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Conceptual design of offshore platform supply vessel based on hybrid diesel generator-fuel cell power plant

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HIGHLIGHTS

- Conceptual design of PSV ship with hybrid diesel electric-FC power plant is presented.
- Two methanol-fed 250 kW SOFC systems are installed on board with 21 days autonomy.
- Cogeneration heat from SOFC allows answering hot water needs on board.
- Optimized hull design allows sailing with SOFCs and only one diesel generator.
- At *ECO-Speed* operation mode pollutant emissions are notably reduced.

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ABSTRACT

Nowadays increasing fuel prices and upcoming pollutant emission regulations are becoming a growing concern for the shipping industry worldwide. While fuel prices will keep rising in future years, the new International Convention for the Prevention of Pollution from Ships (MARPOL) and Sulphur Emissions Control Areas (SECA) regulations will forbid ships to use heavy fuel oils at certain situations. To fulfil with these regulations, the next step in the marine shipping business will comprise the use of cleaner fuels on board as well as developing new propulsion concept. In this work a new conceptual marine propulsion system is developed, based on the integration of diesel generators with fuel cells in a 2850 metric tonne of deadweight platform supply vessel. The efficiency of the two 250 kW methanol-fed Solid Oxide Fuel Cell (SOFC) system installed on board combined with the hydro dynamically optimized design of the hull of the ship will allow the ship to successfully operate at certain modes of operation while notably reduce the pollutant emissions to the atmosphere. Besides the cogeneration heat obtained from the fuel cell system will be used to answer different heating needs on board the vessel.

1. Introduction

Currently, important consideration is given to the environment and renewable energies with a view to promoting a cleaner world. It is known that the global energy availability and sustainable development is a big challenge and big efforts have to be undertaken in all energy consumption sectors, being the shipping industry one of the most urged to addressing changes in order to comply with upcoming pollutant emissions regulations. Thus the new International Convention for the Prevention of Pollution from Ships (MARPOL) and Sulphur Emissions Control Areas (SECA) regulations [1,2] will forbid ships to use heavy fuel oils at certain situations. At the same time, given the concerns for high oil prices and fossil fuel depletion, ship owners and operators are looking for different ways of generating power on board. As a result, the shipping industry is promoting the use of cleaner fuels on board [3] as well as developing new propulsion concepts, as the fully electric powered ship, or All-Electric Ship [4,5]. Within this context, several countries and companies have begun to focus on a new horizon not yet sufficiently explored: the installation of fuel cells on board ships [6–9]. Fuel cells could eventually represent a major advance in the shipping business as they have higher efficiency than traditional internal combustion engines, allow flexibility of fuel utilization, show low or zero emissions and operate with low vibration and noise level.

The use of fuel cells in *surface vessels* is still fairly innovative and therefore, currently remains at the Research, Development & Demonstration stage [7–9]. In respect of surface ships, Polymer Electrolyte Membrane (PEMFC), Phosphoric Acid (PAFC), Molten Carbonate (MCFC) and Solid Oxide (SOFC) Fuel Cells can be suitable to be installed on board. Suitability will depend, on one hand, on the characteristics and fuel used by the fuel cell under consideration and, on the other hand, on power consumption on board.

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Operating temperature of these fuel cells ranges from 80 °C (PEMFC) to 850 °C (SOFC) and efficiency varies from 40% to 85%. This last value corresponds to the case of high temperature fuel cells (MCFC and SOFC) using cogeneration, i.e., combining heat and power (CHP) production. On board, fuel cells can be used for the following:

– Auxiliary Power Units (APUs).
– Small scale power generation.
– Main propulsion system for boats and small vessels.
– Low power propulsion in special modes of operation of large vessels.
– Hot water/vapour generation when CHP is possible.

Fuel availability represents an important issue to be taken into account and fuel cells can use either hydrogen or gases with a high content in hydrogen, such as methane and liquid hydrocarbons, or alcohols, such as methanol. When fuels other than hydrogen are used, incorporation of a reforming process is required in many cases.

The power consumption on board surface ships ranges from a few hundred kilowatts to more than one hundred megawatts. Therefore, adequacy of a fuel cell type to be installed on board, fed with a specific fuel, must be assessed taking into account the characteristics and specifications of the vessel under consideration. Moreover, it can be said that in general and contrary to that occurs with small surface vessels (low power surface ships), PEMFC and PAFC are ideal for cargo ships that transport hydrogen, but they are not considered so suitable for other types due to hydrogen's low volumetric energy density and the fact that it involves installing enormous storage tanks that can only offer limited autonomy. For this reason, in addition to the difficulties of obtaining it in harbours, hydrogen may not always be a good choice as a fuel for large surface vessels (high power surface ships), and other alternatives should be considered [9].

Regarding fuel cells installed on board surface ships, a variety of marine fuel cell demonstration projects are currently in development or have been launched in recent years [7–9]. Within the *small surface vessels* category, PEMFC fuel cells are the most commonly used. Two examples of small surface vessels, one in operation and the other under study, are to be mentioned here. Thus, the Zemships project [10] developed the Alsterwasser, a 100-passengers boat which sails the waters of the river Alster in Hamburg since 2008. It carries a hybrid propulsion plant consisting of a battery and two 48 kW PEM fuel cells with hydrogen storage at 350 bar [11]. Not yet going into service, the Hydrogen Hybrid Harbour Tug (HHHT) project [12] is developing the Green Tug, an 85 metric tonne of dead weight tug equipped with hybrid fuel cell/diesel power plant. Two 100 kW PEMFC fed with hydrogen stored at 430 bar are intended to be installed on board, so that it is expected a higher efficiency and substantial reduction in emissions, SO_x and NO_x by 90% and CO_2 by 50%. The vessel will use fuel cells for standby, fuel cells and batteries for deployment and transit, and fuel cells, batteries and diesel generators (gensets) for ship assistance operations. Sailing in green mode, the vessel will achieve zero emissions.

When projects devoted to *large surface vessels* are examined, the use of a variety of fuels and fuel cell types becomes evident [8,9]. Two significant projects are mentioned here. In 2009, in the frame of the FellowSHIP project [13], the Viking Lady, a 5900 metric tonne of dead weight offshore supply vessel [14], started serving in oil platforms in the North Sea with high-temperature MCFC (550–700 °C) fed by liquefied natural gas (LNG) to generate part of the energy used on board. It is worth to mention that the power needs of supply vessels range from about 2 to 5 MW. Four diesel engines are used for main propulsion. The 320 kW MCFC fuel cell installed on board, which works together with batteries, is able to generate electrical power for the ship but only to operate at low speed and low power, the appropriate conditions for use in port. This feature is of capital interest because the vessel is designed to sail in the North Sea, where there are strict regulations on exhaust emissions. Through this project it was determined that not only a decrease in CO_2 emissions can be achieved, but that NO_x emissions are decreased by 180 tons. A decrease in fuel consumption has also been observed. Nevertheless no information on cogeneration (CHP) features concerning this project is given. Another important project concerning large surface vessels is the METHAPU project [15] whose main objective consists on validating the use of methanol as a marine fuel. An APU [16] for commercial vessels, based on a 20 kW methanol-fed SOFC fuel cell, has been developed by Wärtsilä and demonstrated on board a Walennius Wilhemsen car carrier, Undine, in 2010. Emissions reduction has been demonstrated, with no CO or SO_2, low NO_x and 40% of CO_2 reduction. As a consequence, higher power SOFC systems for marine applications are currently being developed. Therefore, SOFC fuel cells, which are high temperature fuel cells operating at 650–850 °C with possibility of cogeneration, is another type of fuel cell to be considered for use on large ships, not simply as APU systems but as part of their power plant.

Then, this work presents the conceptual design of a large surface ship, the so called *Balmat* offshore supply vessel, Fig. 1, with an innovative hybrid power plant based on heat engines and high temperature SOFC fuel cells using methanol as a fuel. The ship, a 2850 metric tonne of dead weight platform supply vessel, incorporates two fuel cell systems of 250 kW each, taken at the stage of conceptual design also. In this project, SOFC fuel cells are incorporated to the power plant supplying 500 kW, not as an APU system, and in a certain mode of operation the electrical power from the fuel cell system represent about 20% of the vessel's needs. Calculations to estimate the heating needs on board have also been performed verifying that cogeneration heat obtained from the high temperature fuel cells installed can satisfy such demand. To make this project come true, the shapes of most offshore vessels built up to date have been considered in order to calculate and optimize the *Balmat* shapes and properly integrate the fuel cell units within the ship. This new configuration provides the ship with an electric propulsion system that gives her a high manoeuvrability while in operation and a lower fuel consumption, as well as less environmental impact as she is able, based on her hydrodynamic optimized hull shapes, to sail inside an offshore platform park by means of the power output generated by the fuel cells and only one diesel generator. To develop this work the latest rules and regulations, applicable to marine fuel cell installations have been taken into account [17].

Therefore, it can be claimed that this new concept of offshore supply vessel represents an improvement of knowledge in naval architecture as much as in the application and generation of energy, based on the integration of fuel cells on the power system, which represents the first steps of a technological breakthrough that will be part of future developments in the shipbuilding industry.

2. Ship's main particulars

2.1. Ship chosen to integrate the fuel cell system

Prior to the design of integration of the fuel cell system an important decision had to be made: what type of vessel would be the right candidate to integrate the fuel cell system? The answer is mainly subject to the dimensions of the fuel cell system and to its power output. An easy solution could be to integrate the fuel cell system in large vessels as tankers or ferries. However the amount of electrical power needed on board is so important that adding fuel cells to the system would not make a relevant