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USE OF THERMOCHEMICAL RECUPERATION OF WASTE HEAT TO ENHANCE ENERGY EFFICIENCY OF LNG CARRIERS

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Abstract. Growth the fleet of LNG carriers will increase carbon dioxide emissions. The International Maritime Organization (IMO) has developed the energy efficiency design index (EEDI) to cut carbon dioxide emission for new ships. To meet the stringent EEDI requirements, applying thermochemical regenerators (TCRs) fed by main engines exhaust gases is suggested on LNG carriers.

Keywords: gas carriers, liquified natural gas (LNG), energy efficiency design index, thermochemical heat recovery.

Global energy demands will continue to grow to meet various needs. Developed countries focus on renewable energy sources. However, despite the proliferation of the technologies using these energy sources, the share of such fossil fuel as natural gas will continue to grow. Gas consumption in the world energy balance will increase from 23% in 2016 to 26% in 2040 [1].

It is predicted that almost 50% of natural gas is expected to be transported by sea as liquified natural gas (LNG) in 2035 [2]. The share of LNG carriers continues to rise and is currently 3% of the world fleet [3]. However, enlarging the number of gas carriers will result in additional emission of carbon dioxide.

The level of carbon dioxide emission from vessels is measured by the energy efficiency design index (EEDI) for new ships. Several groups of parameters have an impact on the attained EEDI: ship's power plant parameters and sea-going qualities, as well as non-dimensional factors that consider the ship design features, region of navigation, and availability of innovative energy saving technologies [4].

It is worth to mention that EEDI calculation for LNG-carriers has distinctive features for ice-class ships, vessels with various propulsion systems (direct diesel-driven, diesel-electrical, steam turbine), those with dual-fuel engines operating on fuel oils and natural gas, and those with a re-liquefaction system or compressors for supplying pressured gas, so-called boil-off gas (BOG). BOG is a part of the cargo, evaporating because of heat exchange between the surfaces of the cargo transportation system and the environment.

In this paper there are results of estimation EEDI for modern 17 LNG carriers. Four out of them are equipped with steam turbine (ST) propulsion systems, the rest are equipped with diesel propulsion systems with dual-fuel engines (DF). Only one ship has a direct diesel-driven propulsion system with a low-speed engine, while others with diesel propulsion systems have main medium-speed engines. Ships were selected from the Significant Ships issues published by the Royal Institution of Naval Architects in 2011–2017.

A comparison of the EEDI data for LNG carriers operating on fuel oils and natural gas is shown in Fig. 1. The attained EEDI for ships operating on natural gas complies with the current EEDI requirements. However, even operation on natural gas cannot provide the compliance of some LNG carriers with the EEDI requirements of the most rigorous Phase 3.

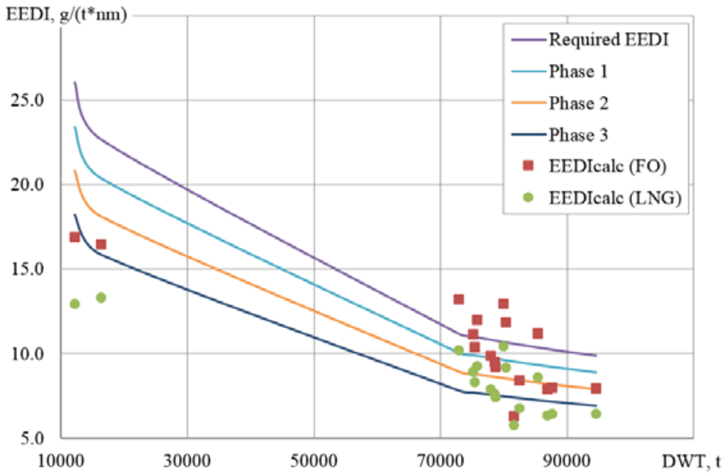

Fig. 1 Comparison of the attained EEDI and the EEDI reference lines for LNG carriers operating on various fuels: EEDIcalc (FO) is the attained EEDI for operation on fuel oils; EEDIcalc (LNG) is the attained EEDI for operation on LNG

A promising solution for reducing carbon dioxide emission is the application of thermochemical regenerators (TCRs) fed by main engine exhaust gases. As indicated by numerous studies, the use of TCRs ensures not only a decrease in specific fuel consumption (SFC) in the propulsion system but also a significant reduction in carbon dioxide generated at fuel combustion.

The estimation of efficiency of TCRs application on LNG-carriers has been made on the example of a ship with the diesel-electrical power plant with a total output of 64.35 MW based on DF four-stroke engines (D4S) [5]. Calculations show that the attained EEDI is 12.89 g/(t·nm) when the engines operate on fuel oils and 10.4 g/(t·m) when they operate on BOG (Fig. 2).

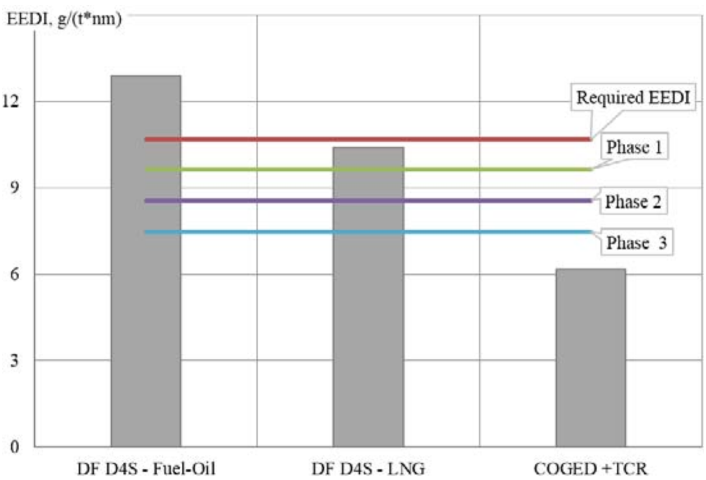

Fig. 2 Comparison of the attained EEDI and the EEDI reference lines for various power plants on the LNG carrier

The alternative combined power plant (COGED) with TCR and total output of 65.55 MW consists of one gas-turbine (GT) engine and five diesel engines. Results show that despite the application of a GT engine with a considerably lower efficiency than a diesel engine, the total efficiency of the power plant is almost the same and makes up 49% on engine flanges. This is because TCR utilization can reduce specific fuel consumption in the power plant engine by 7%. Thus, the SFC is 0.137 $kg/(kWh)^{-1}$ for diesel engines and 0.189 $kg\cdot(kW\cdot h)^{-1}$ for GT engines (Fig. 2).

Although the hourly fuel consumptions for the basic and alternative plants are almost the same (9.5 tons per hour), TCR utilization can significantly decrease the EEDI by reducing the carbon content in the fuel. According to the calculations, the attained EEDI for the alternative plant is 6.18 g/(t·nm).

To summarize, operation on BOG (methane) cannot ensure the energy efficiency of LNG carriers built in 2017, and the carriers are thus subject to the Phase 1 requirements. However, EEDI declines by 20% in this case compared with the EEDI associated with operation on fuel oils. Meanwhile, the application of the COGED with TCR ensures the energy efficiency of LNG carriers at the level of the most stringent requirements for carbon emission, which almost halves.

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AN FUEL CELL STACK DESIGN COMBINING THE ADVANTAGES OF CROSS-, CO- AND COUNTER FLOW ARRANGEMENT PATTERNS

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Summary. Physics fields distributing characteristics within solid oxide fuel cell (SOFC) stack are greatly affected by the key structure factors. These distribution qualities are essential to the stack performance and durations. In this paper, a new structure design for the SOFC stacks is firstly proposed to achieve high physics fields distribution qualities. A 3D large scale multi-physics model basing on the realistic solid, space and porous components of a 24-cells stack is successful developed with 15,656,579 specially designed meshes. The results show that the special designed interconnect with 27-parallel serpentine fuel rib channels on one side and discrete cylindrical air rib channels on the other side can conveniently divide the *N*-cells air flow path into two oppositely placed *N*/2-cells flow paths by 180ºC rotating the even interconnects. This is benefit to the construction of big stacks. For a 48-cells stack, all the cell units can be supplied at an average air mass flow rate more than 84%. The deviation of the average temperature among the piled units is only 95 K. Most electrolyte surfaces can obtain the oxygen over 15%. Trapezoidal distributor is important to ensure the similar flow feeding rates among 4 inlet manifolds with a deviation <3%.