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Natural gas as an alternative fuel in marine steam turbine of AL-HAMRA LNG carrier

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Abstract

This paper discusses the economic benefits of using natural gas as a fuel with marine steam turbine as a propulsion option for LNG carriers benefiting the boil-off gas that occurs during loaded voyage. It also aims at studying the possibility of replacing the heavy fuel tanks of the ship with liquefied natural gas which is makes it possible to gain about 4% to the cargo. Several studies have referred to the possibility of using the natural gas as an alternative fuel to the heavy fuel of the ship in the marine engines. The current research study analyzes and discusses the performance of steam turbine engines when using the natural gas compared to the different kinds of marine fuel (Heavy fuel oil ,Marine gas oil) . The study has shown that the liquefied natural gas saves about 90% of the operation costs compared to the consumption rate on using the heavy fuel. The study has also shown the decrease of emissions of about 57%, (CO_2) with about 28% of carbon dioxide and it is void of the nitrogen oxides (NO_2). The fears increase about the harmful effects arising from the wide use of the traditional fossil fuel in the marine fields and the internal combustion engines in general. This leads to the huge amount of efforts to look for the development of alternative source and renewable energy sources

Keywords: *Natural gas, Emission etc.*

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1. Introduction

Marine fuel plays a key role in operation of power plants onboard ships [1]. Use of the conventional marine fuels as a source of energy for traditional marine power plant have been faced a lot of barriers due to its demerits especially regarding to the environmental and economic point of views[2]. Environmentally, several inventory studies suggested that in 2000, 15% of all global NOx emissions and 4-9% of global SO_2 emissions have been emitted around by ocean going ships. [3]

Marine conventional fuels are normally fossil fuels which contain large quantities of carbon and sulfur leading to increased harmful emissions along with nitrogen oxides resulting from the high temperature combustion of these hydrocarbon fuels [29]. Gaseous fuels such as natural gas, propane and hydrogen can be considered as alternatives to marine fuel. Not only are these fuels very low in sulfur content, but they also combust; thus, NOx, PM, and CO_2 emissions are also reduced. Furthermore, they can be carried in compressed or liquefied states. There is many researchers studied the possibility of using some of alternative fuels, mostly liquefied natural gas [4, 7, 11, 14, 16, 17, 22 and 38]. Moreover, other researches pointed out the feasibility of using other types of alternative fuels such as hydrogen [27, 28, 29, 30, and 31]. Global warming, the greenhouse effect, acid rain, end of conventional energy sources (i.e. fossil oil), fluctuation of conventional source of energy prices, increased population and increased energy consumption. These entire factors make it clear that it is a must to find out new sources of energy and alternative power plants. Some researchers studied the possibility of use renewable or green energy sources for special marine application [3, 32, 33, and 34]. The need for renewable or green energy sources, in addition to improving the efficiency of using current fossil fuels in the marine field, makes it necessary to replace or improve current fossil-fueled engines [35, 29].

2. Natural gas

Many studies have pointed to the possibility of using natural gas as an alternative fuel for marine power plants [7], experiences of natural gas 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 [8].

Natural gas is a gaseous fossil fuel that contains methane as its primary component. It is derived from organic matter that was deposited or buried under the earth, millions of years ago [9], it is a mixture of paraffinic hydrocarbons such as methane, ethane, propane and butane. Natural gas is a low-density and low-sulfur content fuel as compared to petroleum products and is practically free from carbon monoxide emission. Natural gas is converted to LNG by cooling it down to -162 C, at which it becomes a liquid, and this process reduces its volume by a factor of more than 600. Thus, natural gas has emerged as the most preferred fuel due to its inherently environmental benignity, greater efficiency and cost effectiveness [10].

Natural gas can be found in three forms on-board ships: Gas form, Liquid form (liquefied natural gas, LNG); compressed gas form (compressed natural gas). The shipping industry has known LNG decades as a bulk commodity transported by large LNG tankers around the world. Recently a number of forward –looking companies have been paving the way by pioneering the use of LNG as a fuel especially for ships engaged on regular coastal or short sea shipping services. It is believed that in 5- 10 years time the majority of ship contracted for short sea trades will use LNG as marine fuel oil [11,12].

From the view point of availability; In the last ten years the world production of natural gas shows annual increase of 3.2%, while the world consumption was 3.05%, refers that the sustainability of natural gas is greater than that of traditional liquid fuel (Diesel oil) [13], natural gas is well established as a major contributor to the world's energy needs due to its availability, it derived from raw gas from offshore or onshore field as a dry, light fraction and mainly comprise from methane and some ethane. It is available directly at the gas field itself, in pipeline systems, condensed into liquid as LNG or compressed as CNG. The NG has lower level of noxious emission, carbon dioxide (20% than standard diesel), good combustion Characteristics (its ignition temperature about 600°C), led to reduction in maintenance and longer interval of overhaul [14].

Table (1) Comparison between alternative fuel for marine use [16,17]

	Coal	F-T diesel	H_2	LNG
Availability	Good	Good	Excellent	Very good
Renewability	Fairly good	Good	Excellent	Fairly good
Safety	Excellent	Excellent	Fairly good	Excellent
Cost	Excellent	Good	Fairly good	Excellent
Adaptability	Good	Excellent	Good	Excellent
Performance	Good	Very good	Good	Excellent
Environmental Impact	Bad	Very good	Excellent	Excellent

The use of natural gas in internal combustion engines has been researched thoroughly to reach the optimum case in both engine performance and environmental impact. Both types of internal combustion engines were studied: the compression ignition and the spark ignition engines. All problems associated with the use of natural gas in these engines were dependent on the injection timing inside the engine cylinders and the cylinder geometry; accurate control is needed to avoid engine knocking and high-emission formation levels. Lean burn concepts also were investigated to reach low-emission conditions [4,15].

3. Boil off gas

Most of LNG carriers have the boil-off gas problem which takes place during storage, loading or discharging and the ship's voyage. LNG is stored in a liquid state at a temperature below its boiling temperature point and at atmospheric pressure. As a result of imperfect insulation, the heat enters the cargo tank during storage and transportation. So, a portion of LNG cargo evaporates gas which is called Boil-Off Gas (BOG) [18,19] The propulsion options for LNG carrier should be able to utilize boil-off gas (BOG) very safely and easily [20], The boil-off gas contains the methane gas which is lighter than air, when using it as a fuel and in case of leakage it will exit from ventilation hatch openings outside the engine room. So, it can be exploded when any flame approach to it [21]. There are many propulsion options applied in LNG carriers which can utilize the BOG as fuel like steam propulsion, dual fuel diesel electric (DFDE), gas turbine and two stroke slow speed diesel engine with gas injection [22,23], most of LNG carriers have the boil-off gas problem which occurs during storage, loading or discharging and the ship's voyage. LNG is kept in a liquid state at a temperature below its boiling temperature point and at atmospheric pressure. As a result of imperfect insulation the heat gets into the cargo tank during storage and transportation. So, a part of LNG cargo evaporates gas which is called Boil-Off Gas (BOG) The boil-off gas averages between 0.1- 0.15 % per day; LNG ships utilize the boil-off gas as fuel for the propulsion systems.However, the high fuel consumption of steam turbine with low thermal efficiency, in comparison with the low consumption of diesel engines with high thermal efficiency, consequences of their replacement. However for custody transfer purposes when precise calculation of the heating value and density is needed the specific qualities relied on actual component analysis must be used. During an ordinary sea voyage, heat is transferred to the LNG cargo via the cargo tank insulation, resulting in vaporization of part of the cargo, boil-off. [24].

There are four main ways for the BOG created during LNG storage and handling:

a. Releasing it to the atmosphere.
b. Flaring it.
c. Capturing it for utilization as gaseous fuel. (main point).
d. Capturing and re-liquefaction it, return to cargo [25].

Due to its cryogenic nature, LNG is continuously vaporized and lost as boil-off gas (BOG) during storage and transportation.The amount of BOG depends on the design and operating conditions of the LNG tanks and ships. In order to utilize the boil-off gas, calculation of BOG quantity must be carried out to the LNG vessels in order to know the loss of LNG during laden (loaded) voyage.

$$V = BOR * C \quad (1.1)$$

Where "V" is volume of boil off gas in m^3,"C"is cargo capacity in m^3

The mass of methane in boil-off gas is determined by following equation:

$$M = V * \rho\, LNG \quad (1.2)$$

Where "M" is mass of boil off gas in tonne, "V" is volume of boil off gas in m^3

By multiplying the rate of boil-off gas in tonne with the LNG carrier cargo capacity, the volume of BOG can be determined.

Firstly, according to AL-HAMRA LNG carrier with capacity 136357 m^3 and by applying the above equations it can be calculate the volume of BOG in cubic meter per day (m3/day). Secondly, by knowing the rate of BOG which is 0.15% the volume of BOG per day is 204.63m^3/day. Mass per day can be obtained which are 90 tonne/ day. The amount of BOG volume per day and the mass of methane in tonne per day with different voyage rout and different BOR. can be seen in figure 1

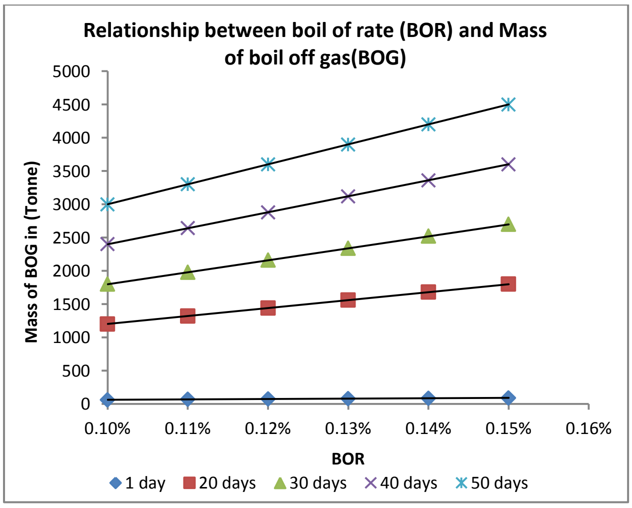

Figure 1 Relationship between Boil-off gas rate and Mass of Boil-of gas

Additionally, by knowing the LNG price which is 439.45 USD/ton of LNG. Therefore, by multiplying the mass of methane by 439.45 USD the cost of the lost LNG cargo can be obtained from the following equation:

$$The\ cost\ of\ BOG = BOG\ mass * LNG\ price \quad (1.3)$$

The BOG price per day which is lost from LNG cargo is 39551 USD per day for the capacity 136357 cubic meters, thus the loss of about 1,186,515 USD in one month and increases if increased voyage time.

4. Steam turbine

Steam turbine installation has dominated in LNG shipping so far. This is because it can easily handle the evaporated boil-off gas (BOG), in addition to its high reliability and maintainability. The boiler most commonly fires HFO and natural boil-off gas (N-BOG) [22, 26]. This study further assessed economic benefits of using the boil-off gas with the marine steam turbines for the liquefied natural gas carriers. Actually, the use of the BOG will greatly reduce the operating costs with about 90% provided that it is in its natural state where its density is 440 kg per m^3.

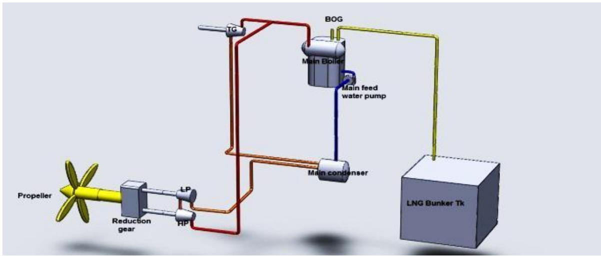

Figure 2 Steam plant for LNG Carrier of 150,000m^3. LP: Low pressure turbine; HP: high pressure turbine

5. Natural gas is the alternative fuel for the LNG Carriers

The marine fuel plays a key role in determining the performance of marine power plants onboard ships. A lot of studies have pointed to the possibility of using natural gas as an alternative fuel in propulsion system for LNG carriers. Moreover by increasing the number of LNG carriers worldwide and the growing of its capacity in the last decades, this had given the opportunity to increase the possibility of using natural gas as a main fuel taking into account advantage of evaporation process which occurs during the voyage for energy renewable.

Several previous studies have shown that the amount of boil-off gas which used as fuel to operate the boiler during a voyage could saves about 90% of the operational costs instead of using the heavy fuel oil. In this case, the boil-off gas could cover about 90% of the voyage and the remaining 10% could be taken from the LNG cargo that can be carried in the no longer used heavy fuel oil tanks. As long as the heavy fuel oil is replaced, there will be no need for the heavy fuel oil systems (i.e., transferring system, purification system, sludge tanks, etc.) which will tend to decrease the initial cost of the ship, added 4% to the LNG cargo and would also gain some benefit in terms of the ship speed due to reduction in ship weight.

This study has been performed on the ship Al-WAJBAH because of the unavailability of the capacity of the tanks on Al-HAMRA ship. We suppose that the capacity of the heavy fuels on Al-WAJBAH ship is 6259 m^3 is the same as on Al-HAMRA neglecting the difference between the design of the liquefied natural gas tanks and that of the heavy fuels. It is supposed that both have the same capacity.

Conclusion

• The natural gas can be successfully use as alternative to replace the currently used diesel fuels in the marine steam turbines. Also, the thermodynamic performance using the natural gas in the steam turbine cycle was found to be close to the performance when using heavy fuel oil or marine gas oil.

• The study showed that one of the main advantages of using natural gas with steam turbine is reduction in the value of specific fuel consumption is lower than that of heavy fuel by about 14.5% at the same power output and specific fuel consumption is lower than MGO by about 9.5 %.

• This feasibility study shows that it is environmentally feasible for ship owners to switch to LNG propulsion. This can be of great importance in reducing emission as well as contributing to a cleaner environment.

• Pollutant emission of NOx, CO_2, and SO_2 was reduced by 57 percent, 28 percent, 100 percent respectively when using NG as fuel.

• The cargo tanks are well insulated some quantities of boil off gas are produced due to heat in leak. Typical values are about 0.1 to 0.15 percent of the full contents per day, which over a 20 day voyage, becomes a significant amount. By calculating the BOG capacity of AL-HAMRA ship that the capacity 136357 cubic meters during the voyage which is equal to 1200 tonne when BOR 0.1 percent and was to be 1800 tonne when BOR 0.15 percent .

• By using BOG as fuel to be used for the propulsion system in the boilers in steam turbine plant which reduce operation cost with about 90 percent .

• Remaining 10% could be taken from the LNG cargo that can be carried in the no longer used heavy fuel oil tanks. As long as the heavy fuel oil is replaced, there will be no need for the heavy fuel oil systems (i.e., transferring system, purification system, sludge tanks, etc.) which will tend to decrease the initial cost of the ship, added 4% to the LNG cargo and would also gain some benefit in terms of the ship speed due to reduction in ship weight.

Reference

[1]. Seddiek I. S. , El Gohary M. M. , Ammar N. R. , (2015), The hydrogen-fuelled internal combustion engines for marine applications with a case study. Brodogradnja/Shipbilding, 66 (1), 23-38.

[2]. El Gohary M. M., Ammar N. R., Seddiek I. S., (2015), Steam and SOFC based reforming option of PEM fuel cells for marine application, Brodogradnja, Original scientific paper.

[3]. El Gohary MM, Seddiek IS, Salem AM, (2014b). Overview of alternative fuels with emphasis on the potential of liquefied natural gas as future marine fuel. Proceeding of the Institute of Mechanical Engineering, Part M: Journal of Engineering For the Maritime Environment (Proc. IMechE), 228, 1-11. DOI.

[4]. El Gohary MM, Welaya YMA, Saad AA, (2014). The use of hydrogen as a fuel for inland waterway units. Journal of Marine Science and Application,13(2), 212-217.

[5]. Banawan A. , Elgohary M. M. , Saddak I , (2010), Environmental and economical benefits of changing from marine diesel oil to natural gas fuel for short-voyage high power passenger ships. Journal of Engineering for the Maritime Environment, SAGE, 224(2), 103-113.

[6]. Elgohary, M. M., & Seddiek, I. S. (2012). Comparison between Natural Gas and Diesel Fuel Oil Onboard Gas Turbine Powered Ships. Journal of King Abdulaziz University, 23(2), 109.

[7]. El Gohary, M. M., & Seddiek, I. S. (2013). Utilization of alternative marine fuels for gas turbine power plant onboard ships. International Journal of Naval Architecture and Ocean Engineering, 5(1), 21-32.

[8]. Elgohary M.M. , Hemida K. , (2015). The future role of natural gas in Saudi Arabia, International Journal of Multidisciplinary and Current Research,Vol.3, ISSN: 2321-3124.

[9]. Radwan A, Morsy M and Elbadan A., (2007). Economical and environmental advantages of using NG as a fuel in inland water transport. In: 25th CIMAC conference, CIMAC. International Council on Combustion Engines: Vienna, paper no. 114.

[10]. El-Gohary, M. M. (2012). The future of natural gas as a fuel in marine gas turbine for LNG carriers. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, 1475090212441444.

[11]. El Gohary M. M. , Ammar N. R., (2016), Thermodynamic Analysis of Alternative Marine Fuels for Marine Gas Turbine Power Plants J. Marine Sci. Appl. (2016) 15: 95-103 DOI: 10.1007/s11804-016-1346-x

[12]. El Gohary M. M. , (2013), Environmental analysis of present and future fuels in 2D simple model marine gas turbines, International Journal of Naval Architecture and Ocean Engineering.

[13]. El-Gohary M.M. , EL-Sherif H.A. , (2006). Future of hydrogen as green energy in marine applications, 9th World Renewable Energy Congress, Florence Italy,360-366.

[14]. El Gohary MM ,(2009), Design of marine hydrogen internal combustion engine. Alexandria Engineering Journal, 48(1),57-65, January.

[15]. Welaya Y. M. , El Gohary M. M. , Ammar N. R. , (2012) , Steam and partial oxidation reforming options for hydrogen production from fossil fuels for PEM fuel cells, Alexandria Engineering Journal.

[16]. El Gohary MM, Naguib A, Ammar NR, (2008). Evaluation of applying fuel cell technology in Nile floating hotels . 7th International Conference on Role of Engineering towards a Better Environment (Global Environmental Changes: Challenges and Opportunities), Alexandria, Egypt, 20-33.

[17]. El Gohary M. M. , Banawan A. , Gasser M. H. , (2014), Marine applications of Fuel Cell as alternative power plant: Case study, International Marine and Offshore Engineering Conference.

[18]. El Gohary M. M., (2013), Economical analysis of combined fuel cell generators and absorption chillers, Alexandria Engineering Journal.

[19]. Welaya Y. M. , El Gohary M. M. , Ammar N. R. , (2011), A comparison between fuel cells and other alternatives for marine electric power generation, International Journal of Naval Architecture and Ocean Engineering.

[20]. Osberg, T. G., (2008), Gas fuelled engine applications in ships – an overview. In Where industry and technology meet, Proceedings of the SNAME Annual Meeting and EXPO, Houston, Texas, USA, paper 026 (Society of Naval Architects and Marine Engineers, Jersey City, New Jersey).

[21]. Astbury, G.R., (2008). A review of the properties and hazards of some alternative fuels. Process Safety and Environment Protection Journal, 86(6), pp.397-414.

[22]. Kumar S, Kwon HT, Choi KH, et al, (2011). LNG: an eco-friendly cryogenic fuel for sustainable development. Appl Energ; 88(12): 4264–4273.

[23]. Magalog, (2008). LNG a clean fuel for ship. Newspaper, [online] Available at: <http://www.eu-magalog.eu/ uploads/media/Magalog_News_01_en.pdf> [Accessed 5 September 2011].

[24]. Bp, (2011). Statistical review of world energy. [online] Available at: <www.bp.com/.../ bp.../statistical_energy_ review.../statistical_review_of_world_energy_full_ report_2011.pdf> [Accessed 10 February 2011].

[25]. El-Gohary MM., (2013) Overview of past, present and future marine power plants. J Mar Sci Appl; 12: 219–227 DOI: 10.1007/s11804-013-1188-8.

[26]. Dobrota D., Lalid B., Komar I., (2013). Problem of Boil - off in LNG Supply Chain, University of Split, Faculty of Maritime Studies, Zrinsko-Frankopanska, Split, Croatia.

[27]. Bahgat W., (2015). Proposed method for dealing with boil off gas on board LNG carriers during loaded passage, Vol.3, ISSN: 2321-3124.

[28]. Namba N, (2003). Transportation of clean energy at Sea-Mitsubishi LNG carrier, at present and in future. Mitsubishi Heavy Industries Ltd, Technical Review: pp.1–6.

[29]. Cusdin, D. R., (1998). The development of Liquefied Natural Gas Carriers– a marine engineering success, The Institute of Marine Engineers, London.

[30]. Sinha R. P. and Norsani W. M. Wan Nik, (2011). Investigation of propulsion system for large LNG ships", 1st International Conference on Mechanical Engineering Research.

[31]. Tusiani M., Shearer G. , (2007). LNG a nontechnical guide book, United State.

[32]. Lawell D., Wang H. , (2013) Assessment of the fuel cycle impact of liquefied natural gas as used in international shipping. The international council on clean transportation, United State.

[33]. Kuver, (2002). Evaluation of propulsion options for LNG carriers. In: GASTECH, Germany.