

Study of The Technical Approach on Recent Fuel Efficiency to Reduce Ship Emissions

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Abstract— Engine emissions of ships have been highly concerned in the last decades. Most of the current ship operations worldwide are powered by the combustion engine. Advance ship powering is still on research and hard to implement directly. High cost in the application is the main issue. Meanwhile, the fuel engineering approach is proposed in the recent research to advance engine combustion, thus increasing the combustion efficiency and lowering the emissions target. This study aims to evaluate the development trend on the fuel efficiency technique to lower ship emissions. Emissions management, fuel conversion, and power conversion are the most research focus to improve fuel efficiency. However, implementing some of that research is still hard on ship operation. Technical and economic issues are the main reason. Moreover, fuel efficiency on ships is still highly based on management. Low cost, new combined fuel without separation, and less fuel treatment technology are proposed to avoid confusion on fuel consumption in the near future.

Keywords— emissions management, fuel efficiency, ship emissions.

I. INTRODUCTION

Ship existence has a significant impact on cargo movement all over the world. The ship's main reason is to move the enormous amount of cargo with low cost than other transportations. Besides, many ships are operated in the open sea with bigger cargo capacity to overcome the demand. Many main engines are manufactured, and the main engine used onboard is more extensive than usual with a more major power. Thus, the ship exhaust emissions increase significantly, harming the environment [1,2].

However, the massive increase in ship manufacture with higher capacity is unavoidable. The ship exhaust gas emissions are a significant concern nowadays. Were after land transportation, the exhaust gas emission of the ship is the second largest contributor to the world's greenhouse gas [3]. Thus, the International Maritime Organization (IMO) and the regional government forced the shipowner with stringent rules to ensure the lower environmental impact from increasing GHG emissions [4].

Based on new ship design or operation, several options are proposed to achieve low ship exhaust emissions. Meanwhile, there is a gap between low emissions and low operation costs [5]. Low emissions application these days usually causes high costs on the operation. Besides, many strategies can also be options to lower ship emissions with low-cost operation besides adopting the high technology for an extreme reduction on ship emissions [6]. Achieving high fuel efficiency is the most favorable option for lower ship exhaust gas

emissions [7–9]. Felayati et al. were investigating the effect on emissions and combustion. Combining the split natural gas injection with several dwelling times at dual-fuel engines in low load conditions and diesel injection timing shows that the concentration of optimum emission can be achieved with the combination of retarding diesel injection timing and (DT30). These configurations generated very low hydrocarbon and carbon monoxide emissions, as illustrated in Figure 1.

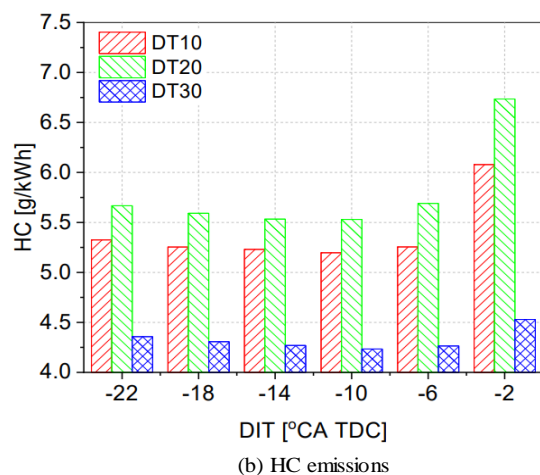
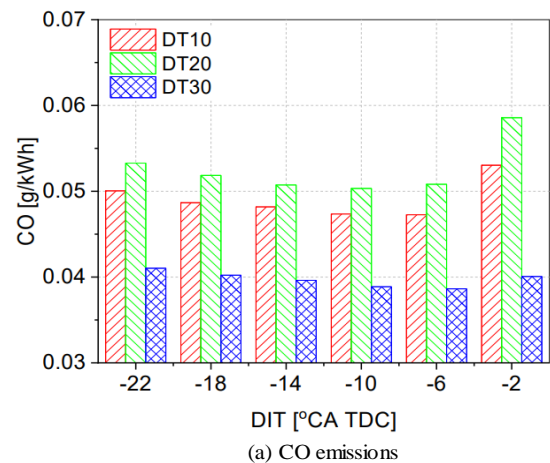


Figure. 1. Emissions concentration at some condition

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This study reviews the recent technical approach to fuel efficiency to reduce ship exhaust gas emissions. Moreover, other options which possibly be applied in the future are discussed to extend the possibilities. New perspectives on fuel efficiency are also proposed to consider the development of high fuel efficiency implementation on the ship.

A. Ship emissions and fuel efficiency correlation

Ship exhaust gas emissions are highly related to fuel efficiency. Higher fuel efficiency on the engine combustion means more fuel is burned completely, converted to engine power [10]. Uncompleted fuel combustion increases exhaust gas emissions and lowers the engine power output [11]. However, the perspective on exhaust emissions should be based on the type of emissions. Several exhaust gas emissions are of the most concern nowadays, such as soot, CO, HC, NO_x, and CO₂ emissions [6,12].

However, CO₂ emissions are opposite to the other emissions, especially soot, CO, and HC. Higher CO₂ emissions mean lower emissions due to higher complete fuel combustion [6]. The CO emissions are formed from the low combustion temperature and low oxygen concentration, leading to an increased amount of carbon formed incompletely as CO₂ [13]. Carbon monoxide was formed by incomplete combustion, where the oxidation process did not occur ultimately. The concentration mainly depends on the fuel mixture or the air, and it might be highest if the excess-air factor (λ) is less than 1.0, and it was classified into a rich mixture.

Moreover, soot and HC emissions are formed due to low temperature near the cylinder wall and produce unburned hydrocarbon. At this state, the air-fuel mixture temperature is less than the center of the cylinder. Hydrocarbons have harmful impacts on human health and the environment. It played a significant role in forming ground-level ozone with other pollutant emissions. With significant respiratory tract irritation, toxic hydrocarbons can cause cancer.

Besides, NO_x emissions are formed due to high-temperature combustion [14]. Nitrogen oxide and nitrogen dioxide are considered toxic materials. Still, nitrogen oxide has a level of toxicity five times lower than that of NO_x, and it was an indirect concern to human lung disease. NO₂ could impact the lower resistance to respiratory infection and irritate the lungs. Nitrogen oxide emissions might be causing both terrestrial and aquatic ecosystems caused by acid rain.

The approximate composition of diesel exhaust gas is shown in Figure 2 [15]. In diesel exhaust gas, pollutant emissions have a rate of less than 1%. NO_x has the highest proportion of diesel pollutant emissions, with a rate of more than 50%. After NO_x emissions, particulate matter (PM) has the 2nd highest proportion in pollutant emissions. Carbon monoxide and hydrocarbons concentrations are minimal since diesel engines are considered lean combustion engines. Besides, pollutant emissions include a fraction of sulfur dioxide depending on the specifications and fuel quality. It was produced in diesel fuel which contains sulfates. At present, there is not any after-treatment system like a catalytic converter

to eliminate sulfur dioxide. Nowadays, to prevent the harmful effect of diesel engines, most oil distributors and customers prefer ultra-low sulfur diesel (ULSD) of SO₂.

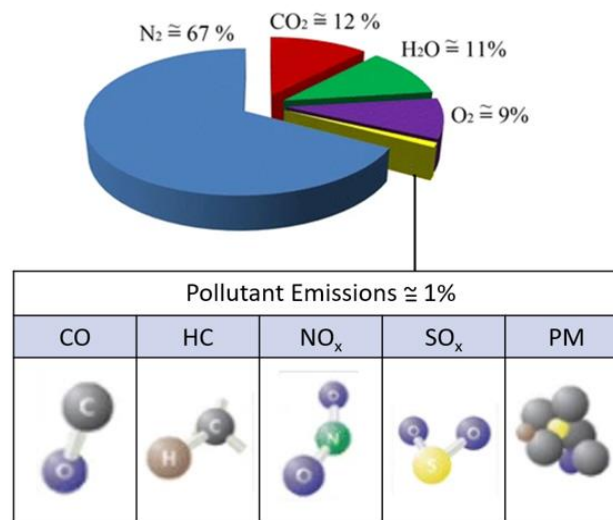


Figure. 2. The concentration of emissions at some diesel injection

If those emissions concentration on the exhaust gas becomes a problem for the environment thus, it needs another option other than increasing the fuel efficiency. Meanwhile, most of the existing ships are operated with fuels. Increasing fuel efficiency is still in high concern to compromise the environmental impact. It means the existing combustion engine still has the potential to exist for several years ahead. Reducing ship operational costs with high fuel efficiency is another benefit besides the environmental issue. Although, the alternative ship power is developing to ensure the low cost on the operation with high efficiency on the power output.

II. METHOD

The data for this paper was compiled based on around the internet (on official organization websites, scientific publications, patents, and classification society rules) and in relevant references such as books, etc. The data analysis was performed on the sampled data by reviewing all the relevant data. As a result, the technical approach on recent fuel efficiency to reduce ship emissions is discussed.

III. DISCUSSION

A. Technical approach on ship emissions reduction approach

Several techniques are proposed to improve the ship's fuel efficiency, which affects the ship's emissions. However, traditional fuel efficiency by combustion is less discussed in this case. Fuel combustion is essential for fuel efficiency improvement. Nevertheless, there is a trade-off between the type of emission on the combustion, which is highly based on the fuel and combustion characteristics. Moreover, it is hard to capture the big picture on ship emissions reduction by the combustion. The operational technique focuses on this discussion, directly impacting the low cost and emissions target.

1) Reduce ship emissions by emissions management

The recent popular solution for reducing ship exhaust gas emissions is using emissions management. A lot of emissions management can be performed to reduce exhaust gas emissions. Reducing emissions means less modifying the existing ship engine or choosing other strategies rather than directly on the engine. However, several strategies are discussed in this section briefly as an example, such as add after treatment, route optimization, and speed optimization.

Additional engine after treatment is applied to the ship based on the emissions reduction requirement. The ship can be added to the after-treatment, such as scrubber, as illustrated in Figure 3 [15]. A scrubber installed on the ship can significantly reduce the ship's emissions, such as acid and particulate emissions. It is installed after the exhaust gas pipe. However, the installation needs space that can reduce the space on the engine room or other space near the engine room; thus, it needs rules approval to implement. Moreover, the shipowner should invest an additional cost for the equipment and installation.

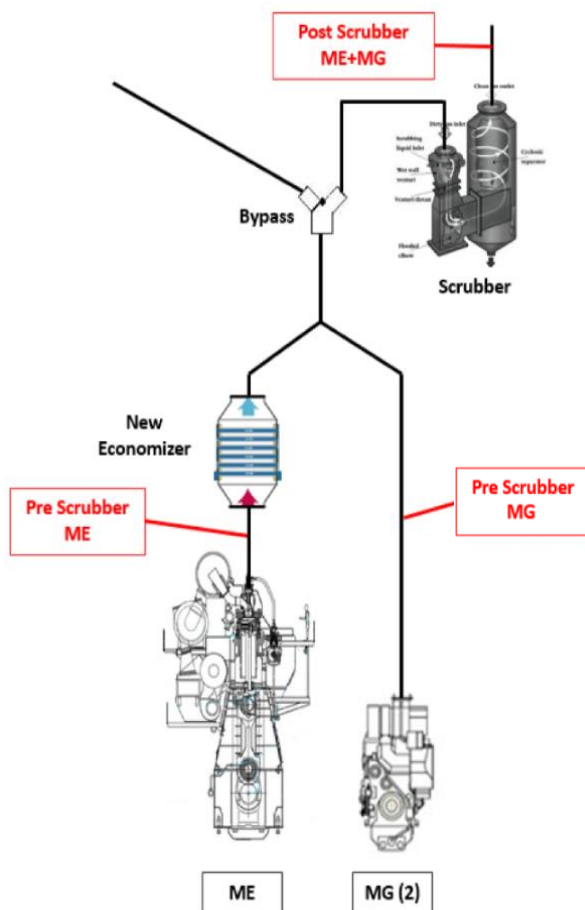


Figure 3. Schematic diagram of the OGV engine layout

However, some approaches can be performed at a lower cost to reduce emissions. Fuel efficiency optimization is the solution by optimizing the ship route

and speed [16]. This strategy is highly related to the emissions management that needs serious concern between shipowner and crew. The owner should be managed carefully to optimize the shipping route. It causes fuel consumption if the routing is efficient [17], as illustrated in Figure 4. Thus, lower fuel consumption can be achieved, producing lower emissions.

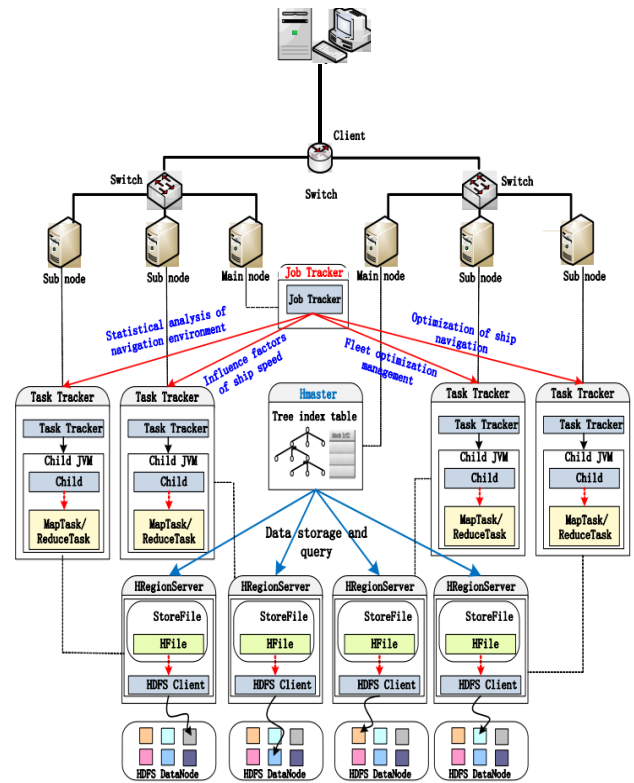


Figure 4. Big Data analysis platform design of SEEM [17]

The ship route optimization can be achieved by combining speed optimization [18]. The ship's performance is related to several factors such as hull condition, engine power, and propulsion. The condition of those each factor is related to the shipping speed; thus, speed optimization is the key factor to improve the performance.

Higher ship performance means lower total fuel consumption, which leads to lower exhaust gas emissions. However, IMO has already proposed as (SEEMP) [19]. The category is defined as follows: fuel-efficient operations, optimized ship handling, hull maintenance, propulsion system, waste heat recovery, improved fleet management, improved cargo handling, fuel type, etc. The exact energy improvement method of SEEMP is shown in Table 1.

TABLE 1.
 ENERGY IMPROVEMENT METHOD OF SEEMP [19]

Category	Improvement method	Description
	Improved voyage planning	An execution of voyages for careful planning
	Weather routing	By using routing tools from existing providers. Potential efficiency savings
	Just in time	Speed optimization based on early communication with next port on berth availability
	Speed optimization	Fuel consumption minimization, by considering the arrival times/availability of berths at port and engine manufacturers optimal settings.
	Ship power optimization	By setting constant RPM the efficiency can be improved
Optimized Ship Handling	Trim optimization	Optimizing the trim operation for specified draft and speed
	Ballast optimization	Optimizing the ballasting trim and steering conditions
	Propeller and propeller inflow considerations optimization	To improve efficiency by possible retrofitting of improved propeller designs and/or inflow modifiers such as fins or ducts
	Rudder and heading control systems (autopilots) optimization	Reducing distance sailed ‘of track’ and minimizing losses caused by rudder corrections. Possible improvements through retrofitting optimized rudder designs
Hull Maintenance	-	Use of advanced coating systems, better management of cleaning intervals and underwater inspection.
Propulsion System	Maintenance of Propulsion system	Systematic minimization of heat and mechanical loss through routine maintenance and optimization
Waste Heat Recovery	-	Thermal heat loss from exhaust gases to generate electricity or propulsion via shaft motors
Improved Fleet Management	-	Better utilization of fleet capacity and use of ‘best practice’
Improved Cargo Handling	-	Cargo handling which is matched to ship and port requirements
Energy Management	-	Review of energy usage such as electrical and HVAC systems
Fuel Type	-	Potential use of emerging alternative fuels
Other Measures	-	Computer software to calculate fuel consumption; use of renewable energy technology; use of shore power

2) Reduce ship emissions by power conversion

An extreme reduction in ship emissions also can be achieved by a power conversion [20]. However, the ship power conversion in the future may lead to a significant improvement in achieving the lowest emissions produced by ship. The conventional diesel engine can be converted with a new power plant type. However, this may cause a very high cost on the conversion; thus, this solution may be arguable.

It should be a high impact reason behind the conversion to realize. Unfortunately, the strict regulation and lower cost may be the only reason the history leads to this issue. The diesel engine can be converted by diesel-hybrid or full-electric power plant type [21]. The hybrid system of ship propulsion can be illustrated as shown in Figures 5 to 6, based on Dedes et al. [21].

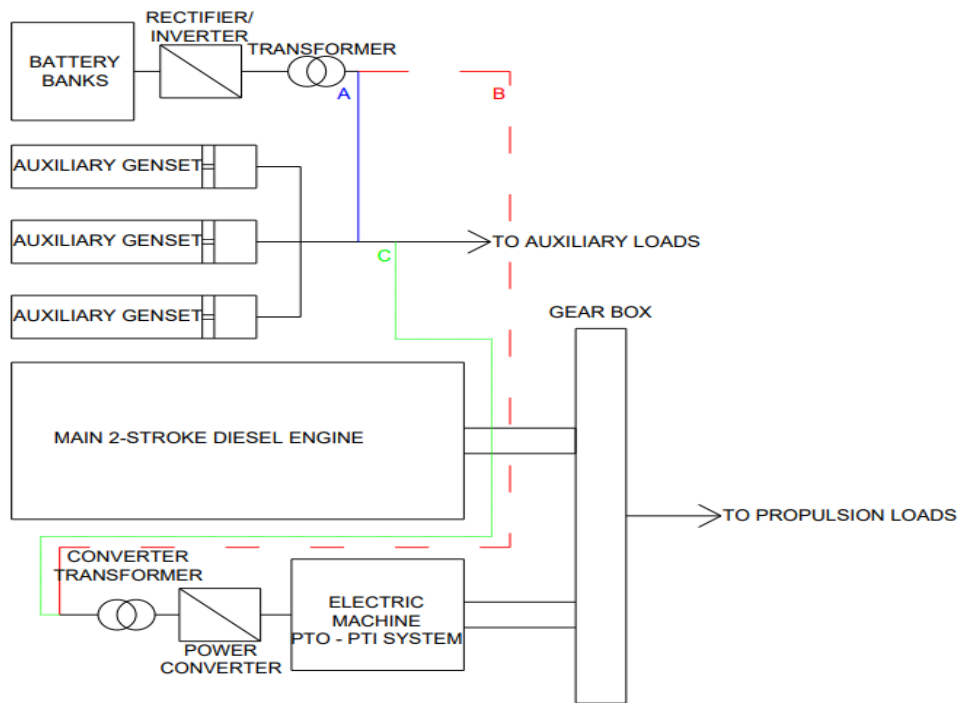


Figure. 5. Hybrid Diesel-Mechanical System

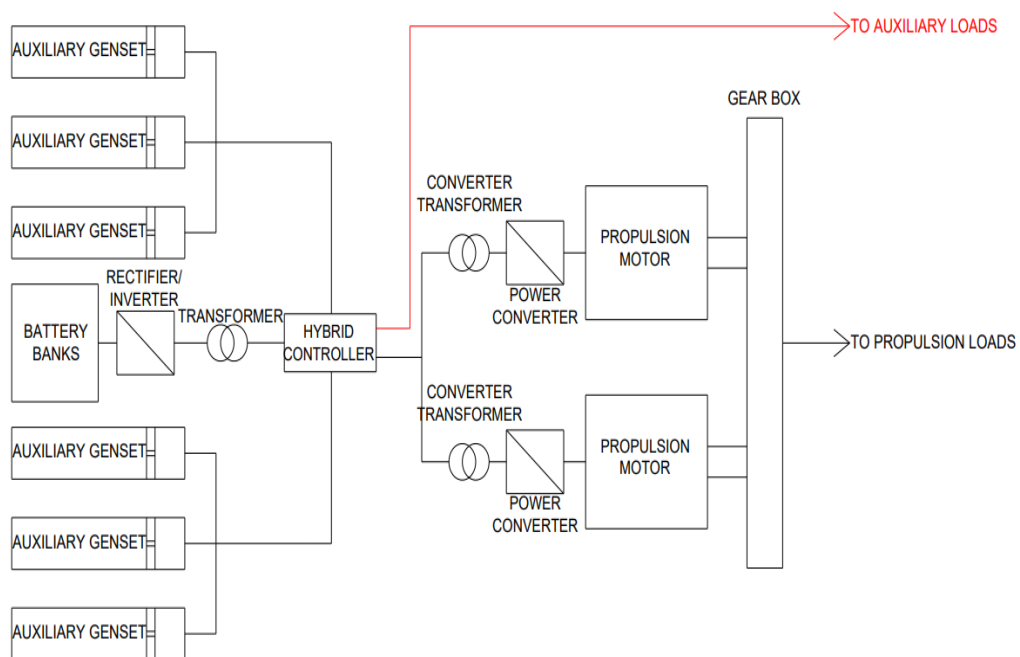


Figure. 6. Hybrid- Ship Propulsion Layout

Several institutions have proposed the technology. Furthermore, a new type of ship also has the prospect of using energy storage devices combined with electrical propulsion and integrated into Energy Management

Systems (EMS) and autonomous navigation technology [22]. This integrated propulsion system is illustrated in Figure 7.

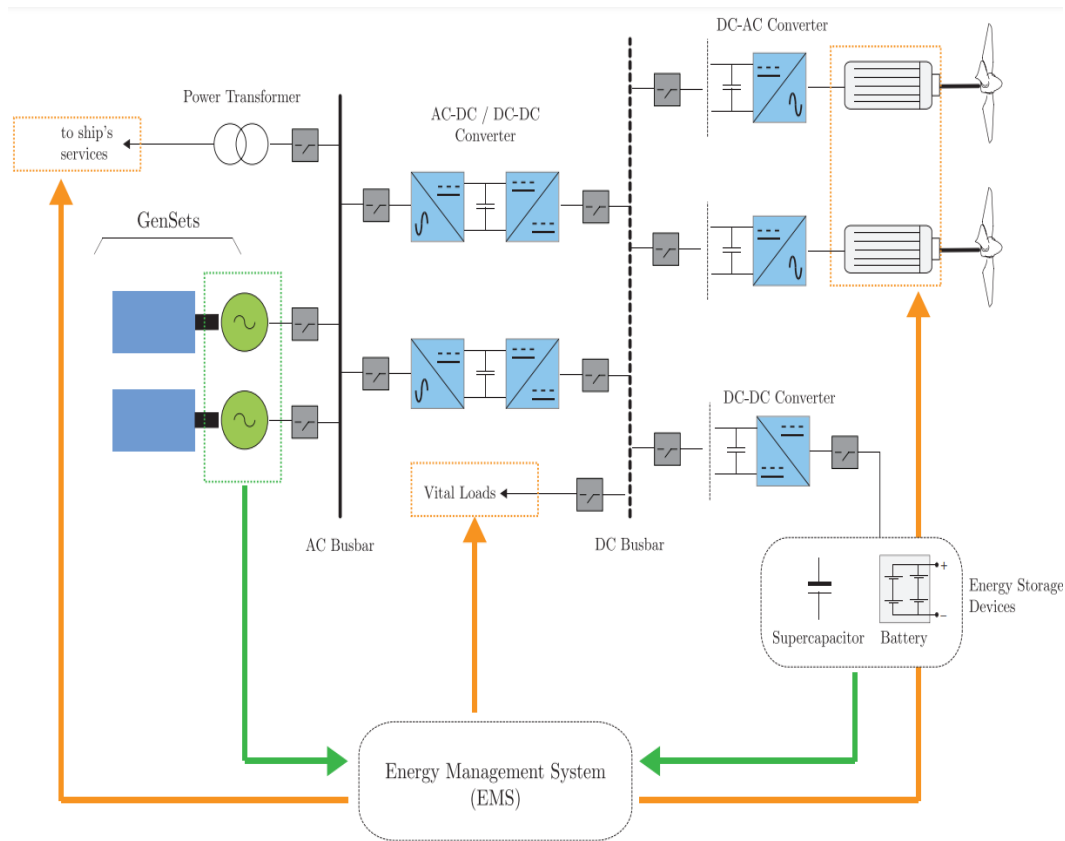


Figure. 7. Integrated energy storage devices and EMS.

The conversion of diesel to electric propulsion power can significantly reduce emissions or zero emissions. Besides, the maturity level of the research is still questionable, especially for ship applications. It may take several years to implement until the cost is favorable with high safety assurance. Zero emissions are an excellent solution for the environmental future, although the technology should meet the competitive cost for the business based on the level of research maturity.

3) Reduce ship emissions by fuel conversion

Most ships use fuel as the primary power source for the operation. However, fuel utilization on combustion engines is converted to power and emissions. Thus, fuel can be the main object to improve to lower exhaust gas emissions [23]. There are many options for improving the ship fuel; the fuel can be converted to alternative fuel or improved by the characteristics. The conventional ship usually uses a combustion engine fueled by diesel due to its low cost and high efficiency. However, the stringent rules forced the conventional ship to use alternative fuels to lower the exhaust gas emissions [6]. Besides, there are several types of research for improving conventional fuel characteristics.

The fuel conversion is the most practical solution for recent emissions targets such as low SO_x and NO_x emissions [6]. The diesel fuel on conventional diesel engines can be converted to dual-fuel using

diesel/natural gas, diesel/methanol, diesel/hydrogen, or other combinations. It is reported that a dual-fuel engine has a promising characteristic to improve exhaust gas emissions [24–26]. The conventional ship can add or modify the fuel storage and engine intake manifold for other fuel in dual-fuel mode. However, this option may cause a complex multiplier effect on the business, such as the additional cost, ship insurance, and fuel availability. Besides, if dual-fuel conversion becomes national regulation or agenda, it becomes easier to implement.

However, enhancing the diesel fuel characteristics or using other diesel fuel types is the better solution, such as biodiesel. Compared with biodiesel, diesel fossil fuel has different characteristics on combustion and emissions. Nevertheless, some aspects should be considered for the fuel characteristic, such as engine filter maintenance. An optimistic perspective should be created in the future a competitive single diesel fuel characteristic with high performance and emissions improvement, thus avoiding complex engine systems and confusion on the implementation.

IV. CONCLUSION

This study is discussed the technical approach to improving fuel efficiency to reduce ship emission. The fuel efficiency is highly influenced by combustion,

which leads to improved ship emissions. However, executable technical approaches can increase fuel efficiency and decrease ship emissions by emissions management, power conversion, and fuel conversion. Emissions management is the most executable short-term solution for reducing emissions. Besides, the power conversion needs a high cost and strict regulation. Fuel conversion can be a solution in the near future with the lower intention on the high cost and complex procedure.

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