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APPLICATION OF HTFC POWERED BY LNG ON A CRUISE SHIP: A CASE STUDY

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***Abstract* - The work is a case study of a cruise ship supplied by LNG and equipped with a solid oxide fuel cell. It is considered that 5x200 kW SOFC systems integrated with gas turbines are installed onboard assisting a dual fuel diesel/LNG engine to generate 10 MW during the stay in port time. The cruise ship spends almost 12 hour per day in ports thus contributing significantly to the local environmental pollution. Results indicate that the use of SOFC system allows both to save about 6.75% of LNG, in comparison to the dual fuel engine, and to reduce emissions of SO_x, CO, NO_x, PM by about 10% and CO_2 by 5.3%.**

***Index Terms* – Cruise ships, Emissions, GNL, SOFC.**

I. INTRODUCTION

Marine sector contributes to the global emissions of greenhouse gases (GHGs) and other hazardous air pollutants approximately for an amount of 5% [1]. It is subordinated to the current stringent international environmental standards as well, forcing to search alternative fuels and new technologies with lower environmental impact.

There are several fuels or energy carriers that can be used in shipping among which Liquefied Natural Gas (LNG) is one of the most commonly considered today. The use of LNG allows to reduce both 25% of carbon dioxide and a remarkably amount of sulfur oxides emissions (SO_x) in comparison to traditional marine Diesel oil fuel [2].

Nevertheless, using the traditional endothermic engines with LNG could not satisfy the environmental requirements, therefore alternative technologies are being sought. Among these, the use of Fuel Cell technology (FC) seems to be very promising [3].

Considering a vessel supplied by LNG, the use of High Temperature FCs (HTFCs) is more suitable than low temperature FCs since they can be powered directly by LNG, with no complex fuel treatment system and allowing higher efficiencies if used in cogenerative configurations [4].

Nowadays, it possible to find several commercial Solid Oxide FCs (SOFCs) products offering attractive potentials for electrical generation in centralized and distributed applications. The SOFC is the simplest and most rugged among all FCs covering wide power ranges (up to few MW) and with very long lifetimes (up to 60000 h) [5].

According to this, the present study considers a case of a cruise ship supplied by LNG and equipped with SOFC modules integrated with gas turbines (GT), assisting the dual fuel diesel/LNG (DF) engine to generate electricity on board during the stay in port of the ship. The aim is to predict the CO_2, CO, SO_x, NO_x and particulate matter (PM) emissions of the SOFC system in the harbors compared to the DF engine. The fuel consumption has been estimated and compared as well.

II. METHODS

A. General layout of the cruise ship

Main characteristics of the cruise ship are summarized in Table I.

TABLE I
Main cruise ship characteristics

Passengers	6600 + 2035 crew members
Main dimension (m)	Length: 350-360; Breadth: 40-45; Height: 50-60
Design draught (m)	7.74
Decks	18
Cruise speed (kn)	19 (maximum: 21)
Autonomy	10 days
Propulsion	Double propeller with gas engines
Fueling	A complete fuel gas handling system for LNG fueled ships.
Maximum power (MW)	62.2

The propulsion power and the electrical power production are provided by four Wartsila Dual fuel diesel/LNG engines (model: 18V50DF) with a nominal power of 17.55 MW at 60 Hz.

Emission factors of such engine are estimated from data reported in recent literature [6], considering average values. It must be noted that we considered only the data of DF engines with emissions that respect the IMO tier II regulations [7].

B. Solid Oxide Fuel Cell

Technical data and emission factors are taken from some commercial SOFC-GT products sold by worldwide companies, such as Mitsubishi Hitachi Power Systems (Japan), BloomEnergy (USA), Convion (Finland), SunFire GmbH, (Germany), Elcogen (Estonia), etc., and considered in average values.

It is assumed that the SOFC is integrated with a GT in order to generate more electric energy allowing an increase of the efficiency from 57% to 85%.

C. Case Study

The cruise ship stays in port 12 hours per day requiring about 10 MW. Generally, the primary engines supply this power demand. In this case study we assumed that 9 MW are provided by a single DF engine, working with an efficiency of roughly estimated at 20%, and 1 MW by five SOFC-GT modules of 200 kW fueled by GNL.

III. Result

Emissions factors both for the DF and SOFC-GT have been evaluated and reported in Table II.

TABLE II
Dual fuel Diesel/LNG engine (DF) and SOFC-GT emission factors

Emissions	Unit	Value	
		DF	SOFC-GT
SO_x	mg/kWh	32 ± 17	negligible
NO_x	mg/kWh	7000 ± 2100	4.8 ± 0.2
CO	mg/kWh	15000 ± 4230	2.1 ± 0.1
PM	mg/kWh	175 ± 108	negligible
CO_2	g/kWh	725 ± 234	343 ± 37

As expected, it resulted that the DF engine has NOx, CO emissions significantly higher than SOFC-GT system. Any appreciable emissions of SOx and PM are found for the SOFC-GT. CO_2 emission of SOFC-GT is lower than DF due to the higher efficiency of the SOFC.

Emissions in port of SOFC-GT system have been calculated and compared to those of DF. As expected, it results that the SOFC-GT emissions are lower and this allows to reduce the global emission of the cruise ship in port by the values reported in Table III.

LNG consumption of the SOFC-GT system, during the stay in port of the cruise ship, is estimated to 8 L/day. At the same time, the DF engine consumes about 94 L/day of LNG to generate a power of 9 MW for 12 hours. It means that in this case it is possible to save about 6.75 % producing 10 MW with such hybrid configuration.

TABLE III
Emissions reduction by using a SOFC-GT system

Emissions	Reduction, %
SO_x	10
NO_x	9.99
CO	10
PM	10
CO_2	5.27

IV. Conclusion

It has been presented a case study of a cruise ship supplied by LNG working with a hybrid configuration made by a SOFC-GT system and a DF engine during the stay in port of the ship. A preliminary evaluation of the emissions and fuel consumptions in the port have been carried out both for the SOFC-GT and DF. It resulted that such a configuration allows to reduce the CO, SOx, NOx and PM emission by 10% and CO_2 by 5.27 %. In addition, about 6.75 % (8 L/day) of LNG is saved.

Favoring the introduction of high temperature fuel cell technology (SOFC) in cruising sector can contribute to respect the more and more stringent environmental regulations.

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