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COMPARISON OF DIFFERENT PLANT LAYOUTS AND ENGINEERING SOLUTIONS FOR FUEL CELLS UTILIZATION ON A SMALL FERRY

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***Abstract* – In the present study, a process simulation model is implemented to compare different plant layouts to be installed on board of a ferry. Liquid Natural Gas (LNG), hydrogen (H_2) and ammonia (NH_3) have been considered as alternative fuels for power generation plants based on Internal Combustion Engines (ICE) and Polymer Electrolyte Membrane (PEM) fuel cells. Results show overall system efficiency, emissions and fuel volume in comparison with a traditional Internal Combustion Engine (ICE) fuelled by Marine Diesel Oil (MDO) with Selective Catalytic reduction (SCR).**

***Index Terms* – fuel cells, LNG, marine propulsion, ship emissions.**

I. INTRODUCTION

International Maritime Organization (IMO) and other bodies are making growing efforts to impose severe limits on shipping pollution especially for vessels, whose routes are concentrated in coastal areas [1]. For this reason, ship-owners are looking for different technologies to be used on ships in order to reduce emissions. It has already been demonstrated [2] that the use of different fuels such as Liquefied Natural Gas (LNG) is an interesting alternative to expansive and bulky exhaust gases after-treatment equipment or fuels with low sulphur content. Among the possible alternative energy systems, fuel cells are currently considered one of the promising solutions for power generation on board of vessels [3], even though the lack of specific certification on their application on board is still the main issue for a large-scale application on a large scale.

In the present study, a process simulation model is utilized to evaluate, at a preliminary stage, different power generation systems on board of a ferry in terms of conversion efficiency, pollutant and greenhouse gases emissions and tank size variation due to different fuels considered.

II. METHODOLOGY

The ferry considered in the simulations is a typical car and passenger ferry with an installed power of 1.5 MW that operates about 30 travels per day. Auxiliary power is considered 75 kW. The ship operating profile is implemented in the built up simulation model through the definition of three different operating conditions:

- Harbour phase: 60 % of time; power demand of 75 kW (auxiliary power);
- Manoeuvring phase: 12% of time; power demand of 1350 kW (propulsion and auxiliary power);
- Cruise phase: 28 % of the time; power demand of 765 kW (propulsion and auxiliary power).

Different power generation systems have been evaluated to cover both propulsion and auxiliary power demand during the day. A traditional Marine Diesel Oil Internal Combustion Engine (MDO-ICE) generation plant with Selective Catalytic Reduction (SCR) is taken as reference plant for comparative analysis with alternative fuels and power generation systems. The maximum efficiency for traditional MDO-ICE is considered 39 % [4]. Other generation systems included in the calculations are based on Polymer Electrolyte Membrane fuel cells (PEMFC) and Internal Combustion Engines (ICE). Logistic fuels considered for PEMFC are LNG, ammonia (NH_3), and hydrogen (H_2). Both compressed hydrogen (CH_2) and liquid hydrogen (LH_2) storage solutions are evaluated. ICE plants solutions are considered fuelled by LNG and ammonia-hydrogen mixture with 5% content of H_2 in mass [5]. Efficiencies of the considered ICE and PEMFC at different load conditions are based on commercial products datasheet[6][7]. If PEMFC utilizes a logistic fuel different from hydrogen, a fuel-processing unit is needed to produce H_2. If LNG is the hydrogen carrier, an efficiency of 78 % is considered for the LNG reformer [8]. If NH_3 is considered, an efficiency of 76 % is set for the cracking unit [9].

Systems overall conversion efficiency, emissions and required fuel volume are calculated.

III. RESULTS

As shown in Fig.1, overall system conversion efficiency appears to be the highest for PEM fuel cells generation systems ran by hydrogen, due to the better response of fuel cell systems at partial load operation. When LNG or ammonia feed fuel cells, the fuel-processing units

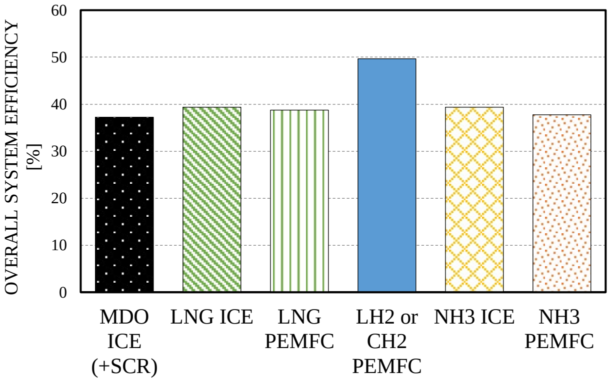

Fig. 1. Comparison of overall conversion efficiencies of different generation systems.

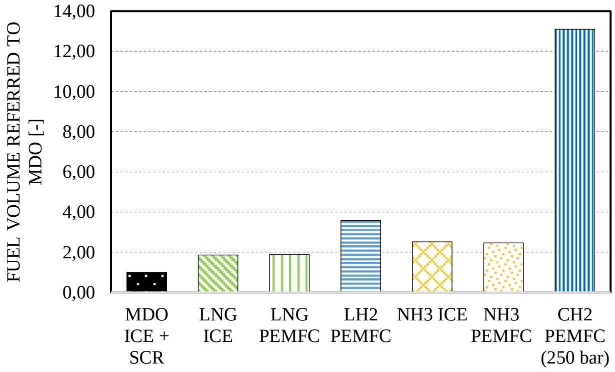

Fig. 3. Volume required by the fuel for different generation systems under consideration.

(reformer for LNG or cracker for ammonia) are responsible for significant decrease in overall efficiency. Local pollutant and greenhouse gases emissions are zero for fuel cells systems fed by hydrogen and ammonia, and therefore are not reported in Fig. 2. If PEMFC are fed by LNG there are carbon dioxide (CO_2) emissions due to the reforming process. ICE fuelled by ammonia-hydrogen mixture and LNG presents lower CO_2, sulphur oxides (SO_x) and particulate matter (PM) emissions than the MDO case, however an emission abatement system (for example SCR) should be applied to decrease nitrogen oxide emissions (NO_x).

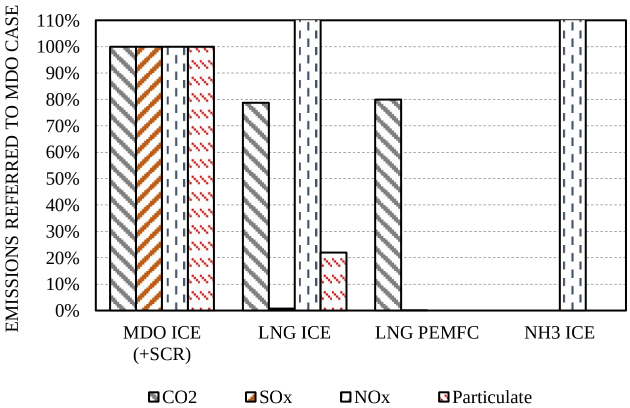

Fig. 2. Comparison of pollutant emissions and carbon dioxide emissions from different generation systems, with reference to emission factors in [5] [10].

Fig. 3 shows alternative fuels volume requirements with reference to MDO case. Compressed hydrogen storage is the most critical, requiring approximately 14 times the space needed by MDO.

IV. Conclusions

The use of fuel cells based generation systems on ferries has the potential to reduce emissions and to improve the average system efficiency, especially for ships where engines often operate in transient conditions and at part loads. A downside of alternative fuels is the fuel volume, especially for hydrogen. However, this aspect needs further investigations to determine the effective useful cargo volume reduction by taking into account the overall power generation system volume. Ammonia could represent an interesting solution, even though the low technology maturity and the ammonia toxicity limit its implementation in the near future.

The research will continue taking into account different alternative fuels and hydrogen carriers, such as Liquid Organic Hydrogen Carriers (LOHC) and Methanol. Other aspects, like safety, thermal optimization and optimization of fuel volume as function of the specific ferry route are also essential to complete the present study.

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