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Research paper

Optimization of Marine Diesel Engine Performance Using Advanced Stimulation Techniques

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Abstract

Most ships, from small boats to huge oceangoing vessels, are diesel-powered, which are the most efficient engine. Thirty-four member states are regulated by international environmental laws established by different global institutions and organizations, with the goal of curbing greenhouse gas emissions. Optimization techniques are needed to lower marine engines' fuel consumption and exhaust pollutants. Choosing the right combustion control settings is crucial for marine diesel engines because it allows for the simultaneous improvement of efficiency and emissions while maintaining a steady target engine speed. Basing their discussion on their wide-ranging experience with emission control systems, especially plasma aftertreatment systems, the authors offer a distinct view of marine diesel engines and aftertreatment technologies in "New Technologies for Emission Control in Marine Diesel Engines". For oceangoing ships, the feasibility of a load leveling approach and energy management optimization using a hybrid diesel propulsion system is examined. By using less fuel oil and introducing an energy storage medium, diesel hybrid systems aim to lower exhaust gas pollutants.

Keywords: *Optimization; Fuel Consumption; Propulsion System; Energy Management.*

1. Introduction

In spite of shipping's undeniable CO2 efficiency measured in grammes of CO2 released per tonne-km, the marine industry acknowledges that these totals need to be reduced (IMO, 2009). However, exhaust emissions from international shipping account for a large portion of the transportation sector's overall emissions. Based on the high scenarios, CO2 emissions will alter by 5.2% and -0.8%, respectively [2]. The base scenarios, on the other hand, have estimated an increase in CO2 emissions by 1.9% to 2.7% annually. This emission growth is directly related to the expected growth of maritime transport. In order to meet global targets to contain average global temperature rise to 2°C by 2050, the shipping industry needs to stabilize or decrease its emissions. Otherwise, the industry will contribute 12% to 18% of all allowable CO2 emissions. [1]

Shipping is the most efficient transport mode, transporting more than 70% of international A "business as usual" strategy could have long-term, far-reaching effects on climate change globally, as well as direct, short-term effects on human health and life [16]. Limiting exhaust emissions has consequently grown in importance for these organizations [4]. Even though PM emissions are linked to health problems and associated expenses, there is no regulation on them. One industry impacted by these more stringent regulations is shipping. Often, new vessel designs offer a specialized solution to a given logistics problem. Their profitability in a particular trade can be significantly impacted by their size, primary parameters (quay length, draughtt), design speed (the ideal crossing time is typically no more than eight hours), and cargo type (trucks and/or cassettes). Because of the installed power constraints, regulations that impose particular solutions may endanger particular trades [6]. The extremely fast ships may remain in service for longer, which could have an impact on current ships. This holds true for all ship types, including container ships, general cargo ships, and passenger transport ships [3].

2. Literature review

Pme-20, a gasoline combined with pungam oil, releases heat at a slower rate than diesel. Pungam oil esters have lower levels of pollutants like HC and CO than diesel fuel. Gnanamoorthi and Devarajane (2016) [17] investigated how the combustion chamber affected the diesel blend's performance, combustion, and emissions in diesel engines. The intake swirl, piston motion, and geometry all contribute to the air motions in the cylinder. The design of the combustion chamber is changed from the typical one utilizing pure diesel and a 40% diesel mixture to improve evaporation and mixing during the compression stroke of a diesel engine with a single cylinder. At a compression ratio of 19.5:1, the combustion chamber generates higher turbulence, squish, and swirl, contributing to better combustion as a result of improved swirl. The brake thermal efficiency improves significantly to 33% and increased cylinder peak pressure. In addition to that, in comparison to a hemispherical chamber, the combustion chamber has strong emissions reduction advantages with 60% less CO, 20% less HC, 40% less NOx, and a significant 90% less smoke emissions [8].

The status of biodiesel as a diesel engine alternative fuel, as well as its history and recent advancements, production methods, including the various types of biodiesels, and the industry's characteristics, processing, and economics, were reviewed by Annamalai and Jaichandar (2011) [5]. Research has indicated that biodiesel has comparable combustion characteristics to diesel, with similar engine power output. Additionally, biodiesel reduces engine emissions considerably when utilized in diesel engines. An economic analysis of feasibility established that biodiesel extracted from non-edible oils is cheaper compared to that extracted from edible oils [10].

The study was conducted using materials that could change phases and were shaped like capsules. The device could only recover roughly 10–15% of the energy produced by the fuel's combustion as heat energy. Nonetheless, the recovery temperature is high enough for appropriate follow-up uses. From experimental investigation and waste heat recovery estimation, they derived the operational performance of the double-loop ORC. The output indicated that more net power was produced in the second loop than in the first loop, bringing a significant input to the performance evaluation of the ORC system. When the ORC was operating at its maximum thermal efficiency, the power inputs of one loop relative to the other increased from 14% to 16%. However, when operated under part load conditions, the same climbed by 38% to 43%. Additionally, over the course of the engine's operation, the BSFC of the cycle related to both loops combined type reduced.

Scientists investigated the use of turbo-compounding technology to minimize fuel consumption and recover lost heat from an internal combustion engine using laboratory experiments [18]. Thus, the catalytic converter efficiency might be maximized by maintaining the catalyst's optimal temperature level using the waste heat collected in the phase-changing material.

Vegetable oils and their biofuels have been studied at length as a possible fuel for diesel engines. Biodiesel has a very small effect on the greenhouse effect because the CO2 released when combusted is compensated by the process of photosynthesis in plants, which recycles the CO2. A number of adjustments have been discovered for power and thermal efficiency recovery, including changes to the injection process parameters, compression ratio, and oil preheating. These modifications also have an impact on the engine's emissions. Vegetable oil's physical qualities were improved using a number of methods; however, it was discovered that these were not long-term viable. Yet, extended operation with raw vegetable oil in diesel engines may result in negative consequences, including thickening of lubricating oil, extreme engine deposits, sticking of piston rings, and coking of injectors [7]. Therefore, vegetable oil derivatives, like alkyl esters and diesel blends, were found to be more appropriate and efficient fuels.

3. Methodology

A cruise vessel plying the Baltic Sea was the basis for designing, modeling, optimizing, and assessing its energy system. The vessel, which undertakes daily round-trip journeys between Mariehamn in the Aland Islands and Stockholm on the Swedish mainland, can accommodate more than 1800 passengers. The ship's length and width are 176.9 and 28.6 meters, respectively, and it is built to reach 21 knots. According to the itinerary, the ship is expected to depart Stockholm at approximately 18:00 and head out to sea, where it will spend the night before sailing to Mariehamn early the following morning. The ship then departs Mariehamn at around nine, returning to Stockholm at around sixteen. The cruise ship's energy load [19], which includes thermal, electrical, and mechanical loads, is depicted in Figure 1. The study takes into account three different seasons: winter (182 days), summer (62 days), and transition (121 days), based on the changing operational conditions. The lifespan of the vessel is estimated to be 15 years.

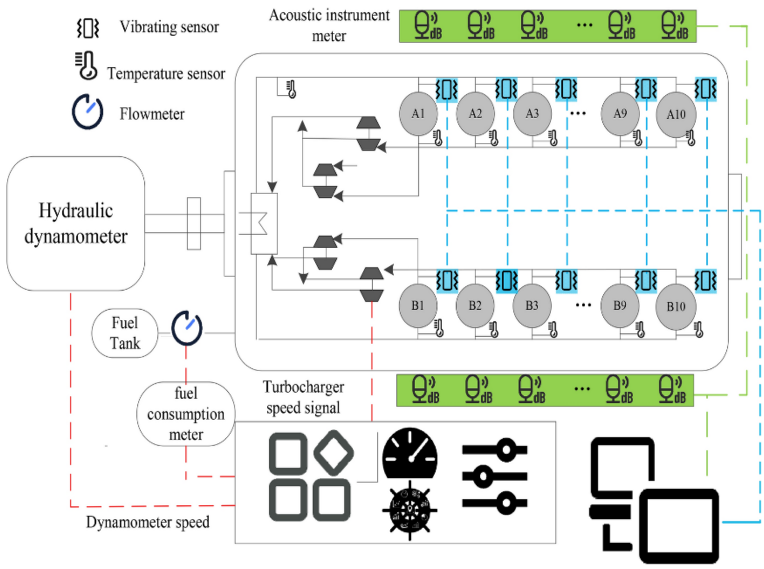

Fig. 1: Marine Diesel Engine Framework.

In general, ship energy conservation and emission reduction techniques fall into four major categories: waste heat recovery, green energy application, ship form optimization, and ship operation optimization, among others [9]. A simple but effective solution is operational optimization that includes strategies like speed optimization, navigation scheduling, route optimization, and trim optimization. Therefore, the use of ballasting or load distribution to realize a low-resistance trim is a practical approach to minimizing fuel consumption. Trim optimization could effectively reduce carbon emissions and enhance operational economics, but it has very little impact on operating expenses and has no effect on a ship's design or building costs. Trim optimization is therefore an effective way to save energy and reduce emissions, and in recent years, it has drawn attention from researchers.

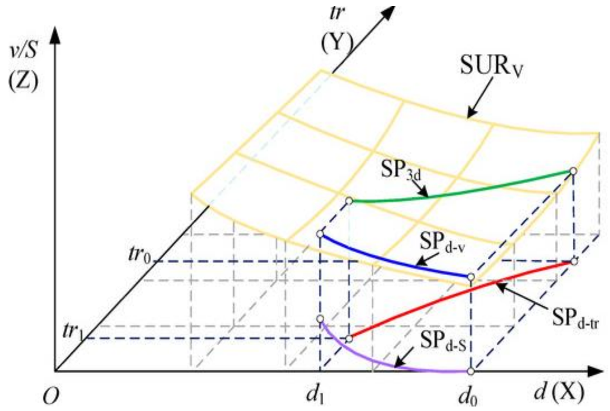

Fig. 2: Optimization Performance.

Studies by Lokukaluge et al. showed that calculating the optimal trim based on navigation and ship performance data can result in greater log speed or fuel savings. A trim optimization investigation by Sun et al. employing computational fluid dynamics (CFD) and model basin tests indicated that adjustments to ship trim could reduce considerably ship resistance and fuel consumption and serve as an efficient method to minimize emissions and save energy under real operational conditions of ships. In the meantime, Coraddu et al. contrasted three fuel consumption forecasting models and explored the difficulties in forecasting fuel consumption with precision based on onboard automation system data. Du et al. suggested a two-stage optimization method, in which ship speed is optimized in onshore planning and trim optimized onboard in actual weather and sea conditions. With training a neural network model from navigation data, their approach demonstrated promise for large bunker fuel savings in simulated tests of two container ships. In addition, Gao et al. utilized CFD numerical calculations on an oil tanker to examine trim optimization and proved that it can effectively decrease fuel consumption and hull resistance [11-13] [20].

4. Discussion

Emissions Control Areas (ECAs) have been established in an attempt to reduce emissions of air pollutants like SOx, NOx, and indirectly particulate matter (PM). It should be mentioned that the impending worldwide sulfur cap, which mandates a 0.5% sulfur content limit, will take effect on January 1, 2020. [14]

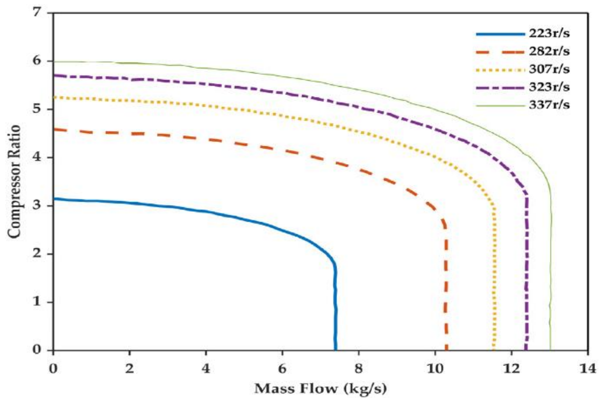

Fig. 3: Marine Diesel Engine Performance.

To guarantee that this limit is regularly implemented, the IMO has approved the carrying ban on non-compliant fuel, which will take effect in March 2020. Nevertheless, these areas were accepted by the IMO as NOx-ECA, and they will go into effect on January 1, 2021. This study will examine three viewpoints in light of the aforementioned emissions control regulations) the effectiveness of marine engines, ii) the selection of technologies to reduce air pollutants associated with shipping, and iii) the challenges confronting the shipping industry in the era of digitalization [15].

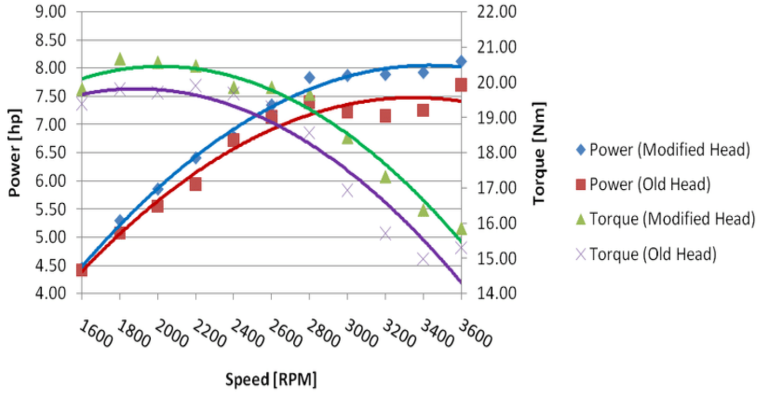

Fig. 4: Engine Efficiency.

Large bore diameters (usually more than 250 mm) and extended injection durations (up to 5 milliseconds at high loads) are characteristics of medium-speed diesel engines that lead to increase near wall combustion and a longer combustion time. The thermal efficiency would decrease as a result of both of them. An innovative fuel system consisting of two or more injectors per cylinder has been suggested in order to rectify engine efficiency problems. For Koci et al., such a configuration would enhance fuel/air mixing and decrease the local equivalency ratio by using external air-assisted fuel spray. The side injectors also provide fuel concentration at the center of the cylinder, reducing the effect of the flame on the cylinder wall and diminishing heat loss. Research, including the PREDIC and MULDIC ideas, has investigated diesel engines with plural injectors, indicating that they can reduce heat loss.

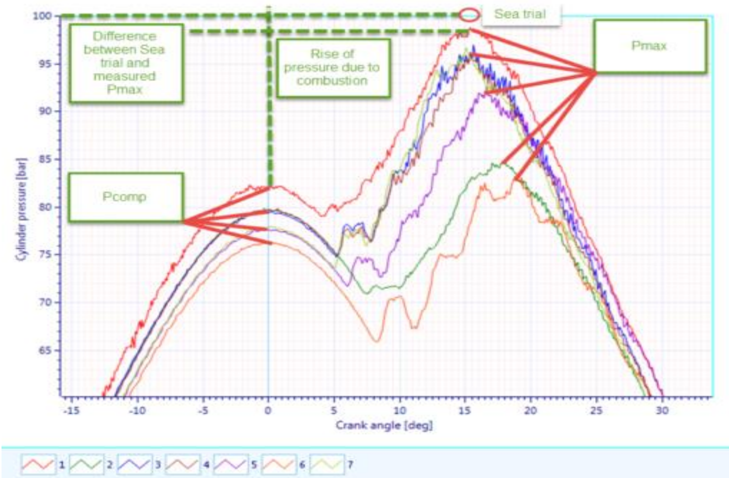

Fig. 5: Cylinder Pressure.

Noboru Uchida et al. carried out experiments and numerical simulation on a multi-injector single-cylinder engine, realizing less heat loss, friction loss, and NOx emission with retaining thermal efficiency through the control of injection timing for each injector and also enhancing braking thermal efficiency through a new nozzle design.

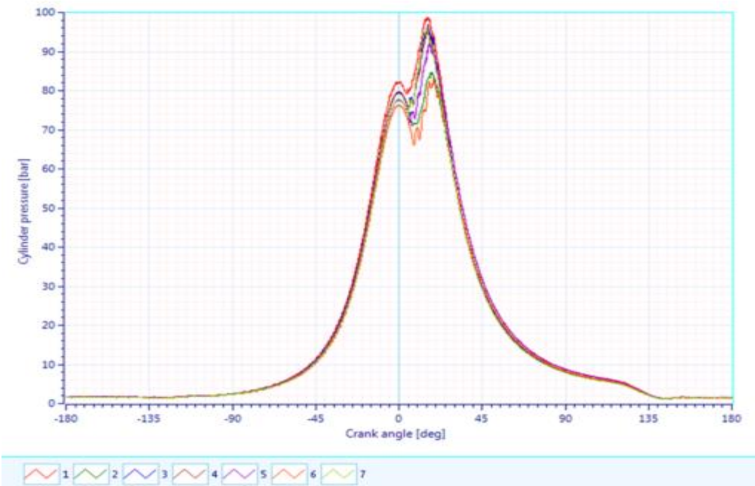

Fig. 6: Engine Performance Optimization.

Three injectors were added to a conventional single-cylinder diesel engine by Takeda Y and colleagues. Two injectors were positioned on the cylinder's sides, while one was positioned vertically in the middle of the cylinder. Through the studies, they validated a number of optimization parameters for each injector's fuel quantity and injection timing. Fuel consumption and particle emission both improved while NOx levels stayed low.

5. Conclusion

The shipping sector is currently navigating regulatory turmoil in order to meet the corresponding goals for emissions management and energy efficiency. This study has examined the challenges of regulatory compliance from both a theoretical and practical standpoint. The framework that has been established provides theoretical insights into the potential effectiveness of specific environmental interventions associated to shipping. It provides a starting point for further financial quantification of the connections discovered in later research. Additionally, if it turns out that private benefits do not outweigh costs, it enables the determination of the levels of compensation or incentives that need be given to operators in order to force them to implement a particular solution. The first of the three predicted benefits of the innovative multi-injector system in terms of combustion is a shorter time of fuel injection. To shorten the time needed for combustion and increase thermal efficiency, more fuel could be pumped into the cylinder. Second, the mixture is simpler to mix when there is a constant air flow upstream of the spray. Using experimental and numerical findings.

References

[1] Ammar, N. R., & Seddiek, I. S. (2017). Eco-environmental analysis of ship emission control methods: Case study RO-RO cargo vessel. *Ocean Engineering*, *137*, 166-173. https://doi.org/10.1016/j.oceaneng.2017.03.052.

[2] Gurudiwan, P., & Mire, S. K. (2024). A Review of Pharmaceuticals in Aquatic Environments Risk Assessment and Ecological Impacts. *Natural and Engineering Sciences, 9*(3), 88-99. https://doi.org/10.28978/nesciences.1606589.

[3] Ng, H. K., Gan, S., Ng, J. H., & Pang, K. M. (2013). Simulation of biodiesel combustion in a light-duty diesel engine using integrated compact biodiesel–diesel reaction mechanism. *Applied energy*, *102*, 1275-1287. https://doi.org/10.1016/j.apenergy.2012.06.059.

[4] Fakiha, B. (2024). Investigating the Secrets, New Challenges, and Best Forensic Methods for Securing Critical Infrastructure Networks. *Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications, 15*(1), 104-114. https://doi.org/10.58346/JOWUA.2024.I1.008.

[5] Puisa, R., Pawling, R., Bliault, C., Pratikakis, G., & Tsichlis, P. (2015). Description of uncertainty in design and operational parameters. *Report number: FAROS D*, *6*.

[6] Jakhir, C., Rudevdagva, R., & Riunaa, L. (2023). Advancements in the novel reconfigurable Yagi antenna. National Journal of Antennas and Propagation, 5(1), 33–38. https://doi.org/10.31838/NJAP/05.01.06.

[7] Van, C., Trinh, M. H., & Shimada, T. (2025). Graphene innovations in flexible and wearable nanoelectronics. Progress in Electronics and Communication Engineering, 2(2), 10–20.

[8] Malbašić, V. (2021). The Strategy of Management and Utilization of Mineral Raw Materials in the Republic of Srpska Through the Globalization Era. *Archives for Technical Sciences, 2*(25), 17–28. https://doi.org/10.7251/afts.2021.1325.017M.

[9] Wang, J., Shen, L., Bi, Y., & Lei, J. (2021). Modeling and optimization of a light-duty diesel engine at high altitude with a support vector machine and a genetic algorithm. *Fuel*, *285*, 119137. https://doi.org/10.1016/j.fuel.2020.119137.

[10] Sun, C. (2023). The Bit Query for Labels in a Binary Tree-Based Anti-Collision Recognition Algorithm. *Indian Journal of Information Sources and Services, 13*(2), 68–75. https://doi.org/10.51983/ijiss-2023.13.2.3853.

[11] Gnanamoorthi, V., Marudhan, N. M., & Gobalakichenin, D. (2016). Effect of combustion chamber geometry on performance, combustion, and emission of direct injection diesel engine with ethanol-diesel blend. *Thermal Science*, *20*(suppl. 4), 937-946. https://doi.org/10.2298/TSCI161104279E.

[12] Jaichandar, S., & Annamalai, K. (2011). The status of biodiesel as an alternative fuel for diesel engine–an overview. *Journal of Sustainable Energy & Environment*, *2*(2), 71-75.

[13] Shereena, K. M., & Thangaraj, T. (2009). Biodiesel: an alternative fuel produced from vegetable oils by transesterification. *Electronic journal of biology*, *5*(3), 67-74.

[14] Pandiyarajan, V., Pandian, M. C., Malan, E., Velraj, R., & Seeniraj, R. V. (2011). Experimental investigation on heat recovery from diesel engine exhaust using finned shell and tube heat exchanger and thermal storage system. *Applied energy*, *88*(1), 77-87. https://doi.org/10.1016/j.apenergy.2010.07.023.

[15] Zhang, H. G., Wang, E. H., & Fan, B. Y. (2013). A performance analysis of a novel system of a dual loop bottoming organic Rankine cycle (ORC) with a light-duty diesel engine. *Applied energy*, *102*, 1504-1513. https://doi.org/10.1016/j.apenergy.2012.09.018.

[16] Banawan, A. A., El Gohary, M. M., & Sadek, I. S. (2010). Environmental and economical benefits of changing from marine diesel oil to natural-gas fuel for short-voyage high-power passenger ships. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment*, *224*(2), 103-113. https://doi.org/10.1243/14750902JEME181.

[17] Ong, H. C., Masjuki, H. H., Mahlia, T. I., Silitonga, A. S., Chong, W. T., & Yusaf, T. (2014). Engine performance and emissions using Jatropha curcas, Ceiba pentandra and Calophyllum inophyllum biodiesel in a CI diesel engine. *Energy*, *69*, 427-445. https://doi.org/10.1016/j.energy.2014.03.035.

[18] Millo, F., Arya, P., & Mallamo, F. (2018). Optimization of automotive diesel engine calibration using genetic algorithm techniques. *Energy*, *158*, 807-819. https://doi.org/10.1016/j.energy.2018.06.044.

[19] Singh, D. K., Raj, R., & Tirkey, J. V. (2022). Performance and emission analysis of triple fuelled CI engine utilizing producer gas, biodiesel and diesel: An optimization study using response surface methodology. *Thermal Science and Engineering Progress*, *36*, 101486. https://doi.org/10.1016/j.tsep.2022.101486.

[20] Venkatraman, M., & Deveradjane, G. (2010). Experimental investigation of performance and emission characteristics of diesel-pungam oil methyl esters diesel blends fueled DI diesel engine at optimum engine operating parameters. *International Journal of Green energy and environment*, *1*, 7-12. https://doi.org/10.13005/msri/070209.

[21] Choset, K., & Bindal, J. (2025). Using FPGA-based embedded systems for accelerated data processing analysis. SCCTS Journal of Embedded Systems Design and Applications, 2(1), 79–85.

[22] James, A., Elizabeth, C., Henry, W., & Rose, I. (2025). Energy-efficient communication protocols for long-range IoT sensor networks. Journal of Wireless Sensor Networks and IoT, 2(1), 62-68. https://doi.org/10.31838/WSNIOT/01.01.01.

[23] Madhanraj.(2025). Blockchain-Assisted Peer-to-Peer EV Energy Trading in Vehicle-to-Grid Networks.National Journal of Intelligent Power Systems and Technology, 1(1), 48-56.