AN OVERVIEW: ENVIRONMENTAL AND ECONOMIC STRATEGIES FOR IMPROVING QUALITY OF SHIPS EXHAUST GASES

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SUMMARY

In spite of the fact that most of different transport means have achieved a significant reduction of their emissions quantity during the last few years; maritime field still suffers from the steady increase in the quantity of exhaust gases emitted from ships. As a result, the International Maritime Organization was prompted to issue a set of regulations for facing the seriousness of those emissions. The present paper handles the different methods which can be used to reduce the environmental damage caused by ship emissions. Through the study of the advantages and disadvantages of ships' emission reduction strategies; use of natural gas, selective catalytic reduction and sea water scrubbing systems have appeared as the best ways that can be utilized to reduce the environmental harms caused by ship emissions. Applicability of these methods aboard ships could vary from ship to another. Two high-speed passenger ships of different age were studied to evaluate the importance of applying these strategies. The results showed the possibility to attain valuable emission reduction percentage by using of selective catalytic reduction and sea water scrubbing systems, but they will be of high initial cost and will increase operating cost of both ships. On the other hand using of LNG as alternative fuel will be more convenient from the point of view of environment and economic issues for the newer existing ship.

NOMENCLATURES

ACI	Annual saving/increment cost	($/year)
C.V	Fuel calorific value	(k J/kg)
C_A	Capital conversion cost	*$*
C_i	Total installation cost	*($/year)*
C_M	Annual operating cost	($/year)
C_O	Annual maintenance cost	($/year)
C_1	Percentage of diesel oil	-
C_2	Percentage of natural gas	-
E_{fDO}	Diesel engine emission factor	(g/Kwh)
E_{fNG}	Emission factor in case of dual engines	(g/Kwh)
fc_{LNG}	Natural gas fuel cost	*$/MMBTU*
$fc_{D.O}$	Diesel fuel oil cost	$/ton
F_C	Fuel cost increment in case of using marine gas oil	($/year)
FSC	Difference of fuel cost	$/year
i	interest percent	-
L_{fDO}	Diesel engine load factor	-
L_{fNG}	Dual engine load factor	-
$m^{\cdot}_f$	Fuel consumption in is in,	(kg/s)
N	Ship working years	-
P	Engine power	(kW)
r_p	Reduction percentage of emissions factor	-
sfc_{LNG}	Specific fuel consumption of NG	*MMBTU /kWh*
$sfc_{D.O}$	Specific fuel consumption of diesel engine	*g/kWh*
t_T	Ship sailing time	(h)
V_i	Ship's speed after speed reduction	*(Knot)*
V_o	Ship's speed before speed reduction	*(Knot)*
$SC_{M\&O}$	Difference maintenance and operating cost.	$/year
$\Delta F_{M.E}$	Percentage of fuel saving amount	-
Δ Bunkering	Difference bunkering cost	$/year
η	Engine thermal efficiency	-

1. INTRODUCTION

Merchant ships have been depended, for a long time; on the fossil fuel as a main source for operating of ships' machineries. The coal was used for steam power plant, which soon replaced by diesel fuel in its forms; heavy and light, for internal combustion engines. Although its merits, especially with regard to safety, performance, and adaptability; using of traditional fuels onboard ships face many problems nowadays. This included a surge in fuel prices, especially with the world political events [2] in addition to the environmental damage resulting from the exhaust gases emitted from ships [36] and finally the sustainability issue [51]. Environmentally, using of huge amount of conventional marine fuel oils onboard ships have an adverse impact due to increasing of ship emissions [58/40].The main ship emissions are Sulfur oxides (SOx), Nitrogen Oxides (NOx), Particulate matter (PM), Carbone dioxide (CO_2), Carbon mono Oxide (CO), Volatile Organic Compounds (VOC) and Hydrocarbons (HC). As a step towards minimizing these effects International Maritime Organization (IMO) has been planned to push ships for use of marine fuels of good quality, particularly in so-called Special Areas (SECAs) and to be applied universally so gradually [23]. The present paper gives a scope of statistics, regulations, and the proposed strategies for achieving ship emissions reduction.

2. SHIP EMISSIONS INVENTORY

It was shown by [22] that in year 2000; ocean-going ships were responsible for about 15% of all global NOx emissions and 4–9% of global SO_2 emissions and have emitted at least 600 Tg of CO_2 emissions. IMO in its publications [34] revealed that in 2007, 2.7% of all global CO2 emissions were attributable to ships and the quantity of NOx and SOx exhaust gaseous emissions emitted from ships estimated to be 25 and 15 million tons of respectively. Moreover, it was shown by [17] that shipping-related PM emissions are responsible for 3–8% of global $PM_{2.5}$ -related mortalities. Furthermore, other researches disciplined that by year 2050 the world ships fuel consumptions will be between 453 and 810 Mt (2-3 times present level), with appurtenant emissions ranging from 1308 to 2271 Tg (CO_2), 17 to 28 Tg (NOx) and 2 to 12 Tg (SO_2). These measures will be affected and fluctuated according to propulsion system, fuel type, and emissions reduction means.

3. MARITIME INTERNATIONAL REGULATIONS

IMO has introduced a regulation to limit the emissions from marine engines; the year of 2005 was the starting date for implementation of the provision of MARAPOL 73/78/97 convention which aims to reduce air pollution from ships specifically NOx and SOx. For compliance purposes, all sea-going ships must prepare Engine Air Pollution Prevention (EAPP) and International Air Pollution Prevention (IAPP) certificates for inspection by port-state control [39].

The IMO and the European Union (EU), the rule-suppliers regarding SOx emissions reduction, have moved forward with the issue through a different timetable and on a different geographical scale. To eliminate the effect of sulfur content, the IMO Marine Environment Protection Committee adopted amendments to the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI regulations on sulphur oxide. The current and future emissions regulations regards amended date and acceptable ranges for ship's emissions can be illustrated as shown in Figures (1&2) [27/23/3/34/35].

4. SHIP EMISSIONS CUT- OFF STRATEGIES

There are many processes that can be used for achieving ship emissions reduction, three methods of them appear as the most convenient, including using of: emissions reduction technology, alternative fuels, and fuel saving strategies, as follows:

4.1 APPLYING FUEL SAVING STRATEGIES

Increasing the fuel consumed by ships has two effects. First, the turmoil in the economies of ships, second, the environmental harm, as, ships, emissions have soared in parallel with the growth of international fuel consumed by ships. The present section describes some of the main strategies that may be applicable onboard ships in order to achieve maximum fuel saving, as follows:

4.1 (a) Ship Resistance Reduction

Ship powering depends mainly on the ship resistance and consequently the increasing of ship resistance increases the value of the power needed to achieve the required ship speed; which causes increment in ship fuel consumption. Inversely, reduction of ship resistance leads to save fuel consumption. There are many options to reduce ship resistance, such as anti-fouling, ship's weight reduction as traditional methods [44/54/46], and air bubbles as a new concept [58]. Each method of them can contribute by different fuel saving percentages according to ship type, consequently leads to ship emissions reduction.

4.1 (b) Renewable Energy

Climate change, pollution, and energy insecurity are some of the greatest problems of our time. Addressing them requires major changes in our energy infrastructure. Availability of wind, water, and sunlight (WWS) resources such as wind turbines, concentrated solar plants, solar photovoltaic (PV) power plants, rooftop PV systems, geothermal power plants hydroelectric power plants and tidal turbines resources can power a 2030 WWS world that uses electricity and electrolytic hydrogen for all purposes. Such a WWS infrastructure may reduce the world power demand by 30% [32]. [26/41] and [31] presented studies regards the possibility of utilizing the different types of renewable energy to power and supply electricity for the ships. Unfortunately, until now applicability of using renewable energy is very limited due to the low power density.

4.1(c) Energy Performance Improvement

The conventional marine power plants include: diesel engines, gas turbines and steam turbines. Both gas turbines and steam turbines showed an advanced from the view point of plant efficiency alone or in form of combined gas and steam power plant (COGAS). But until now the value of plant efficiency of these types (gas turbines and steam turbines) still less than that of diesel engines especially in the range of (1-100) MW [55].The contribution of marine power plant efficiency in issue of fuel saving may be achieved through fuel quality improvement and engine tuning process **[**1/24]. Energy performance improvement may be evaluated using the engine thermal efficiency indicator as follows:

$$\eta = \frac{p}{m_{f}^{\cdot}\,.\,CV} \qquad (1)$$

where :(η) is engine thermal efficiency, (p) is engine brake power in (kW), ($m_{f}^{\cdot}$) is fuel consumption in (kg/s), (C.V) is calorific value in (k J/kg), depends mainly on the fuel quality.

4.1 (d) Energy Conservation Management

In the maritime field, energy conservation and management processes onboard ships are made more efficient, concerning the fuel to help stretch the fuel budget as far as possible and make ships more environmentally friendly [10]. This goal has been the cornerstone of main and auxiliary machinery. Basically, Energy Conservation Management (ECM) onboard ships can be achieved through waste heat recovery, which may be carried out through various methods, taken into consideration that this will depends on ship's power plant performance [56/7/18]. One of the new proposed waste heat recovery application was presented by [50], which showed the possibility of using exhaust gases to operate absorption air condition unit.

4.1 (e) Reduce ship speed

Fuel consumption and the amount of ships' exhaust gas emissions are in direct relation. Consequently, saving any amount of ship fuel consumption will affect positively on marine environment [29]. Furthermore, with the fuel price increment continues, some companies forced to reduce their ships speed [53]. Basic estimation of fuel saving percentage as a result of speed reduction can be expressed as follows [2]:

$$\Delta F_{M.E} = 1 - \left[\frac{V_i}{V_o}\right]^3 \qquad (2)$$

where, ($\Delta F_{M.E}$) is the percentage of fuel saving amount, (V_i) and (V_o) are ship's speed after and before speed reduction in knots.

4.1 (f) Shore side power connection

A huge amount of fuel is consumed by auxiliary engines at the ports. Therefore, ports consider a major and growing source of pollution and could impose significant health risks on nearby communities. For example, recent studies of ship emissions state that shipping related particular matters (P.M) emissions are responsible for approximately 60000 cardiopulmonary and lung cancer deaths annually, with most of those deaths occurring along the coasts [61]. Shore power connection system used to saving the quantity of fuel consumption through ships berthing periods. Several studies [28/51], aimed to demonstrate the importance of using shore power side concept to reduce fuel consumption; this indicated that there are various methods to achieve that , this including use of: New fixed installation, Installation of one or two fixed fuel cell units, Fixed plant of dual fuel (DF), and Power barge unit. For example, a work presented by [51] showed the possibility of achieve considerable fuel saving amount as a result of shifting from auxiliary diesel engines to national grid power source. This saving reflected into a reduction of 22, 80, 83, 95, and 95 percentages of CO_2, CO, NOx, SOx, and P.M emissions, respectively.

4.2 USING OF ALTERNATIVE FUELS

Fossil fuels are a finite resource and supply that at some time, run out. Due to the un-constant worldwide consumption in addition to the inaccurate estimate of the size of the actual global reserves, it is difficult to determine the actual time for fossil fuel to run out. But according to the current supply and demand; fossil fuels for shipping will be uneconomic. So ship and engine designers will have to look for ways of reducing dependence on oil, this objective can be achieved through many ways such as ships design that continue to carry large cargos at economic speeds, or by dependence on the usage of alternative fuels and the latter is the less economic solution. The basic criteria for selecting any alternative fuel are: in abundant supply, derived from renewable sources, should have high specific energy content, easy transportation and storage, minimum environmental pollution and resource depletion, and lastly, should have good safety and handling properties [3]. The main alternative marine fuel types may be found in two forms liquid and gaseous fuels. Liquid marine alternative fuels include: Methanol, Ethanol, and Bioliquid fuel, among them methanol has the promise to use for marine application in the future [45]. On the other hand, the main alternative gasses fuels include: Hydrogen, Propane, and natural gas. The characteristics of each alternative fuel can be illustrated as follows:

4.2 (a) Ethanol

Ethanol (ethyl alcohol) is an alternative fuel because it can be obtained from both natural and manufactured sources .It is formed from fermented corn, grains or agricultural waste or it is chemically extracted from ethylene (hydration). It is used primarily as a supplement to gasoline. Pure ethanol is not sold as a stand-alone fuel where it is commonly mixed with gasoline in varying percentages. For example, E85 is a common mixture: 85 percent ethanol, 15 percentage gasoline. Ethanol is considered as a clean burning fuel**,** reduces ozone-forming emissions, and renewable. Its disadvantages being corrosive**,** large amounts of farmland and laborers are required to grow the crops, costly, lower energy ratio compared to gasoline and it has poor cold weather starting characteristics due to low vapor pressure and evaporation [25].

4.2 (b) Hydrogen

A variety of alternative hydrogen energy production technologies are available in practice, including: Steam reforming, Off-gas cleanup, Electrolysis Photo process, thermo chemical process and Partial oxidation of hydrocarbons [12]. Until now the use of hydrogen as a main fuel for marine power plants is very restricted because it is expensive to generate, has a very low volumetric energy, and does not burn efficiently in an internal combustion engine due to some problems. In addition power range is limited, has to be liquefied or highly compressed and stored in a high pressure tank to gain driving distance and requires careful handling and special storage tanks [15].

4.2 (c) Biodiesel

Biodiesel is a name applied to fuels manufactured by the use of renewable oils, fats and fatty acids. By renewable, it is meant that supplies of these raw materials can be replenished by the growth of plants or production of livestock [48]. Biodiesel has some advantages including: cleaner than diesel where it reduces emissions of carbon monoxide, carbon dioxide, sulfur dioxide and particulate matter, renewable; it[s] plant based. In spite of the previous advantages Biodiesel has disadvantages as follows: it requires special handling in cold weather, and tends to weaken non-synthetic or natural rubber fuel system parts. Furthermore, both the lower heating value and NOx emissions are considered as the main disadvantages of using biodiesel as alternative fuel oil for marine applications [4].

4.2 (d) Natural gas

The use of natural gas also offers a number of environmental benefits over other fossil fuels, particularly liquid fuels [20/51/3]. The combustion of natural gas, releases very small amounts of sulfur dioxide and nitrogen oxides, virtually no ash or particulate matter, and lower levels of carbon dioxide, carbon monoxide, and other reactive hydrocarbons [11]. Many researchers showed the possibility of using natural gas for marine application either for ships powering system [43/19/51] or for electric generation, using fuel cells [57/ 58].

Table [1] was extracted from the compression which had been presented by [9/3] among the most marine alternative fuels and the other one, which was presented by [11] between current onboard fossil fuel and liquefied natural gas. The matrix indicates that NG considers the best alternative fuel for marine applications. This is due to its moderate cost, availability, and adaptability for existing engines. However, the only disadvantage is being nonrenewable compared to the hydrogen, which comes in the second grade after LNG.

4.3 APPLYING REDUCTION TECHNOLOGIES ONBOARD SHIP

Many researches are underway into developing technologies for reducing exhaust emissions from onboard ships. Some of them are being done by a Scandinavian marine Technology research institute, by marine manufacturers in response to the proposed IMO and national standards, and by pollution – control equipment manufacturers. The process of emissions reduction onboard ships can be carried out through using of exhaust gaseous cleaning, and fuel and engine technologies, as follows:

4.3 (a) PM emissions reduction technology

PM emissions reduction can be achieved through using a catalyzed particulate filter. In this case the exhaust gas from the engine is passing through the filter while most of the particulates matter are restrained within the filter and can be removed by another means [16]. Despite the greater reduction on P.M emissions by using this filter, there are many problems related to these technologies which include: Adaptability, increase in nitrogen oxides, increase in fuel consumption rate and carbon dioxide concentration [62].

4.3 (b) VOC emissions reduction

Volatile Organic Compounds emitted from ships as a result of incomplete combustion processes, and escaping from the cylinder. So, tankers emit VOC during cargo loading and crude oil washing operations as well as during sea voyages. The amount of VOC emissions depends on many factors including the properties of the cargo oil, the degree of mixing and temperature variations during the sea voyage. Two abatement strategy options are being considered by IMO: firstly, vapor recovery at load and discharge ports to shore-based treatment facilities. This is accepted as desirable and signatory governments to IMO have been invited to instigate this control strategy via MARPOL Annex VI Regulation 15. Secondly, a requirement for an onboard VOC management plans to reduce VOC emissions during operations.

4.3 (c) NOx emissions reduction technology

To overcome NOx emissions this can be done by many methods as follow: using a liquid fuel of suitable nitrogen concentration, viscosity, and cetane rating. It was shown by [5/38/37] that an acceptable NOx emissions reduction can be achieved through many process. According to wartsila; running an engine on fuel-water emulsions makes it theoretically possible to reduce NOx emissions by up to 50% with the required water quantity being about 1% in volume for each percentage point reduction in NOx [49]. But Practically NOx reduction percentage by the previous method may reach only 20% due to engine design problems. [52] revealed that a reduction of NOx emissions by about 20% can be achieved using the puriNOx product, who mix Lubrizol proprietary additives with liquid fuels to form a stable product. [37] showed that caring out of some engine internal modifications such as water/fuel percent, return of the exhaust gas to the intake line, modification engine valve timing, and cooling water temperature may be achieved NOx reduced by significant percentage. Unfortunately, most of the previous proposed methods will not comply with recent IMO regulations which will apply in the next few years.

Selective Catalytic Reduction (SCR) system of NOx emissions using ammonia or urea has been used for many years in marine diesel applications. The ammonia SCR system was designed for about 92 % Nox reduction, the first unit was installed in 1989. Since that time numerous vessels have been fitted with various SCR (NOx reduction) systems, primarily in Europe, it has been successfully using SCR system on diesel engines burning low quality fuel oil with a sulfur content of 3.5 % [5/38].

4.3 (d) SOx emissions reduction technology

SOx emissions consider one of the most ship emissions harmful, especially in case of low quality liquid fuels; therefore many researchers were carried out to eliminate this effect. [47] showed that a reduction of SOx emissions can be achieved through mixing low quality liquid fuel (heavy fuel oil) with a certain type of oil, which produced from Waste Plastics (WPD). Unfortunately, applying of this strategy for large extent was difficult due some technical problems. This attempt followed by using of high quality liquid fuel oils. Two such fuels being discussed as substitutes for residual oil are marine gas oil (MGO) and marine diesel oil (MDO) [11]. But the use of acceptance low sulfur content diesel (LSD) oils is very costly, so CO_2 emissions will increase due to the required refining process. To overcome the harmful of SOx emissions and keeping the operating cost at the acceptable limit, seawater scrubbing system was used [6]. Applicability of such system may be restricted upon satisfactory resolution of the issue of its impact on water quality and ship operating cost [33].

4.3 (e) CO and CO_2 emissions

CO emissions reduction achieved through improving the process of fuel combustion inside the engines to insure the complete combustion process. Moreover, reduction of CO_2 will be achieved as a part of whole ship's emissions reduction technology [51/2].

Table [2] summarizes the average emissions reduction percentages as a result of using the mentioned and other emissions reduction technologies for marine diesel engines. From the table, it can be seen that the most effective way to reduce SOx emissions is to utilize a low – sulfur liquid fuel, and scrubber system, while the most effective technology for NOx reduction is SCR technology. Unfortunately, those methods are very expensive and lead to increase the ship annual operating cost.

5. CHOICE OF THE SUITABLE EMISSIONS REDUCTION METHOD

Ship type, power rating, economic issue, adaptability, and compliance with the current and future emission regulations are factors affecting choice of the suitable ship emissions reduction method. To evaluate the importance of applying certain emissions reduction, the present paper study effect of this factors in case of applying the previous methods onboard high speed passenger ships. Choice of high speed crafts is the matter of power rating which conjuncts directly with the amount of exhaust gas emitted from ships. Moreover, these ships call ports on more regular basis in short time compare to any other ships which make them more effect in the health of population at the areas near from ports. According to the nature of ships' operating and based on the previous researches, carried out by [20/15/33] using of alternative fuels and emission reduction technologies seem the most suitable methods to be applied for passenger ships, especially from the point of view of applicability.

6. STRATEGIES OF EMISSIONS REDUCTION FOR HIGH-SPEED CRAFTS AT THE RED SEA AREA

The Red Sea considers one of the importance tourist areas. A long costal of it lays at Egypt, has many commercial such as Safaga port and tourists ports such as Sharm El-Shekh and Hurgad port. By the end of current century the number of short-voyage passenger ships sailing in the Red Sea area has increased due to the increase of tourists and the depended of passengers for using the high speed craft instead of the conventional passenger ship for traveling from Egypt to Saudi Arabian and Vice versa. There is no doubt that these ships have contributed to develop maritime transport in this area. On the other hand, [50/51] shown that the high power of these ships contributed to the increasing gaseous emission rate and affect adversely on the environment in this area. The present paper discusses the viability of applying the mentioned two methods onboard two of the high-speed crafts operating in the Red Sea area, called AL- MTAHEDA and Al-Kahera. These ships operate between Safaga port in Egypt and Duba port in the Kingdom of Saudi Arabia. Ships' technical data are summarized as shown in Table (3).

6.1 APPLYING EMISSIONS REDUCTION TECHNOLOGIES

Environmentally, the quantity of ship's emissions (E) that could be reduced in case of installation SCR and sea water scrubber systems may be estimated from the following equation for both NOx and SOx emissions.

$$E = E_f \,.\, r_p \,.\, P \,.\, t_T \tag{3}$$

where, (E_f) is emission factor in (g/Kwh), (r_p) is emissions factor reduction percentage due to installation of SCR, and $(\boldsymbol{t_T})$ ship sailing time in (h).

On the other hand, the main draw-back of applying these systems is the additional annual costs. Economical, applying SCR system will show some extra costs including: Urea consumption (\$/ L. MWh), investment costs (\$/ MW) running costs (urea) (\$/MWh), and maintenance cost (\$/MWh). Moreover, the main component of the catalyst requires rebuilding depending on the type of fuel during operation. There is noticeable uncertainty concerning the time estimate; this study assumes a grim window of 5 years, these costs may be expressed as follows:

$$ACI = C_i \cdot \frac{i[1+i]^N}{[1+i]^N - 1} + F_C + \sum C_O + \sum C_M \qquad (4)$$

Where (C_i) is total capital installation cost, which depends on fuel sulfur content, (N) ship working years after installation, (i) interest percent, (C_O) annual maintenance cost in (\$/year), (F_C) fuel cost increment in case of using marine gas oil in (\$/year), (C_M) annual operating cost(\$/year). Take into consideration that the life time of SCR will depends on sulfur content.

6.2 APPLYING ALTERNATIVE FUELS

Discussion of using alternative fuels as a strategy for ship emissions reduction revealed that natural gas appears as the most common alternative fuel onboard ships. One of the most outcomes of applying this strategy is the environmental benefit, which may be quantified according to the amount of emissions reduction (ERQ) as follows:

$$ERQ = \left[L_{fDO} \cdot E_{fDO} - C_1 . L_{fNG} \cdot E_{fNG} + C_2 \cdot L_{fDO} \cdot E_{fDO} \right] P . t_T \qquad (5)$$

where, L_{fDO} *, and* E_{fDO}, are load factor, emission factor in case of diesel engines. So, L_{fNG} *, and* E_{fNG} are load factor, emission factor for natural gas , *while* C_1 *and* C_2 are percentage of diesel oil and natural gas in case of dual-fuel engines. It should be take into consideration that using of natural gas will be during sailing only. Factor emissions for diesel and dual-fuel natural gas engines can be illustrate as shown in table (4) [51].

Cost analysis of using natural gas, in form of LNG; instead of diesel oil onboard ships depends on some essential items, including: the present and future of diesel fuel prices trend, cost of conversion onboard diesel engine to dual-fuel engine, and the difference in maintenance, operation and bunkering costs. The annual saving or increment cost $[ACI]$ due to shifting to natural gas may be expressed as follows:

$$ACI = FSC + \sum SC_{M\&O} - C_A \cdot \frac{i[1+i]^N}{[1+i]^N - 1} - \Delta BC \qquad (6)$$

where, (C_A) the capital cost of conversion from diesel oil to dual-fueled engine, (FSC) the difference between fuel cost of diesel and natural gas, (ΔBC) is the difference cost between ship bunkering process of diesel oil and NG and$(SC_{M\&O})$ the difference between maintenance and operating cost of diesel and natural gas engines. Moreover, annual fuel cost difference (C) could be estimated as follows:

$$FSC = \left[sfc_{D.O} * fc_{D.O}\right] P * t_T - \left[C_1 * sfc_{LNG} * fc_{LNG} + C_2 * sfc_{D.O}\ fc_{D.O}\right] P * t_T \qquad (7)$$

where, $(sfc_{D.O})$, and $(fc_{D.O})$ are specific fuel consumption, and fuel cost of diesel fuel oil. (sfc_{LNG}), (fc_{LNG}), are specific fuel consumption, fuel cost in of case of dual-fuel. LNG fuel cost different from area to other worldwide, includes cost of production, liquefaction, logistic, and bunkering process. The fuel price, in 2013, was about 11–12 USD/mmBTU for LNG [30] and nearly 20 USD/mmBTU for marine diesel oil [14]. Figure (3) represents the environmental outcome due to apply the emissions reduction strategies for both vessels. It can be noticed that applying of those strategies will achieve nearly the same emission reduction regards NOx, SO_X, and P.M emissions by about 90%. On the other hand, LNG will achieve more CO_2 reduction and cause more HC emissions as shown in Figure (3). Economically, regarding vessel (2), all methods will be costly due to the fact that expected working years are few to apply such strategies. While, is case of vessel (1) using of SCR system with MGO fuel and sea water scrubbing system will increase the ship annual operating cost by about 35 and 45 \$/kW, respectively. On the other hand, saving of ships' annual operating cost by about 20 and 50 \$/kW can be achieved in case of using liquefied natural gas with and without adding conversion costs, respectively. Moreover, Figure (4) shows effect of ship's age regarding value of the annual required cost in case of conversion from diesel oil to natural gas fuelled engines.

7. CONCLUSION

Ship emissions reduction became one of the technical and economical challenges that facing the ships' operators. The present paper studied the different strategies that can be used to reduce those emissions. The strategies included: applying reduction technologies onboard, using of alternative fuels, and follows one of fuel saving strategies. Environmentally, regarding vessels (1) and (2), using of SCR and marine gas oil could be achieved more than 90% reduction of NOx, SOx, and PM emissions, while using of SCR and sea water scrubbing system appeared as the best method to achieve considerable percent of HC emissions. Economical, it was noticed that ship's age playing main role regarding this issue as applying any strategy will be costly for vessel (2). On the other hand, in case of vessel (1) applying of LNG strategy will achieve saving in annual ship operating cost. Conversely, both SCR with MGO and SCR with sea water scrubber systems will cause increasing of the annual ship operating cost.

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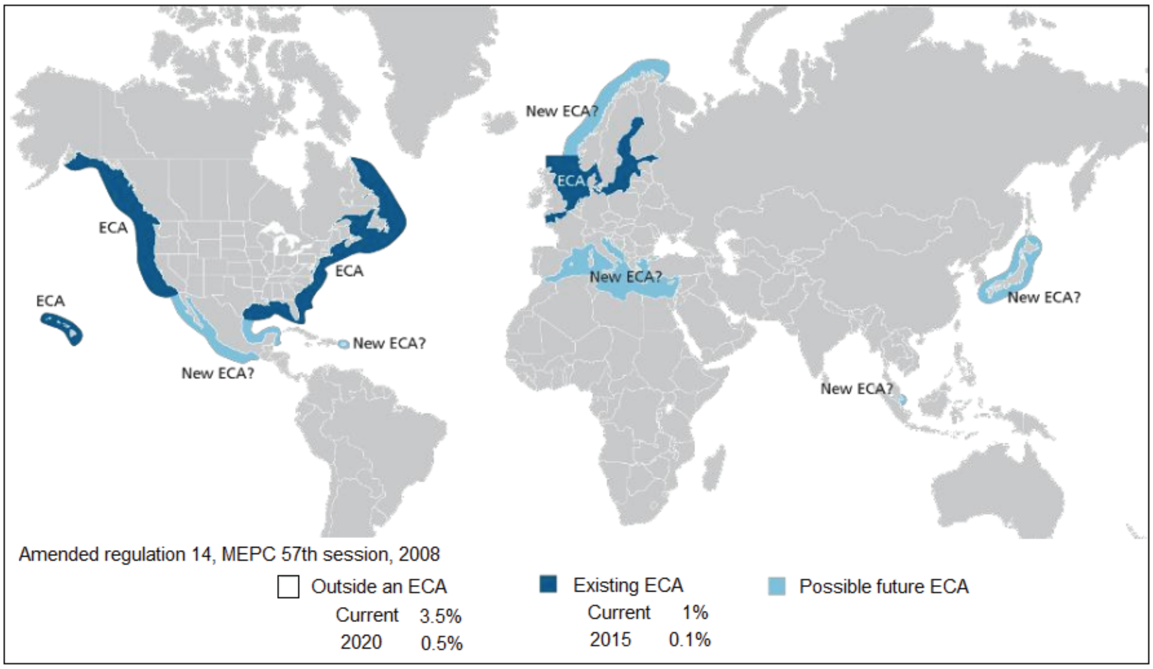

Figure (1) Permissible Sulfur content percentage

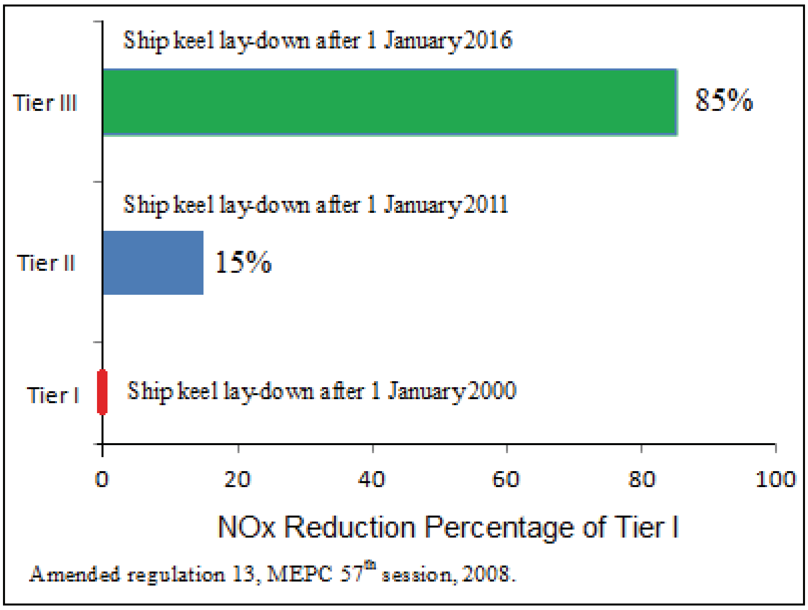

Figure (2) NOx Emissions Reduction Percentage

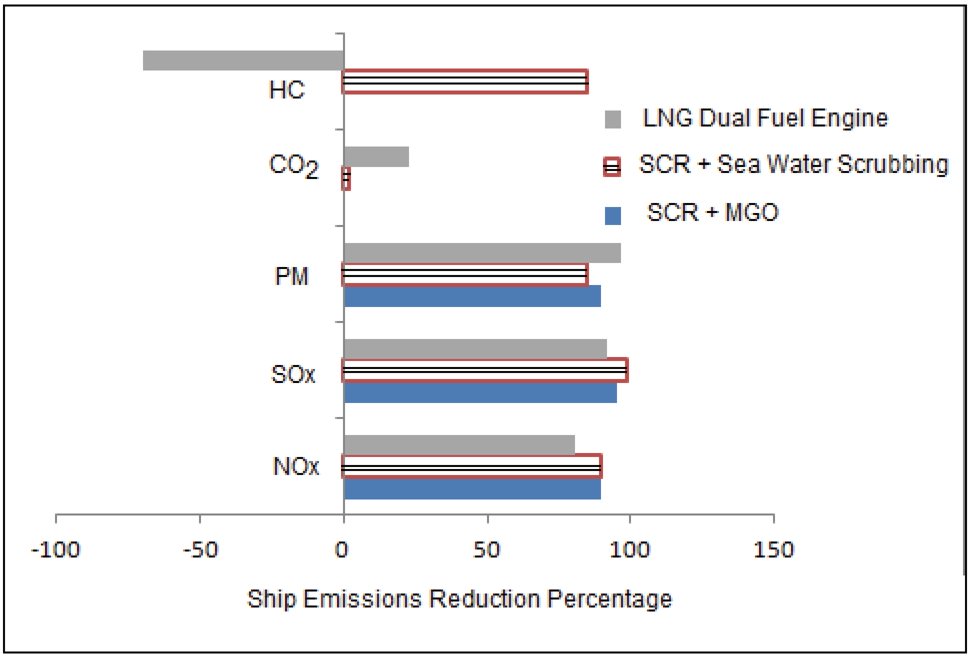

Figure (3) Ship's Emission Reduction @ various strategies

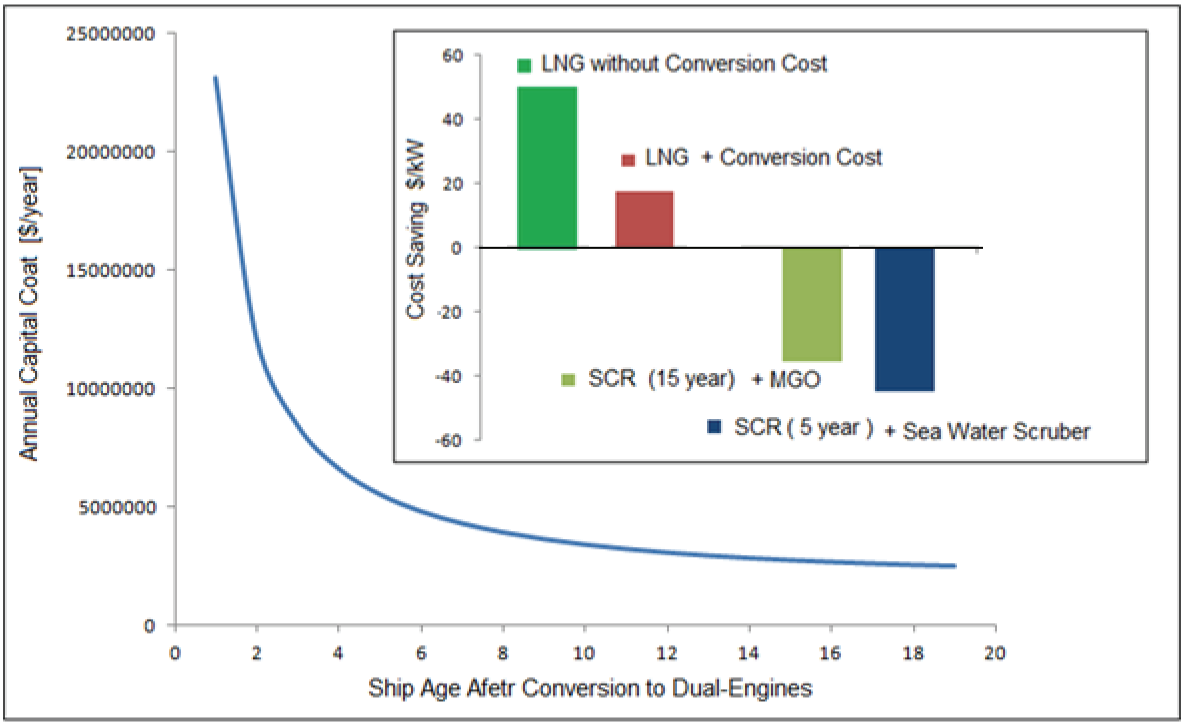

Figure (4) Ship's Cost saving @ various strategies

Table 1: Weighting matrix of alternative marine fuels

	LNG	Propane	Bio-diesel	Alcohol	F-T diesel	H_2
Renewability	Fairly good	Fairly good	Good	Very good	good	Excellent
Performance	Excellent	Very good	Very good	Good	Very good	Good
Cost	Excellent	Excellent	good	good	good	Fairly good
Adaptability	Excellent	Very good	Excellent	Good	excellent	Good
Availability	Very good	Very good	Very good	Very good	good	Excellent
Safety	Excellent	Very good	Excellent	Very good	excellent	Fairly good
Environmental Impact	Excellent	Very good	good	good	Very good	Excellent

Table 2: Available methods for reducing ship emissions [Buhaug, et al., 2009; EPA, 2009, Ariana, et al., 2006; and Woodyard, 2004]

Component	Reduction Method	Potential Reduction
NOx	Selective catalytic reduction (SCR)	95%
	Emulsification	20-25%
	Humid air	70%
	Engine tuning	50-60%
	Exhaust gas re-circulation	10-30%
SOx	Fuel Switching Process*	60-90%
	Sea water scrubbing Exhaust below water line	Up to 95%
CO_2	Energy Management	1-10%
PM	Electrostatic filters	Up to 85%

*Switching from residual fuel to distillate fuel

Table (3): Ships' main technical data

Specifications	Vessel (1)	Vessel (2)
Ship's Name	Al-kahera	Al-motaheda
Propulsion	Four steerable / reversing Water Jets	Four steerable / reversing Water Jets
Classification Society	Germanischer Lloyd (GL)	Germanischer Lloyd (GL)
Passengers	1200	600
Vehicle Capacities	120 Cars plus 15 x 15 tone trucks	Cars plus 15 x 15 tone trucks
Service Speed (90% MCR, fully loaded)	34 knots	36 Knots
Main Engines	4xMTU 20V 8000 M71R	4xMTU 20V1163TB73
Main Engine Fuel	1200 Lit/h @ MCR	1250 Lit/h @ MCR
Engine Power	4x7,200 kW @ 1,150 rpm ± 1.5%	4x6000Kw at 1250 R.P.M
Number of trips	200 per year	200 per year
Sailing & Maneuvering time	8 h per trip	8 h per trip
Expected working years	19	6

Table 4. Engines Emissions Factors

Engine Emission Factor [g/kWh]	CO_2	SOx	CO	NOx	PM_{10}	HC
Onboard Diesel Engine	698	2.562	1.68	13.43	0.55	0.53
Natural gas Dual-Fuel	553	0.2	0.597	2.59	0.015	0.901

