A proposal on SOFC-PEMFC combined system for maritime applications

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Abstract : *Maritime transportation is going to transfer to alternative fuels as a result of the worldwide demands toward decarbonization and tougher maritime emissions regulations. Methanol is considered as a potential marine fuel, which has the ability to reduce SOx and CO_2 emissions, reduce climate change effects, and achieve the objective of green shipping. This work proposes and combines the innovative combination system of direct methanol solid oxide fuel cells (SOFC), proton exchange membrane fuel cells (PEMFC), gas turbines (GT), and organic Rankine cycles (ORC) for maritime vessels. The system's primary power source is the SOFC, while the GT and PEMFC use the waste heat from the SOFC to generate useful power and improve the system's ability to use waste heat. Each component's thermodynamics model and the combined system's model are established and examined. The multigeneration system's energy and exergy efficiency are 76.2% and 30.3%, respectively. When compared to a SOFC stand-alone system, the energy efficiency of the GT and PEMFC system is increased by 19.2%. The use of PEMFC linked SOFC has significant efficiency when a ship is being started or maneuvered and a quick response from the power and propulsion plant is required.*

Key words : *Methanol, SOFC, PEMFC, Combined system, waste heat recovery, thermodynamics*

1. Motivation

In response to global warming and environmental issues, the International Maritime Organization has adopted mandatory measures to control airborne emissions and GHG effects including IMO 2020, MARPOL Annex VI, etc. Those forced researchers and manufacturers to the alternative fuel source with low-or zero-carbon content. Among the possible alternative fuel, methanol is lighting as a promising fuel owing to its high hydrogen content, minimizing SO_x, CO_2 emissions leading to reducing climate change toward a green shipping future [1].

Methanol fuel cells are taking the attention of industry owing its advantages over internal combustion engines [2] such as high efficiency, less noise, reduced air pollution, etc. Depending on the types and operating temperature, methanol will determine whether fed to them directly or indirectly. This study is to propose a methanol SOFC-PEMFC-GT-ORC combined system with the aim of smoothly powered vessels, especially in the start-up and manuvering period and adaptive to the high requirement of environment protection from IMO.

2. System Description

A conventional cargo ship with a 3800 kW electric propulsion system was chosen as the case study.

Figure 1 depicts the designation of SOFC – GT – PEMFC –ORC integrated system. Methanol is supplied to the SOFC combined system by the fuel gas supply system (FGSS). Methanol is supplied directly to SOFC due to high operating temperatures and working characteristics, but indirectly to PEMFC via H_2 generating system that incorporates a methanol reforming system and pressure swing adsorption (PSA). In the SOFC, the primary electrochemical reaction will occur. The afterburner receives the exhaust gas next to complete the combustion process. The substantial amount of heat generated caused the exhaust gas temperature to rise. The exhaust gas is then used in Rankine cycles and gas turbines to provide more energy (GT).

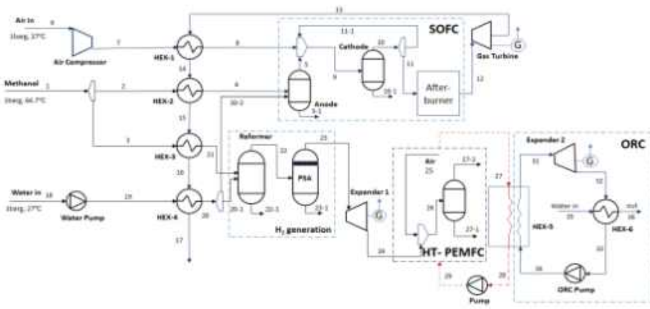

Figure 1. General diagram of proposed combined system

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3. Thermodynamic analysis

SOFC energy efficiency:

$$\eta_{en,\ SOFC} = \frac{\dot{W}_{elect,SOFC}}{\dot{m}_6 h_6 + \dot{m}_{air} h_{air} - \dot{m}_{12} h_{12}} \quad (1)$$

PEMFC energy efficiency:

$$\eta_{PEMFC} = \frac{\dot{W}_{PEMFC}}{\dot{m}_{H_2}\ LHV_{H_2}} \quad (2)$$

ORC energy efficiency:

$$\eta_{en,\ ORC} = \frac{\dot{W}_{ORC,\ Turbine} - \dot{W}_{ORC,\ Pump}}{\dot{m}_{ORC}(h_{32} - h_{34})} \quad (3)$$

ORC exergy efficiency:

$$\eta_{ex,\ ORC} = \frac{\dot{W}_{ORC,\ Turbine} - \dot{W}_{ORC,\ Pump}}{\dot{Ex}_{in,ORC}} \quad (4)$$

4. Simulation results

The process modelling software ASPEN HYSYS V12.1 is selected to modell the thermodynamic process of proposed system. The simulation and calculation results is presented in Table 1, Table 2 and figure 2.

Table 1 Output generation of system

Component	Power output (kW)	Power consumption (kW)
SOFC	3800	-
PEMFC	1152	-
GT	700	-
ORC Turbine	27.41	-
Expander 1	20	-
Air Compressor	-	601.8
ORC Pump	-	2.796
Water Pump	-	0.1338

Table 2. Energy and exergy efficiencies of system

Subsystem	Energy efficiency (%)	Exergy efficiency (%)
SOFC-GT	68.58	27.89
ORC	13.22	56.87
PEMFC-ORC	46.53	40.89
Total system	76.2	30.3

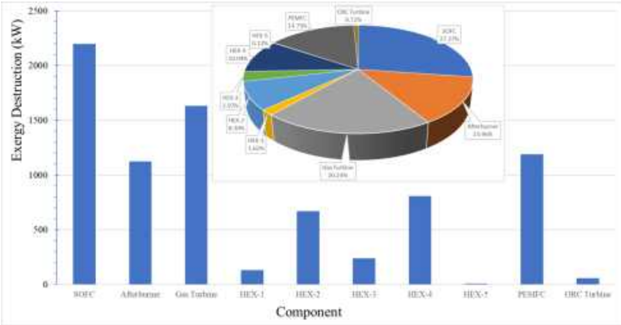

Figure 2. Exergy destruction of main components

5. Conclusion

This study proposed a novel integrated system for marine boats that will overcome the primary barrier to SOFC application during start-up and maneuvering. The integrated system's total energy and exergy were estimated to be 76.02% and 30.3% higher than those of SOFC standalone systems. The GT-PEMFC-ORC supplied 1880.3 kW to the system, or 33.1% of the overall power supply.

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