engines and NG engines can be estimated per trip and per year respectively, as shown in Table 4.

Table 4 indicates that the converted engine has lower emissions of NO_x (72 per cent), SO_x (91 per cent), CO_2 (10 per cent), and PM (85 per cent). These results are satisfactory and match the results reported in reference [**15**]. During this study, where the value of the HC emission factor for conversion engines was unknown, it was very difficult to det-

Table 2 High-speed diesel engine emissions factors

	Emissions factor (g/kW h)				
	NO_x	SO_x	PM	CO_2	HC
At cruise	10.81	4.1	0.3	645	0.2
At standby and manoeuvring	12.7	4.5	0.9	710	0.6

Table 3 High-speed dual-fuel engine emissions factors at 5 per cent diesel oil

	Emissions factor (g/kW h)				
	NO_x	SO_x	PM	CO_2	HC
At cruise	2.59	0.2	0.015	553	Unknown
At standby and manoeuvring	12.7	4.5	0.9	710	0.6

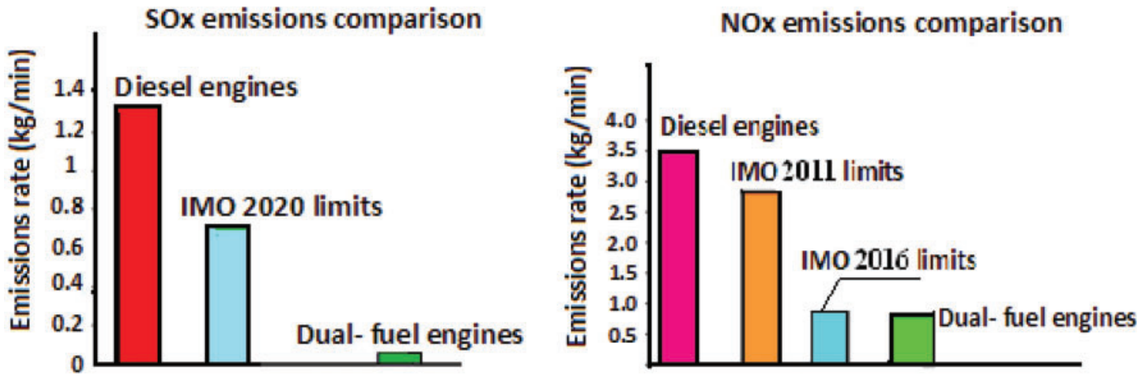

Fig. 5 Comparison of the IMO emissions limits for diesel and DF engines

Table 4 Case study environmental benefits

Emission type	Engine mode	Emissions/trip (t)	Emissions/year (t)	Emissions reduction (t/year)
NO_x	Diesel engines	1.410	352.5	253.25
	NG engines	0.397	99.25	
SO_x	Diesel engines	0.415	103.75	93.43
	NG engines	0.041	10.32	
CO_2	Diesel engines	83.904	20 976	2021
	NG engines	75.823	18 955	
PM	Diesel engines	0.041	10.25	8.75
	NG engines	0.006	1.5	

ermine the effect of conversion on HC emissions; but previous studies on this have indicated that HC emissions will increase when using NG instead of diesel oil as the main fuel in internal combustion engines, since diesel engines are operated at a much leaner mixture than NG engines are, especially for converted engines [**16**].

To evaluate the study, various NG percentages are used, so that the emissions reduction percentages for NO_x and SO_x as the main emission types can be obtained from Fig. 6.

8 ECONOMIC BENEFITS OF THE CONVERSION PROCESS

The economic study indicates savings in fuel cost, savings in maintenance cost, and payment cost due to the conversion from diesel engines to DF engines. Thus, it is necessary to discuss the various issues related to bunkering availability, fuel cost, and fuel storage in the following.

8.1 Estimation of fuel consumption and cost for both engines

According to the previous experiments carried out for determining the performance of NG engines, it is deduced that the brake specific fuel consumption of a converted engine (NG engine) will increase compared with that of a basic engine (diesel engine) by nearly 23 per cent. This is because these engines were originally designed for diesel fuel [**17**]. Although some research studies neglect this, this paper took it into consideration. Thus, estimation of

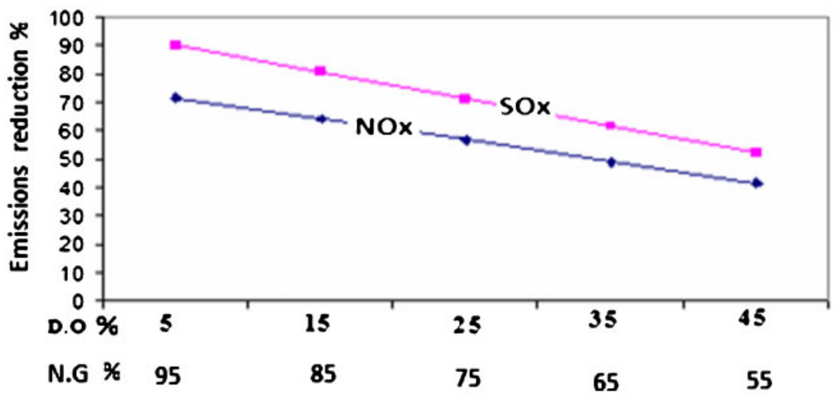

Fig. 6 Different emissions reduction percentages at various NG percentages (DO, diesel oil)

the NG quantity required to obtain the same engine power depends on the actual diesel fuel consumption and the fact that it requires 1197 m^3 of NG for each cubic metre of diesel oil consumption.

The conversion from a diesel engine to a DF engine has to include calculations to determine the volume of NG which is required to operate the vessel in dual mode. Hence, the proposed engine will operate with a mixture of 95 per cent NG gas and 5 per cent diesel fuel in the engine load range from 20 per cent to 80 per cent. With reference to the ship in the case study, the diesel oil and NG quantities are estimated for both options and are shown in Table 5.

8.2 Natural gas storage on board ship

Generally, NG can be stored on board ship either in a compressed form or in a liquefied form but, owing to the higher quantity of NG used during the trip for this case study, it will not be practical to store it in a compressed form. The only suitable storage form here is the liquefied form, which already has the advantage of lower weight and space demands compared with CNG. Table 6 shows the capacity, pressure, and dimensions of IMO-7 LNG container models which are used for this purpose [**18**].

For this study, model TVS-54-60 will be more suitable as regards pressure, capacity, dimensions, and weight. According to the total quantity of NG consumed during one trip, 61.33 m^3 of LNG is required. This means that, to provide the ship with sufficient NG, it will need three to four LNG containers if the bunkering is only at one port and will require two containers if bunkering infrastructure is established at both ports.

8.3 Availability of liquefied natural gas for bunkering

Although Egypt has a large quantity of NG, the form of local NG used is limited to the compressed form. The LNG form is used only for export purposes and this is available only at the ports of Damietta and Idku (near to Alexandria) through LNG plants, as shown in Fig. 3.

For this study, the nearest port is Damietta. Therefore, the LNG can be transferred from the plant to the ship position by various methods; the proposed method is to carry the NG in a liquefied form inside the bunkering container specified in Table 6, where it is filled at the Damietta LNG plant and is transferred by truck to the port. To increase the efficiency of this method, a number of containers are used as reserve containers, where there is a group on board ship and another at the port storage area ready for use. The cost of the bunkering process will be taken as a percentage of the fuel cost. It depends mainly on the distance between the LNG plant and the ship port.

8.4 Cost of transferring liquefied natural gas containers

One of the sensitive cost items which affects the economics is the cost of LNG transfer on board ships, where the volume which is occupied by this container could be used for cars with charges being paid. According to company prices, the annual cost of transferring a container from Hurghada to Duba two ways is US$45 450. Thus the total LNG container transfer cost is US$181 818 per year. This value will be halved if the bunkering process is carried out at both Hurghada and Duba.

Table 5 M/V El-Mottaheda-1 fuel consumption

	Total fuel consumption (m^3)		
	DF engines		Diesel engines (diesel oil)
	Diesel oil	NG	
Per trip	3.58	36 798	35.94
Per year	895	9 199 500	8 985

Table 6 Specifications of the LNG containers

Model	Pressure (bar)	Width (m)	Length (m)	Mass (kg)	Capacity (m^3)
TVS-52-250	17.2	2.438	6.05	9980	19 950
TVS-53-150	10.3	2.438	6.058	7850	20 250
TVS-54-60	4.14	2.438	6.058	6030	20 480

Table 7 The annual cost of fuel consumption for diesel and DF engines

	Local prices (US$/year)		World prices (US$/year)	
Item cost	Diesel engines	DF engines	Diesel engines	DF engines
Diesel oil	1 797 000	179 700	3 887 500	387 500
Diesel oil bunkering	38 875	3 875	38 875	3 875
NG	0	752 682	0	1 793 902
LNG bunkering	0	75 268	0	179 390
Container transferring	0	109 090	0	109 090
Total fuel cost	1 835 875	1 113 369	3 926 375	2 473 757

Referring to both local prices (in Egypt) for diesel oil and NG, which are US$0.2/litre and US$0.08/m^3 respectively, and world prices, which are on average US$500/t for diesel oil and US$117/t, for LNG during the first half of 2009 [**19**], in addition to the cost of bunkering process, which is US$5 for each tonne of diesel oil and 10 per cent for NG, the cost of transferring NG may vary according to the filling position. The final annual costs of the fuel for both diesel and DF engines are summarized in Table 7.

Data deduced from Table 7 indicate that there is a great economic benefit as regards the annual fuel cost in both local and world prices. Furthermore, it provides information about the annual fuel cost reduction percentages in both cases, which are 39 per cent and 37 per cent for local and world prices respectively; this indicates the benefit that the conversion process provides in order to reduce the total annual ship costs.

8.5 Savings in maintenance cost

In addition to the economic benefit of savings in the fuel cost by using NG instead of diesel oil, the maintenance cost is also considered to be a very important item that affects the economic considerations. From previous experiments on using NG as fuel for engines, it is concluded that the mean time between maintenance for NG increased threefold to fourfold in comparison with that of diesel engines [**12**, **17**]. This means that the total running hours of NG-fuelled engines will be at least three times that of engines working by diesel oil. For example, for the case study in question, the main engine overhaul is carried out on average every 22 000 h, which costs US$1.0625 million for each engine. This presents a cost of US$96 590/year. However, in the case of the NG-fuelled engine, it costs one third of this value. For other maintenance activities, which include routine maintenance, lubricating oil consumption, and spare parts consumptions, the cost is expected to be reduced in the case when NG is used to about 50 per cent of original cost [**14**, **20**, **21**]. Thus, Table 8 explains the cost benefits of using NG instead of diesel oil as regards the maintenance activity of DF engines with respect to the maintenance activity of diesel engines. Data about the maintenance activity of diesel engines were obtained from the head office of the company that owns M/V El-Mottaheda-1.

Table 8 The annual maintenance cost of DF engines versus diesel engines

	Annual maintenance cost (US$/year)	
Maintenance item	Diesel engines	DF engines
Lubricating oil	441 250	220 625
General spare parts	100 000	50 000
Complete overhauls/year (annual interest, 10%)	654 340	444 124
Total maintenance cost	1 195 590	714 749
Maintenance savings cost	48 041	

The previous results give us an approximate savings cost benefit per ship power unit of US$49.86/kW, as shown in Table 9. If this value is applied to all ships working in this area, which have a total power rating sum of 155 000 kW, the total savings cost will reach US$7 729 000/year, which will surely confirm the idea of changing from diesel-oil-fuelled engines to NG-fuelled engines and make it more applicable.

8.6 Estimation of the payment cost for the conversion process

The conversion of main engines from diesel-fuelled engines to NG-fuelled engines will include some changes. These changes include the modification of the main engines, NG supply system including NG storage spaces, supply piping and valves, gas detec-

Table 9 Total annual savings cost in the case of change to NG engines

Item	Savings cost (US$/year)
Fuel savings cost	715 959 (according to the local prices)
Maintenance savings cost	480 841
Total savings cost	1 196 800

tion units and alarms, exhaust ventilation system, and other components.

During the study, it was difficult to establish a formal conversion price, as it needed actual quotations from conversion companies but, depending on the writers who quoted for the leading companies with high technology in the conversion field, such as MARINTEK and Wärtsilä in Norway and Proserve in the USA, the approximate conversion cost is near to US$200/kW. This agrees with the cost in reference [**14**]. On the other hand, the data collected from ships which have already undergone a conversion process during the last few years indicated that the average conversion cost was US$220–340/kW [**2**, **22**].

The difference in the conversion cost provides evidence of the development in conversion technology. Thus, both the savings and the cost values can be used to determine the preliminary economic aspects. This may be done using the annual money-saving method.

In this method, the savings value depends on the expected average value of ship age after conversion, applying the capital recovery factor (CRF) with variable interest according to the equation

$$C_A = C_i \text{ CRF}$$

where C_A is the annual cost and C_i is the capital cost (total conversion cost). The CRF is given by

$$\text{CRF} = \frac{i(1+i)^N}{(1+i)^N - 1}$$

where N is the expected ship working years after the conversion process and i is annual interest [**23**].

Figure 7 reveals the relation between the annual cost conversion value and the expected ship working years after the conversion process to be an economical process at variable interest percentages. From the figure, e.g. at 10 per cent interest, the minimum number of working years to recover the conversion cost is close to 12 years. This means that the conversion process will lose its economical benefits if the age of the ship in question exceeds 16 years, with the assumption that the average maximum ship age is 28 years [**24**].

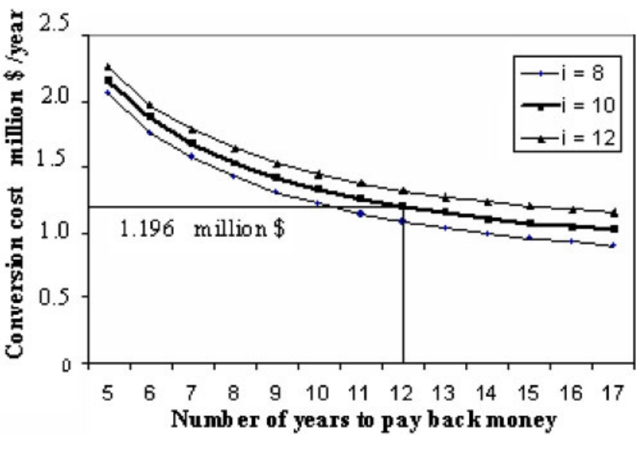

Fig. 7 Annual savings cost and payback money using the CRF

This is the main assumption during the estimation of the economic benefits related to the cost of fuel consumption. Therefore, there is no doubt that the previous economic calculations will have a significant effect in the case when there is a change in the fuel cost (from diesel oil to NG); for all cases, it will be a change for the better.

9 CONCLUSION

This study proves that the conversion process of a ship's main engines from the traditional fuel (diesel oil) to an alternative fuel (NG) has great environmental benefits and demonstrated emissions reduction for NO_x by 72 per cent, SO_x by 91 per cent, PM by 85 per cent, and CO_2 by 10 per cent. Consequently, from the economic point of view, this study shows that, in the case when NG was used instead of diesel oil, the annual costs of the fuel and maintenance will be decreased by 39 per cent and by 40 per cent respectively. In addition, this study reports that there are some factors which need to be overcome in order to make the conversion process easier, such as the capital cost of the conversion and the possibility of bunkering the NG on board ship which requires the infrastructures of the ports to be upgraded to allow refuelling with NG.

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APPENDIX

Notation

CI	compression ignition
CNG	compressed natural gas
CO_2	carbon dioxide
DF	dual fuel
EPA	US Environmental Protection Agency
e_{fd}	diesel engine emissions factor (g/kW h)
e_{fg}	dual-fuel engine emissions factor (g/kW h)
E	emissions

GE	gas engine	NG	natural gas
HC	hydrocarbon	NO_x	nitrogen oxides
IMO	International Maritime Organization	PM	particulate matter
i	annual interest	P	power rating (kW)
LF	load factor	SO_x	sulphur oxides
LNG	liquefied natural gas	T	number of engine running hours (h)