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%.

Keywords: Stack structure design; 3D modeling of large scale stack, stack with realistic structure, Multi-physics simulating.

Text. Fuel cell is a typical electrochemical power generating device which converts the chemical energy in fuel directly into electric energy [1-4]. Solid oxide fuel cells (SOFCs) have attracted increasing attentions due to its high heat-electric co-supply application prospect and flexible fuel alternations features, which are generally considered to be an ideal potential power plant for the ship applications [5-6].

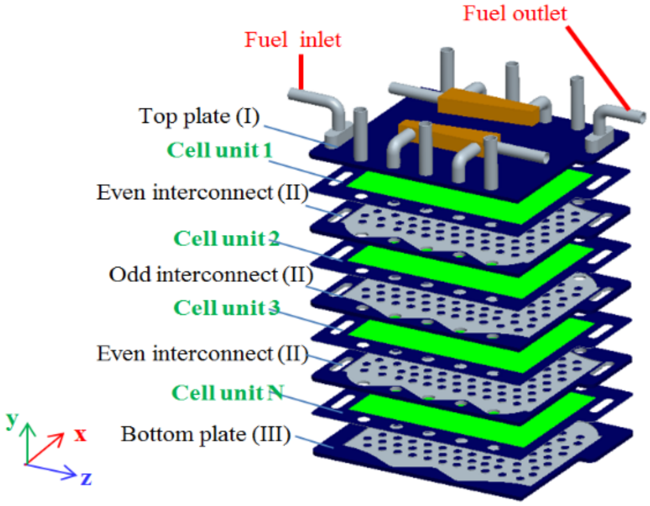

Figure 1. Stack structure and the components.

Fig. 1 shows the scheme of the proposed stack structure. The stack components includes the top cover plate (I), bottom plate (III), odd and even interconnect plates (II), and SOFC units (IV). The SOFC units are inserted between the odd and even interconnect plates. In current stack, the even and odd interconnect plates are designed to have the completely same structure, which includes same air manifolds, fuel manifolds, cathode rib channels and fuel rib channels. They can contribute to two air flow path groups and one fuel flow path group within a SOFC stack without any other additional components requirements.

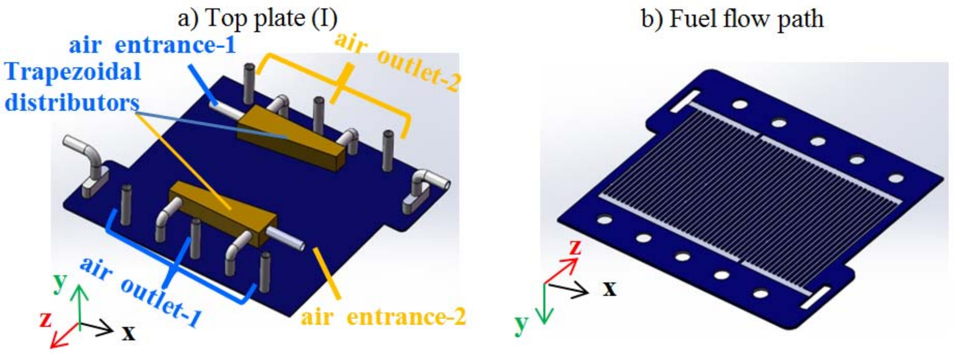

Figure 2. a) Top cover plate (I), b) Fuel flow rib channels on the button side of the top, even and odd interconnect plates.

The top cover plate (I) in ***Fig. 2a,*** consists of import and exit manifolds of two air flow path groups, import and exit manifolds of one fuel flow path, and two trapezoidal distributors.

a) air flow path group-1: As reported in our previous papers [3], for U-type configuration with $A_{in} \geq A_{out}$ (cross section areas of the inlet and outlet manifolds), the air flow rates input to the cell units will be monotonically decreased along the air flowing direction (cell number increasing direction in **Fig 1**) in any situation. On the contrary, for the flow path of U-shaped configuration, the characteristics of open outlet structure are adopted ($A_{in} << A_{out}$) as reported in Ref. [7], The flow rate of air is input to the cell units will be monotonically increased along the air flowing direction in any situation [8]. The overall cross section areas ratio A_{in}/A_{out} is a key factor to determine the air flow distributing condition among the piled units; and the optimized ratio value should be increased with the increasing stack scale (piled cell number) [3]. In current 24-cells stack, the air flow path group-1 will in charge of the air flow feeding for the cell units 2, 4, 6…24. Thus, two air inlet manifolds-1 in one side for flow feeding and three outlet manifolds-1 in the opposite side for cathodic exhaust gases collecting is adopted. It's inlet/outlet manifolds numbers over the SOFC unit surface is called as "2 inlet-3 outlet".

b) trapezoidal distributor: As the air flow statics pressure will be decreased, while it passes through a T-dividing junctions [3, 9], thus distributor using constant cross section area pipe may lead to different air flow feeding rate between two air inlet manifolds-1. In current design, a trapezoidal distributor-1 with a ratio between large and small cross section areas equaling to 2.5 is adopted to maintain the same air pressures between the entrances of two inlet manifolds-1.

c) As shown in **Fig. 1** the configurations of both the air flow path groups 1 and 2 on the *XY* plane are U types. Because the air flow static pressure will be increased (or decreased) while it passes through the dividing (or combining) T junction of the inlet (or outlet) manifold, the use of U-shaped rather than Z-shaped flat SOFC stacking ensures a more even distribution of pressure drop across the stacking units.

d) Similarly, the air flow path group-2 has the complete same structure with the air flow path group-1 and will in charge of the air flow feeding for the cell units 1, 3, 5…23. The air flow path groups-1 and -2 are oppositely arranged in the counter directions, respectively.

e) The fuel flow path has one fuel entrance (5) and one fuel exit (6). They are arranged at the opposite corners of the top cover plate for fuel feeding and the corresponding exhaust collecting. The fuel flow entrance/exit and air flow entrance/exit are separately placed at different sides of the stack like the traditional cross flow arrangement pattern. This could greatly decrease the sealing difficulty and mixing risk between fuel and air flows.

2) *The fuel flow rib channels,* on the button sides of the top, even and odd interconnect plates are shown in **Fig. 2b**. Parallel serpentine rib channels are adopted to distributing fuel flow over anode surface of each SOFC unit (IV). Ensuring relevant high fuel flow resistance and pressure over the anode surfaces can enhance the hydrogen diffusion within the porous anode, relieve the vapor blockage risk and increase the fuel utilization.

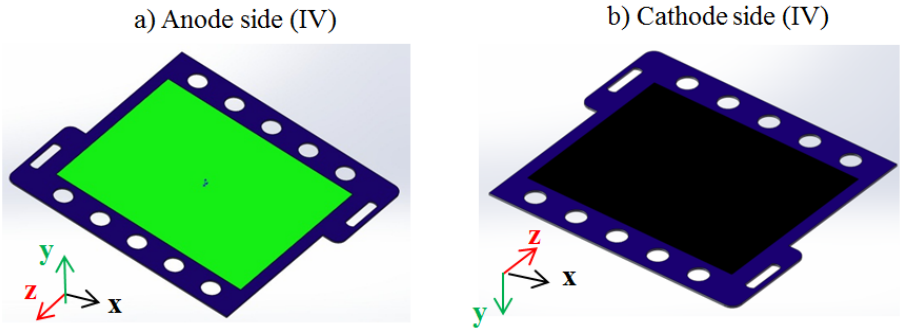

Figure 3. a) Anode surface of the cell unit (IV), b) Cathode surface of the cell unit (IV).

3) The upper and button sides of a SOFC unit (IV), are shown in **Fig. 3a** and **3b**, respectively. Each SOFC unit consists of the porous anode, anode functional layer, dense electrolyte, cathode functional layer and porous cathode.

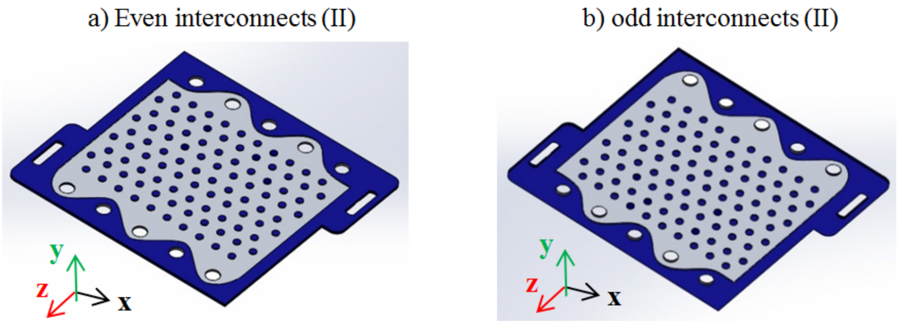

Figure 4. a) Even interconnect plate (II), b) Odd interconnect plate (II).

4) *The air flow rib channels* on the upper surfaces of the oven and odd interconnect plates are shown in **Fig. 4a** and **4b.** It includes two flow inlets, three outlets and rib channels consist of the discrete cylindrical solid ribs. Adopting this discrete cylindrical rib channels for the porous cathodes not only could decrease the total air flow resistance loss within the stack, but also could decease the risk of oxygen depletion on those cathode/electrolyte interfaces zone wrapped by the solid ribs. In other words, different rib channels over the anode and cathode surfaces are recommended to satisfy the different functional requirements and species properties of air and fuel flow transports.

It is interesting to note that rotating the even interconnect (shown in **Fig. 4a**) along *Y* axis with 180° , we can get the air flow rib channels of the odd interconnect plate in **Fig. 4b**. At the same time, the fuel flow rib channels on the button side of the interconnect will not be changed. In other words, rotating all the even interconnect plates can divide the air flow path into two separately two groups without changing the configurations of the fuel flow rib channels.

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