IMPLEMENTATION OF TURBOCHARGER IN SINGLE CYLINDER DIESEL ENGINE

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ABSTRACT
The use of turbocharging in diesel engines to increase performance and reduce emissions is growing in popularity. Turbocharged diesel engines sometimes behave badly when speed and load vary, increasing exhaust emissions and reducing driver comfort. This issue is brought on by features of the turbocharger, such as high inertia and low compressor flow. This work aims to enhance engine dynamics via the investigation of different turbocharging configurations. These include of variable-geometry turbines, coupled supercharging and electrically assisted turbocharging, and two-stage turbocharging. Reducing turbocharger size, using several units, and increasing turbine torque are some strategies to improve transient responsiveness. Moreover, methods to reduce emissions and minimise turbo lag include raising the turbine back pressure and using external energy support. A lot of factors, such as cost, kind of engine, and vehicle use, influence the ideal arrangement. The operational efficiency of a compression-ignition (CI) single cylinder four stroke diesel engine with and without a turbocharger is compared in this research article. The purpose of the research was to determine how turbocharging affected the engine's braking power output when diesel was the only fuel source. Brake power values were recorded for both setups and experimental data was gathered under a range of load circumstances, from 4 to 16 kg.

Keywords: Turbocharger, Diesel Power Unit, Renewable energy, Compression Ignition Engine, Diesel.

I. Introduction

Reducing emissions while maximizing power output is a main challenge in the dynamic field of automotive engineering. The use of turbocharging technology to diesel single-cylinder engines is at the forefront of this endeavor. Numerous studies indicate that employing mechanical supercharging can augment the power and torque output of internal combustion (IC) engines across various operational scenarios. However, the enhancement in thermal efficiency of IC engines remains somewhat restricted due to a portion of the engine actual work being utilized to operate the compressor. In this setup, a transmission shaft links the turbine and compressor. The high temperature and pressure of the IC engine exhaust gas retain substantial energy, which can be harnessed through an exhaust turbine. In an exhaust turbocharging system, the exhaust gas serves as the turbine's employed medium, with the turbine functioning as the power source for boosting pressure within the system. During the expansion process of the exhaust gas, a portion of its energy is recuperated and converted into useful work, subsequently employed to drive the compressor. Another conventional method for pressure boosting is exhaust turbocharging, wherein the energy of IC engine exhaust gas propels the compressor through an exhaust turbocharger. This innovative endeavor holds significant promise and could potentially deliver unparalleled performance and sustainability. Improvements in internal combustion engines (ICEs) will likely be overshadowed by fuel alternatives, advanced fuel technology, improved combustion, and pollution control measures. By increasing the charge air pressure, diesel engine performance and emissions may be enhanced. Today, turbocharging is used to accomplish this. Without expanding the engine's cubic capacity, it increases power production (Sims et al. 1990). Chemical energy is transformed into mechanical energy by diesel engines. Diesel engines release waste products including unburned carbon particles and hazardous gases in addition to mechanical power. Every researcher's main goal is to reduce exhaust emissions that are bad for the environment and increase energy conversion efficiency. Utilizing waste products' energy as much as possible is another crucial goal, and turbocharging helps with this. By using the waste kinetic energy of exhaust gases to increase charge air pressure, turbocharging enhances both the diesel engine's performance and emissions. Unfortunately, the charge air's temperature increases as it is compressed, which is not what is wanted. Air pressure is boosted to make it denser in order to guarantee that there is enough oxygen in the combustion chamber for the fuel to burn properly. However, the temperature rise mostly eliminates the density advantage and may also cause issues with the fuel's ignition timing. The maximum prominent off-design characteristic of diesel engine transient operation that most noticeably separates the torque pattern from the corresponding steady-state circumstances is turbocharger lag, as it has long been known. Because there is no automated connection between the engine crankshaft and the turbocharger, the system's inertia prevents the turbocharger (T/C) compressor air supply from matching the higher fuel flow instantly, even though the fuel pump responds quickly to the increased fueling demand after a load or speed increase. By applying turbocharger in single cylinder diesel engine brake power and efficiency of the engine rises. This phenomenon is further compounded by the T/C compressor's unfavorable characteristics at low loads and speeds. This delayed reaction causes the relative air-fuel ratio to assume extremely low values in the early cycles of a transient event—even lower than stoichiometric—which deteriorates combustion and causes the engine to respond slowly (in terms of torque and speed), take a long time to recover from, and emit excessive amounts of noise, particles, and gases into the atmosphere. Turbocharger uses thermal power wasted could be recovered by expanding the exhaust gas by passing it inside an additional turbine instead of a throttling valve. However, after a speed or load increase transient event, high fuel–air equivalency ratios result in high combustion temperatures, which promote the creation of soot (black smoke emanating from the exhaust pipe) and nitric oxide (NO).

II. Literature review

Internal combustion engines may generate extra power without adding more cylinders by using turbochargers. This mechanical approach enables automakers to lower the displacement of their engines to smaller sizes, a process known as engine downsizing [1, 33]. Turbochargers are broadly used, especially in racing applications, to increase the power of internal combustion engines that are already quite powerful. But these days, the emphasis is on creating solutions for road cars that are both ecologically sound and commercially feasible. As a outcome, the automobile industry has seen a significant rise in the use of turbochargers. The purpose of this research is to deliver an indication of the most current turbocharging technologies used to reduce exhaust emissions and maximize engine efficiency. In order to evaluate their present usefulness, several kinds of turbochargers and superchargers are analyses in the perspective of current developments. New technologies are constantly emerging in response to the growing need for contemporary, environmentally friendly engines. Increased power output and lower emissions are possible with a turbocharged engine because it promotes combustion with a richer air-fuel combination [27, 32]. The research explores how adding a turbocharger or supercharger affects an internal combustion engine's performance, taking into account the fact that air density decreases with altitude. Nevertheless, power recovery in diesel engines may not be guaranteed by the pumping process or overall system performance, even with the best of intentions. Engine downsizing is a common approach in contemporary cars due to increased customer demand for fuel-efficient vehicles and tougher pollution restrictions. Simultaneously, turbocharging is becoming more and more common as a way to increase the power output of smaller engines so they can function on par with bigger displacement engines. Three main areas of modern turbocharger research are covered in this paper heat transfer, flow dynamics, and mechanical analysis. While flow studies are grouped according to different turbocharger components and study strategies, heat transfer studies include results from both modelling and experimental approaches. Medium-speed diesel engines are used in a diversity of power industries, including as maritime propulsion and the production of electricity. The goal of the research is to model and simulate a medium-speed M.A.N. production engine that has a turbocharger and an intercooler. The inquiry looks at the potential effects of the air temperature in the intercooler on engine cylinder volumetric efficiency using the Fortran programming language and applied thermodynamics concepts for internal combustion engines. The findings highlight the important impact of intercooler air temperature on engine performance, showing a noteworthy 98% increase in volumetric efficiency while running with lower intercooler exit air temperatures [28, 29].

Engine running while the exhaust gas turbo charger is operating. The automobile industry uses turbochargers because they may boost an internal combustion engine's (IC) output without increasing the engine's cylinder capacity. Vehicles undergo minor adjustments to increase economy and regulate the amount of exhaust gas emissions. The project's objectives are to decrease two-wheeler emissions and boost volumetric efficiency. Since diesel engines are still used in truck applications, dropping fuel consumption and CO_2 emissions is essential. Under constant load and at moderate speeds, single-stage turbocharged diesel engines are recognized for their fuel efficiency. This work presents a two-stage, in series, air-path system that modifies the turbine expansion ratios to enhance the usual part-load performance at low engine speeds. As long as the engine transient response is preserved, lower engine speeds may provide better EGR rates (for NOx reduction). The performance and pollution results of the IDI CI engine operating on diesel fuel with and without a turbocharger were compared in this experiment [30]. An engine's horsepower may be greatly increased using a turbocharger without causing the engine to become much heavier. A loading panel was used to add load while the engine was operating at its constant rated speed of 1000 rpm. Varied performance, combustion, and emission parameters were assessed under varied engine loads, ranging from 25% to 100%. A thorough testing setup was devised, linking the engine to a smoke meter and five gas analyzers. The engine's performance and emissions were documented across different load conditions. This study delves into the significance of boost pressure recovery in enhancing the operational effectiveness of diesel engines at elevated heights. They suggested that a controlled, two-stage turbocharging system is a workable way to recover power from diesel engines. Their research examines how boost pressure and engine power change at varying altitudes and presents a controlled two-stage turbocharging system made up of a matching low-pressure turbocharger and an original turbocharger [31]. The research showed that even with difficulties brought on by variances in overall turbocharger performance, boost pressure recovery by itself was unable to reliably guarantee power recovery across the engine's working range. Nonetheless, the power recovery goal may be reached by putting fuel injection compensation techniques and valve control schemes for boost pressure recovery into practice. Performance and emission results of an IDI CI engine running on diesel fuel with and without a turbocharger are compared in this single-cylinder diesel engine study. The key to greatly increasing engine horsepower without appreciably adding weight is turbocharging. In the experiment, the engine's rated speed was maintained at 1000 rpm while the engine load was varied between 25% and 100%. Using a loading panel to apply load, performance, combustion, and emission characteristics were carefully measured. By combining the engine with a smoke meter and five gas analyzers, a thorough test setup was created. Mathematical computations were used to determine performance metrics like thermal efficiency and fuel consumption unique to brakes [32].

An efficient waste heat recovery technique called turbo-compounding enhances a single-cylinder naturally aspirated engine's performance and lowers its exhaust emissions [4]. The engine was fitted with a turbocharger system, and both fuel cases underwent the same testing procedures. The analysis of test results revealed that biodiesel produced somewhat lower braking power and torque as well as higher fuel consumption figures, but its brake thermal efficiency was marginally greater than diesel fuel's in both normally aspirated and turbocharged scenarios [5]. In the near future, jatropha combined with ethanol mix will be a promising biofuel replacement for diesel engines [6]. Because it takes a relatively long time to analyze each transient cycle, the significant problem The control of exhaust emissions while diesel engines undergo transient operation is crucial mostly been researched experimentally rather than via modelling. Manufacturers, however, find that the research of transient emissions is crucial since freshly manufactured engines have to adhere to strict standards for exhaust emissions levels. The parameters are categorized into three groups based on the particular subsystem that is being studied: the engine, the load, and the turbocharger. The evolution of the soot and NO emissions during the transient event is shown in demonstrative figures that show the impact of each parameter taken into consideration. Transient NO and soot emissions are also significantly influenced by load parameters and the mass moment of inertia of the turbocharger (T/C) [7]. Since the performance of the diesel engine with jatropha biodiesel blends is comparable to that of diesel, internal combustion engines may utilize them. Because diesel has a higher calorific value (45 MJ/kg) than jatropha biodiesel (38.00 MJ/kg), the latter has a little poorer brake thermal efficiency [8].

III. Experimental setup

In For the current experimental inquiry, a four stroke, vertical, single cylinder, air-cooled, cold starting, compression ignition, high speed diesel engine is employed. Both Table 1 and Figure 1 provide the engine specifications.

Table 1: Engine specification

MODEL	**4325**
Bore	78 MM
Stroke	68MM
Displacement	325CM
Compression Ratio	18:01
Oil Sump capacity	1.0 litres
Lub Oil Consumption	0.013 kg/hr
Dry Weight	38kg
Maximum Torque	1.48Kgm
RPM	3600
SFC	220gm/bhp/hr

Figure 1: Engine specification

The designs of turbochargers must adapt to changing needs in order to account for variables such as use situations, efficiency attributes, rotor inertia, and map size. This propels ongoing innovation in compressor and turbine variations suited to particular engine needs. Furthermore, different emissions restrictions around the globe encourage the creation of unique technological solutions. A diesel engine with just one cylinder with and without a turbocharger made up the experimental arrangement. In both designs, the main fuel source was diesel. Brake power readings were taken for every load situation in which the engine was exposed to 4, 8, 12, and 16 kg of variation. To make sure the results were reliable, the tests were run many than thrice. This single-cylinder diesel engine configuration might have a turbocharger or not. Below is a discussion of all calculations:-

3.1 Calculations

* Diameter of Pulley **(D) - 0.2 m**
* Radius of Pulley **(R) - 0.1 m**

Table 2 shows that a single-cylinder diesel engine's torque output fluctuates depending on the load. For example, the maximum and lowest torque measured with a weight of 16 kg are 15.69 N-m and 3.92 N-m in each case. The torque tests were carried out for both diesel-powered engines—those with or without turbochargers—and the findings were similar for all loads.

Table 2: Load and torque comparison.

Load (Kg)	**Torque (N-m)**
4	3.92
8	7.84
12	11.76
16	15.69

In the diesel engine without a turbocharger, the results from Table 3 and Figure 2 reveal varying power and RPM levels at different loads. Notably, at a load of 16kg, the maximum power output is recorded at 3.12 kW with an RPM of 1900. This experiment demonstrates that as the load increases, the power output also increases, while the RPM decrease.

Table 3: Load vs brake power vs rpm calculation without turbocharger

Diesel engine without Turbocharger		
Load (Kg)	Power (kw)	RPM
4	1.05	2550
8	1.91	2320
12	2.58	2100
16	3.12	1900

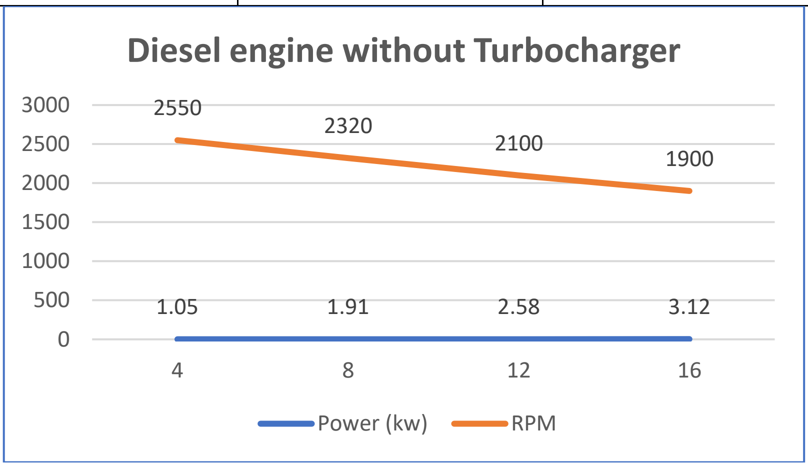

Figure 2: Load vs brake power vs rpm calculation without turbocharger

In the single-cylinder diesel engine equipped with a turbocharger the findings from Table 4 and Figure 3 demonstrate varying power and RPM levels across different loads. Notably, at a load of 16kg, the engine achieves its maximum power output of 3.78 kW at an RPM of 2302. This experiment highlights the trend where increasing the load leads to a rise in power output, while concurrently causing a decrease in RPM.

Table 4: Load vs brake power vs rpm calculation with turbocharger

Diesel engine with turbocharger		
Load (Kg)	Power (kw)	RPM
4	1.19	2894
8	2.15	2618
12	2.95	2400
16	3.78	2302

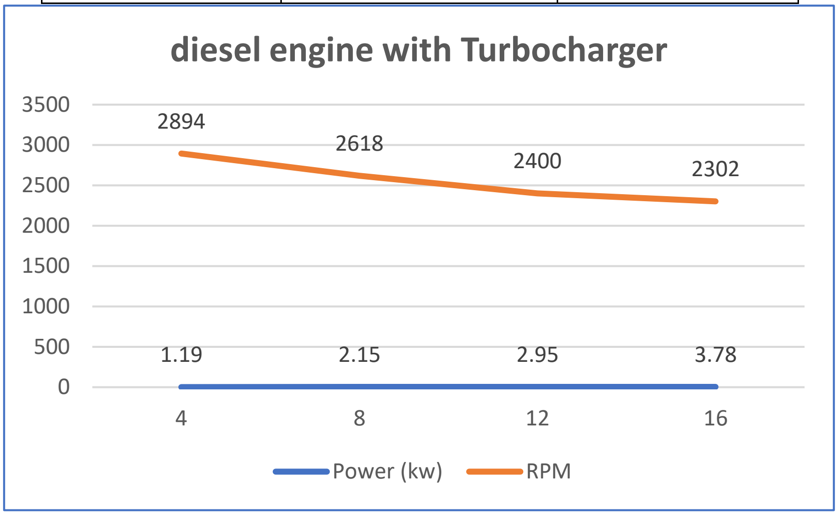

Figure 3: Load vs brake power vs rpm calculation with turbocharger

IV. Results

The research's decision show that fitting a turbocharger significantly rises the amount of brake power produced. The turbocharged engine performed the non-turbocharged engine in terms of brake power under all load circumstances. At the highest load (16 kg), the brake power specifically rises by about 21.15%, from 3.12 kW without a turbocharger to 3.78 kW with turbocharger.

V. Conclusion

In summary, the findings of this research show that single-cylinder diesel engines may run more efficiently when turbocharged. The observed increase in braking power demonstrates how turbochargers may enhance engine efficiency and power output without compromising fuel consumption. These results contribute to the amount of study being done to optimise diesel engine performance for various applications. A single-cylinder diesel engine produces greater power as the load increases, but the engine speed decreases as well. This demonstrates the inverse relationship between load, power, and engine speed in the setup under investigation.

References

[1] Ray, P.P. Internet of Things for smart agriculture: Technologies practices and future direction. J. Ambient. Intell. Smart Environ. 2017, 9, 395–420.

[2] S. K. Kurre, S. Pandey, R. Garg, and M. Saxena, “Condition monitoring of a diesel engine fueled with a blend of diesel, biodiesel, and butanol using engine oil analysis,” *Biofuels*, vol. 6, no. 3–4, pp. 223–231, Jul. 2015, doi: https://doi.org/10.1080/17597269.2015.1081763

[3] H. Li, L. Shi, and K. Deng, “Development of turbocharging system for diesel engines of power generation application at different altitudes,” *Journal of the Energy Institute*, vol. 89, no. 4, pp. 755–765, Nov. 2016, doi: https://doi.org/10.1016/j.joei.2015.04.001. Available: https://www.sciencedirect.com/science/article/abs/pii/S1743967114201310. [Accessed: Oct. 27, 2023]

[4] Swapnil Sureshchandra Bhurat, S. Pandey, V. Chintala, and P. S. Ranjit, "Technical barriers and their solutions for deployment of HCCI engine technologies – a review," *International journal of ambient energy*, vol. 42, no. 16, pp. 1922–1935, May 2019, doi: https://doi.org/10.1080/01430750.2019.1611644

[5] D. Mirza-Hekmati, W. P. Heath, J. M. Apsley, and J. R. Forbes, "Down-speeding diesel engines with two-stage turbochargers: Analysis and control considerations," *International Journal of Engine Research*, vol. 23, no. 1, pp. 78–89, Dec. 2020, doi: https://doi.org/10.1177/1468087420976482

[6] V. Hariram, S. Seralathan, P. Arunraja, A. Salih Arshad, and R. Jaganathan, "Numerical Analysis on Cone Length and its Effect on Performance of an Automotive Catalytic Converter," *International Journal of Vehicle Structures and Systems*, vol. 11, no. 2, Aug. 2019, doi: https://doi.org/10.4273/ijvss.11.2.09

[7] H. M. Herzwan, A. Azri, and M. Rizalman, "Turbocharging small size engine to increase engine output: An assessment of turbocharger study field," *IOP Conference Series: Materials Science and Engineering*, vol. 469, p. 012089, Jan. 2019, doi: https://doi.org/10.1088/1757-899x/469/1/012089

[8] M. Chhabra, A. Sharma, and G. Dwivedi, "Performance evaluation of diesel engine using rice bran biodiesel," *Egyptian Journal of Petroleum*, vol. 26, no. 2, pp. 511–518, Jun. 2017, doi: https://doi.org/10.1016/j.ejpe.2016.07.002

[9] A. Mukhtar *et al.*, "Current status and challenges in the heterogeneous catalysis for biodiesel production," *Renewable and Sustainable Energy Reviews*, vol. 157, p. 112012, Apr. 2022, doi: https://doi.org/10.1016/j.rser.2021.112012

[10] F. Zheng and H. Cho, "Combustion and Emission of Castor Biofuel Blends in a Single-Cylinder Diesel Engine," *Energies*, vol. 16, no. 14, p. 5427, Jan. 2023, doi: https://doi.org/10.3390/en16145427.

[11] K. Pramanik, "Properties and use of jatropha curcas oil and diesel fuel blends in compression ignition engine," *Renewable Energy*, vol. 28, no. 2, pp. 239–248, Feb. 2003, doi: https://doi.org/10.1016/s0960-1481(02)00027-7.

[12] S. M. A. Rahman, H. H. Masjuki, M. A. Kalam, M. J. Abedin, A. Sanjid, and Md. M. Rahman, "Assessing idling effects on a compression ignition engine fueled with Jatropha and Palm biodiesel blends," *Renewable Energy*, vol. 68, pp. 644–650, Aug. 2014, doi: https://doi.org/10.1016/j.renene.2014.02.050.

[13] S. Verhelst, J. W. Turner, L. Sileghem, and J. Vancoillie, "Methanol as a fuel for internal combustion engines," *Progress in Energy and Combustion Science*, vol. 70, pp. 43–88, Jan. 2019, doi: https://doi.org/10.1016/j.pecs.2018.10.001.

[14] X. Fan, X. Wang, and F. Chen, "Biodiesel Production from Crude Cottonseed Oil: An Optimization Process Using Response Surface Methodology," *The Open Fuels & Energy Science Journal*, vol. 4, no. 1, pp. 1–8, May 2011, doi: https://doi.org/10.2174/1876973x01104010001.

[15] R. Mousavi and R. Miri, "Numerical Simulation of the Performance and Emission of a Diesel Engine with Diesel-biodiesel Mixture," *DOAJ (DOAJ: Directory of Open Access Journals)*, Dec. 2022, doi: https://doi.org/10.22067/jam.2021.69149.1023.

[16] I.M. Monirul *et al.*, "Assessment of performance, emission and combustion characteristics of palm, jatropha and Calophyllum inophyllum biodiesel blends," vol. 181, pp. 985–995, Oct. 2016, doi: https://doi.org/10.1016/j.fuel.2016.05.010.

[17] N. Acharya, P. Nanda, S. Panda, and S. Acharya, "A comparative study of stability characteristics of mahua and jatropha biodiesel and their blends," *Journal of King Saud University - Engineering Sciences*, vol. 31, no. 2, pp. 184–190, Apr. 2019, doi: https://doi.org/10.1016/j.jksues.2017.09.003.

[18] G. Dwivedi, S. Jain, and M. P. Sharma, "Impact analysis of biodiesel on engine performance—A review," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 9, pp. 4633–4641, Dec. 2011, doi: https://doi.org/10.1016/j.rser.2011.07.089.

[19] F. K. Forson, E. K. Oduro, and E. Hammond-Donkoh, "Performance of jatropha oil blends in a diesel engine," *Renewable Energy*, vol. 29, no. 7, pp. 1135–1145, Jun. 2004, doi: https://doi.org/10.1016/j.renene.2003.11.002.

[20] Sharma, M., Jain, N.L. and Purohit, J.K. (2022), "A Review of Circular Economy in Manufacturing Sector", *NeuroQuantology*, Vol. 20 No. 10, pp. 9105–9112, doi: https://doi.org/10.14704/nq.2022.20.10.NQ55892.

[21] Sharma, M., Jain, N.L. and Purohit, J.K. (2023a), "Biomedical Waste Management and Circular Economy Actions in the COVID-19 Pandemic Situation in Jaipur District, India", *Advances in Modelling and Optimization of Manufacturing and Industrial Systems*, pp. 149–173, doi: https://doi.org/10.1007/978-981-19-6107-6_12.

[22] Sharma, M., Narayan Lal Jain and Purohit, J.K. (2023b), "Analysis of Circular Economy Enablers in Manufacturing Context for Indian Industries: A ELECTRE method Ranking Process", *Evergreen*, Kyushu University, Vol. 10 No. 3, pp. 1156–1168, doi: https://doi.org/10.5109/7148437.

[23] Sharma, M., Narayan Lal Jain and Purohit, J.K. (2023c), "Analysis of circular economy barriers in manufacturing context for indian industries: a BWM ranking process", *Environment, Development and Sustainability*, Springer Science+Business Media, doi: https://doi.org/10.1007/s10668-023-03868-9.

[24] Sharma, M. and Purohit, J.K. (2019), "Indicators for Sustainable Manufacturing for Industries – A Review", presented at the International Conference on Recent Trends and Innovation in Engineering, Science & Technology (ICRTIEST-2019), pp. 322–325.

[25] Sharma, M. and Purohit, J.K. (2020), "Achieving Sustainable Mass Customization Capabilities–A Review", *Juni Khyat*, Vol. 10 No. 6, pp. 299–304, doi: https://doi.org/10.46528/JK.2020.V10I06N09.30.

[26] J. Fu, J. Liu, Y. Yang, C. Ren, and G. Zhu, "A new approach for exhaust energy recovery of internal combustion engine: Steam turbocharging," *Applied Thermal Engineering*, vol. 52, no. 1, pp. 150–159, Apr. 2013, doi: https://doi.org/10.1016/j.applthermaleng.2012.11.035.

[27] Z. Ma, D. Yang, and Q. Guo, "Conceptual Design and Performance Analysis of an Exhaust Gas Waste Heat Recovery System for a 10000TEU Container Ship," *Polish Maritime Research*, vol. 19, no. 2, Jan. 2012, doi: https://doi.org/10.2478/v10012-012-0012-8.

[28] C. Ramesh Kumar, Ankit Sonthalia, and R. Goel, "EXPERIMENTAL STUDY ON WASTE HEAT RECOVERY FROM AN INTERNAL COMBUSTION ENGINE USING THERMOELECTRIC TECHNOLOGY," Jan. 2011.

[29] J. Fu *et al.*, "A comparative study on various turbocharging approaches based on IC engine exhaust gas energy recovery," *Applied Energy*, vol. 113, pp. 248–257, Jan. 2014, doi: https://doi.org/10.1016/j.apenergy.2013.07.023.

[30] M. He, X. Zhang, K. Zeng, and K. Gao, "A combined thermodynamic cycle used for waste heat recovery of internal combustion engine," *Energy*, vol. 36, no. 12, pp. 6821–6829, Dec. 2011, doi: https://doi.org/10.1016/j.energy.2011.10.014.

[31] A. J. Feneley, A. Pesiridis, and A. M. Andwari, "Variable Geometry Turbocharger Technologies for Exhaust Energy Recovery and Boosting-A Review," *Renewable and Sustainable Energy Reviews*, vol. 71, pp. 959–975, May 2017, doi: https://doi.org/10.1016/j.rser.2016.12.125.

[32] S. Steven *et al.*, "Potential of Corn Cob Sustainable Valorization to Fuel-Grade Bioethanol: A Simulation Study Using Superpro Designer®," *Evergreen*, vol. 10, no. 4, pp. 2287–2298, Dec. 2023, doi: https://doi.org/10.5109/7160904.

[33] E. Adi, Wiliandi Saputro, and None Bayu Wisnu Saputro, "An Investigation of Engine Performance and Exhaust Gas Emissions under Load Variations using Biodiesel Fuel from Waste Cooking Oil and B30 Blend," *Evergreen*, vol. 10, no. 4, pp. 2255–2264, Dec. 2023, doi: https://doi.org/10.5109/7160901.